

THREE-DIMENSIONAL SIMULATION OF COMPOSITE SLABS UNDER FIRE CONDITIONS

LÍDIA DA ROCHA SOUZA LIMA

Dissertation presented to the Escola Superior de Tecnologia e Gestão of the Instituto Politécnico de Bragança – ESTIG – IPB to obtain a master's degree in Construction Engineering.

Supervision of:

Prof. Dr. Carlos Jorge da Rocha Balsa
Prof. Dr. Paulo Alexandre Gonçalves Piloto

Braganca, 2022

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November 15, 2022

*“Porque quando fecho os olhos
sei que sou do tamanho de tudo
que vivi”*

Obrigada, Bragança.

ACKNOWLEDGMENTS

First, I would like to thank my grandparents Hélio Souza and Edileusa Viégas. Without them, nothing would be possible. They are my motivation! I must also express my deep gratitude to my mother Liliane Rocha and my sisters Daniely Rocha and Talita Rocha for encouraging me in crucial moments.

Special thanks to my teachers and supervisors, Professor Carlos Jorge da Rocha Balsa and Professor Paulo Alexandre Gonçalves Piloto, for always giving me the necessary support to develop this work, thank you very much for sharing knowledge and giving important advice that made this project possible.

I thank the Polytechnic Institute of Bragança (IPB) for their teachings and I thank everyone involved in the institution that has been part of my personal and professional growth over these years, both in undergraduate (1st cycle) and master's (2nd cycle). I also want to thank my great friend Ricardo Escrevente and the Modellame Team, the conclusion of this research would have been much more difficult without that support.

Finally, being aware that alone none of this would have been possible, I give special thanks to Bianca Auwarter for her unconditional support, encouragement, and total help in overcoming the obstacles that arose along this path.

Thank you all!

RESUMO

Este estudo apresenta uma análise numérica de lajes mistas através do Método dos Elementos Finitos (FEM) utilizando o Matlab (PDE Toolbox) e compara os seus resultados com os valores obtidos através dos métodos simplificados da norma EN 1994-1-2.

A comparação entre os métodos analíticos e numéricos tem como objetivo analisar o comportamento e a influência dos novos parâmetros, bem como a resposta térmica dos quatro perfis de lajes mistas com o intuito de compreender a evolução temporal nos elementos estruturais durante a exposição ao fogo.

O método de solução requer a caracterização dos materiais a temperaturas elevadas. O modelo de interface adicional inclui uma resistência térmica entre a placa de aço e a cobertura de betão, representada pelo efeito da camada de ar que geralmente se cria durante os testes experimentais.

O principal objetivo deste trabalho é determinar a resistência ao fogo por isolamento de lajes mistas com uma plataforma de aço colaborante ao comportamento do betão de peso normal; o tipo de aço escolhido foi o S350 quando submetido a uma curva de fogo padrão ISO-834. Esta investigação apresenta uma análise da resposta térmica do conjunto e do desempenho de 4 componentes intervenientes na resistência mecânica para avaliação do critério R (todas as partes da placa de aço: flange inferior, intermédia e flange superior e os varões de reforço nas lajes mistas).

Este estudo compreende dois modelos trapezoidais (Cofraplus 60 e Polydeck 59s) e dois modelos re-entrantes (Multideck 50 e Bondek) com diferentes espessuras de h_1 . No total, foram realizadas 80 simulações para a validação e elaboração do estudo paramétrico, utilizando os modelos numéricos desenvolvidos para propor novas propostas e coeficientes (Proposta I, II, III e IV) para estimar a temperatura dos componentes presentes no critério de carga (R) e também a estimativa do tempo de resistência de isolamento (I) em comparação com o modelo proposto no Anexo D do Eurocódigo 1994-1.2.

Palavras-Chave: Resposta térmica; Lajes Mistas de Aço-Concreto; Resistência ao Fogo; Betão de densidade normal; Modelo Numérico; Eurocódigo 4; MATLAB; Incêndio Padrão.

ABSTRACT

This study presents a numerical analysis of composite slabs by the Finite Element Method (FEM) using MATLAB Partial Differential Equations Toolbox (PDE Toolbox) and compares the results with those obtained using the simplified methods of EN 1994-1-2.

The comparison between the analytical and numerical methods aims to analyse the behaviour and the influence of the new parameters, as well as the thermal response of the four composite slab profiles, to understand the temporal evolution in the structural members during fire exposure.

The solution method requires the characterisation of the materials at elevated temperatures. The additional interface model includes a thermal resistance between the steel plate and the concrete cover, defined by the air layer effect that usually occurs during experimental tests.

The main objective of this work is to determine the fire resistance by insulation of composite slabs with a steel platform collaborating to the behaviour of normal weight concrete (NWC); the type of steel chosen was S350 when subjected to a standard ISO-834 fire curve. This research analyses the thermal response of the assembly and the performance of 4 components used in the mechanical analysis to assess the fire resistance R (all parts of the steel deck: Lower flange, Web, Upper flange and the reinforcing bars in the composite slabs).

This study comprises two trapezoidal models (Cofraplus 60 and Polydeck 59s) and two re-entrant models (Multideck 50 and Bondek) with different thicknesses of h_1 . In total, 80 simulations were performed for the validation and elaboration of the parametric study, using the developed numerical models to propose new proposals and coefficients (Proposal I, II, III and IV) to estimate the temperature of the components present in the load-bearing criterion (R) as well as in the estimation of the insulation resistance time (I) in comparison with the model proposed in Annex D of EN 1994-1-2.

Keywords: Thermal Response; Steel-Concrete Composite Slabs; Fire Resistance; Normal Weight of Concrete; Numerical Model; Eurocode 4; MATLAB; Standard Fire.

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ABBREVIATION AND SYMBOLS

Latin letters

| | |
|-----------------|--|
| $\frac{A}{L_r}$ | The rib geometry factor |
| c | Specific heat |
| c_a | Specific heat of carbon steel |
| c_{air} | Specific heat of air |
| c_p | Specific heat of dry concrete |
| $c_{p,peak}$ | Peak of specific heat of concrete according to a certain moisture content |
| D | Maximum deflection |
| d | Distance from the extreme fibre of the cold design compression zone to the extreme fibre of the cold design tensile zone |
| d'_{reb} | Concrete cover for rebar |
| E | Integrity criterion |
| E_b | Largest amount of thermal radiation which can emit from a surface |
| h_1 | Height of the concrete part of a composite slab above the steel deck |
| h_2 | Height of the concrete part of a composite slab within the steel deck |
| h_3 | Thickness of the screed situated on top of the concrete |
| h_{eff} | Effective thickness of a composite slab |
| h_{eq} | Weighted average of window heights on all walls |
| h_{net} | Design value of the net heat flux per unit area |
| h_{cd} | Conduction heat flux |
| $h_{net,cv}$ | Design value of the net heat flux per unit area by convection |
| $h_{net,r}$ | Design value of the net heat flux per unit area by radiation |
| I | Thermal insulation criterion |
| L | Clear span of the structural element |
| l_1, l_2, l_3 | Specific dimensions of the trapezoidal or re-entrant steel deck profile |
| \vec{n} | Normal vector |
| O | Opening factor of the fire compartment |
| Q | External heat flux |

| | |
|------------|---|
| $q_{t,d}$ | Design fire load density related to the total surface area A_t |
| R | Load bearing criterion |
| s_{mesh} | Anti-crack mesh spacing |
| t | Time |
| t_a | Air gap thickness |
| t_d | Thickness of the steel deck profile |
| t_{fi} | The fire resistance for thermal insulation criterion |
| $t_{fi,d}$ | Design value of standard fire resistance of a member in a fire situation |
| $t_{fi,r}$ | Required standard fire resistance in the fire situation |
| t_{lim} | Time for maximum gas temperature in case of fuel-controlled fire |
| t_{max} | Time for maximum gas temperature |
| U | Internal energy |
| u | Moisture content |
| $u_1; u_2$ | Shortest distance of the centre of the rebar to any point of the webs of the steel deck |
| u_3 | Distance of the centre of the rebar to the lower flange |

Greek letters

| | |
|---------------------|--|
| α | Angle of the web |
| α_{cv} | Convective heat transfer coefficient |
| Δ | Variation |
| ε | Emissivity |
| ε_f | Emissivity coefficient of the fire |
| ε_m | Emissivity coefficient related to the surface material of the member |
| ε_{res} | Resulting emissivity |
| Φ | View factor |
| Φ_{low} | View factor of the lower flange |
| Φ_{up} | View factor of the upper flange |
| Φ_{web} | View factor of the web |
| Φ | Conduction heat flux |
| ϕ_{reb} | Diameter of the rebar |
| Θ_g | Gas temperature in the vicinity of the fire exposed element |
| Θ_m | Surface temperature of the element |

| | |
|-----------------|---|
| Θ_r | Effective radiation temperature of the fire environment |
| θ | Temperature |
| θ_a | Temperature of the parts of the steel deck |
| θ_s | Temperature of the rebars in the rib |
| Γ | Time factor function of the opening factor O and the thermal absorptivity b |
| λ | Thermal conductivity |
| λ_a | Thermal conductivity of carbon steel |
| λ_{air} | Thermal conductivity of air |
| λ_c | Thermal conductivity of concrete |
| ρ | Density |
| ρ_a | Density of carbon steel |
| ρ_{air} | Density of air |
| ρ_c | Density of concrete |
| σ | Stefan-Boltzmann constant |

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1. INTRODUCTION

1.1. Contextualization

Fire safety is its primary aim to defend human life and property. Since fire situations in buildings can occur at any time, the importance of user safety and maintaining the structure's integrity becomes relevant. It is impossible to eliminate the risk of fire consequences of its eventual occurrence [1]. Fire safety is therefore seen as a means of prevention to ensure the survival of the users of the buildings and of the rescue teams during the attack, the mitigation of structural damage that limits the action of the propagation of smoke and toxic gases inside the building compartments, the limitation of the fire propagation to the neighbouring buildings avoiding eventual premature rupture. One of the most harmful situations to which a structure can be exposed is fire. Since both material component, concrete and steel, contribute to the mechanical resistance, they must ensure the component's structural integrity in the event of a fire.

The building construction sector is always searching for innovative techniques, materials, or construction methods. Therefore, the economic factor significantly impacts this sector in addition to functionality, durability, and safety. Thus, it becomes the reason for the incessant search for safer and more economic alternatives. However, despite all the technology currently available and the wide range of options and solutions in the construction industry, cost-benefit is one of the primary factors for the viability of a project. One of these solutions is the composite slabs with steel deck, which presents itself as a more efficient, sustainable and lighter structural solution when compared to conventional reinforced concrete slabs.

In this regard, it is vital to experimentally investigate how these slabs respond structurally under fire [2],[3] and [4]. A composite structure is characterised by a structural solution composed of elements that constitute resistant sections, where two or more materials are linked together and work together. Thus, the steel and concrete composite slabs can be described by joining a reinforced concrete layer found above a steel profile, which may or may not be supported by a steel rebar between the ribs.

Profiled steel deck acts as a continuous positive reinforcement in steel deck concrete

slabs under sagging moment, eliminating the requirement for formwork and reinforced concrete bars (rebar) [2]. When these slabs catch fire from the bottom, the steel deck deteriorates, making the slab act unreinforced.

The reduction of concrete is among the advantages presented by composite slabs, which results in a lower self-weight of the structure, besides the decrease in execution time, since the steel deck acts as permanent formwork. However, the presence of the steel deck in the composite slabs may be a disadvantage in fire resistance because of the sensitivity of the thermal and mechanical properties of steel. When the steel deck is exposed to fire, this material presents a rapid loss of its mechanical properties (yield stress and elastic modulus).

According to M. Crisinel and D. O'Leary [5] the first composite slab system was first developed in the late 1930s for high-rise buildings. Due to the efficiency and advantages presented by this new slab model, it soon became widely applied in steel frame-based construction projects (high-rise, low-rise, and industrial buildings). For many years, composite slabs have been widely used in North America, and from the 1980s, there was a rapid increase in their use in Europe. However, according to Cooke G. M. E. [6], it began to be widely used in Europe only after the 1980s, until the scarcity of data guaranteed its good performance in use and safety.

In 2018, J. Jiang et al. [7] cite that one advantage of using this element is the reduced use of concrete and construction time, since the steel plate serves as permanent formwork. Composite slabs are constructed with cold-formed steel plates that act as formwork during the construction period and are later kept reinforcing the concrete slab. The concrete is usually reinforced with a lightweight anti-crack mesh and may traditionally contain individual rebars positioned toward the ribs. As a result, this solution has gained popularity in Europe over the years for its success in achieving the achieved stiffness strength and speed of construction.

Considering that composite structures, especially steel, when they reach elevated temperatures, suffer a high loss of strength and stiffness, and may ultimately collapse if the proper fire safety measures have not been taken in the design phase. According to M. Gillie et al. [8], one of the main objectives in fire safety engineering is to prevent the structure from reaching catastrophic collapse during a fire situation. It becomes fundamental, the knowledge of the time that the system can resist and not collapse, to make possible the safe evacuation of people.

The models for composite slabs differ depending on the intended service life, the resulting strength product, and the calculated stiffness requirements. These steel deck models

can be divided into open (trapezoidal) or (re-entrant) profiles [8], see Figure 1.1. In both models, the steel plate may be exposed to the environment conditions, which leads to more significant concerns about possible external influences, such as fire.

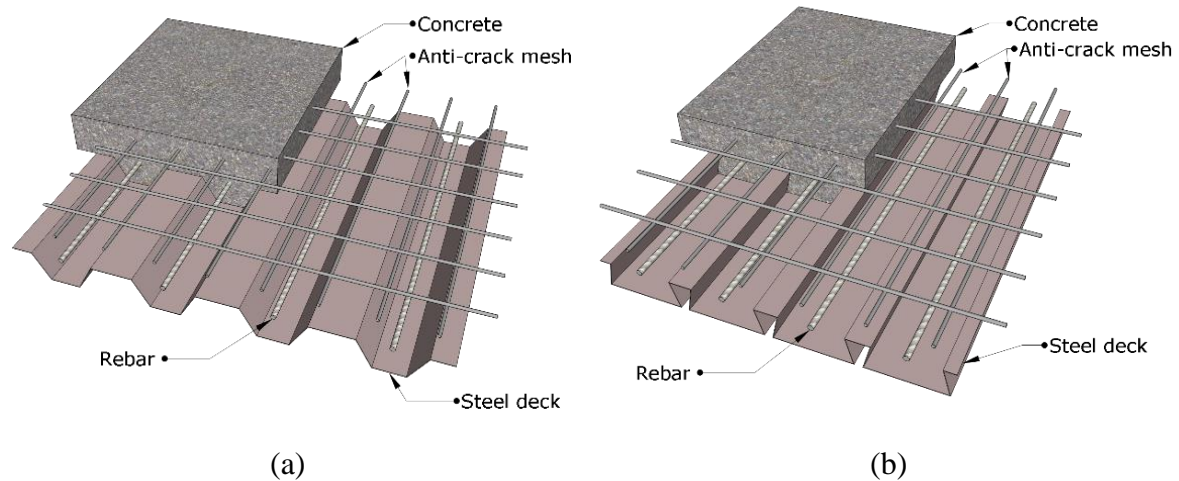


Figure 1.1: Usual layout of composite slab profiles: (a) Trapezoidal, (b) Re-entrant.

Despite the advantages that composite slabs present over conventional slabs at room temperature conditions, the presence of steel plates in composite slabs provides a disadvantage concerning to the stability under fire conditions. Since the collaborating steel deck can be directly exposed to fire, the steel presents a rapid loss of its mechanical properties in this scenario [6].

The material behaviour under fire is given by its ability to resist mechanically or provide insulation against fire [9]. Where the mechanical behaviour of the element is directly affected by the thermal performance of the slabs over fire exposure time, once the boundary conditions of the element are determined, it is necessary to consider the different modes of heat transfer, such as conduction, convection, and radiation. So, the thermal energy transferred by radiation and convection requires special attention because one can determine the fraction of energy absorbed by the slab components.

Composite slabs must meet fire safety requirements according to standards and regulations. Usually, this structural element is classified based on standard fire resistance tests, but can also be predicted by the finite element method. Generally, the fire resistance classification of structural elements is based on fire tests in which the component is subjected over a period to a standard fire curve. The Annex D of EN 1994-1-2 [4] allows the calculation of the fire resistance of composite slabs for the insulation (I) and load bearing capacity (R), when subjected to the standard fire curve ISO 834 of 1999 [1]. The fire resistance can be

determined according to three different criteria, namely Load Bearing (R), Integrity (E) and Insulation (I).

Regarding the insulation criterion (I), the Appendix D presents a simplified calculation method, which depends on the geometry of the steel deck, the thickness of the concrete above the steel, and the view factor of the top flange. The fire resistance classification of structural elements is based on fire tests in which the element is subjected to a standard fire curve for a period. These fire resistance tests of elements are performed in the laboratory by exposing the bottom side of the structural elements to fire conditions and monitoring their behaviour. However, due to the cost associated with these tests, Numerical and Analytical Methods are a more economical alternative for such tests. However, a good definition of the boundary conditions is required for a good prediction and representativeness of the numerical model.

The EN 1994 1-2 [4] is currently responsible for providing parameters for developing composite slab designs under fire situations. This standard presents a calculation model that allows determining the steel components' temperature and after the slab's sagging moment resistance. However, since the last revision was made, the methodology does not consider some essential factors that occur upon fire exposure.

According to C. Both et al. [10], for a good prediction of the temperature in the steel plate and the concrete, it is necessary to consider the thermal resistance coming from the loss of contact between the steel plate and the concrete. Since the initial phase of the fire, steel suffers a different thermal expansion when compared to concrete, introducing the "air-gap" effect, which consists in developing an air layer of about 0.5 mm between the collaborating steel deck and the concrete.

Another aspect that is not taken into consideration when dealing with the simplified model is the thermal influence exerted by the thickness of the concrete in determining the position of the neutral plastic axis. That is, as this thickness effectively contributes to the distribution of the slabs' internal heat flow, it affects the temperatures of the steel and concrete elements.

Thus, to optimise the calculation model presented by EN 1994 1-2 [4], a parametric model was developed to analyse the temperature distribution along the composite cross sections of the slabs using normal-weight concrete (NWC) in four different types of steel deck.

The scope of this investigation concerns numerical simulations to evaluate the fire resistance for the thermal insulation classification. Three-dimensional thermal models are presented to simulate the thermal effects of fire exposure using the standard fire curve ISO 834

[1] on composite slabs using MATLAB Partial Differential Equations Toolbox (PDE Toolbox).

Therefore, with the parametric results, a new proposal is presented for the coefficients of Annex D of EN 1994-1-2 and the analytical method of temperature calculation. Then, a comparison was made between the new improved proposals, the current equation, and an analytical method for the fire resistance (I) and temperature of the steel deck components and the rebars to proceed to the calculation of the load bearing resistance (R).

1.2. Objectives

The main objective of this study is to develop three-dimensional thermal models transient non-linear thermal analysis by Finite Element Method (FEM) using MATLAB software, to investigate the fire behaviour of reinforced concrete composite slabs with profiled steel deck to normal weight concrete (NWC) behaviour based on ISO 834 standard fire curve.

The solution method requires the characterisation of the materials at elevated temperatures and the additional interface model used to include a thermal resistance between the steel plate and the concrete cover. This effect is called the air layer effect and usually occurs during experimental tests. Considering , the average temperature of the four components (All parts of the steel plate: Upper flange and Lower flange, Web, and Rebar), a numerical model will be proposed by using the finite element method (FEM) to determine the temperature of these components for certain fire rating periods, considering two trapezoidal models (Cofraplus 60 and Polydeck 59s) and two re-entrant models (Multideck 50 and Bondek). The parametric study also includes some geometric parameters of the composite slabs, such as length, the diameter of the rebar and thickness of the steel deck. The following specific objectives were addressed to achieve the success of this work:

1. Development of three-dimensional thermal models to investigate the fire behaviour of composite steel-concrete slabs using Normal Weight Concrete (NWC) with profiled steel deck.
2. Determination of the temperature in all steel deck components (Upper flange, Web, Lower flange) and the rebars to the following fire rating times: 45, 60, 90, and 120 min for NWC.
3. Compare the numerical results obtained through the finite element software with the analytical results of the simplified calculation methods of the EN 1994-1-2 [4];

4. Analyse the influence of different parameters on the fire resistance (I), as well as on the temperature of the rebars and the parts of the steel deck of composite slabs to proceed for the fire resistance (R).
5. Present new coefficients and formulas for the simplified temperature calculation method presented in Annex D of EN 1994-1-2 [4]. The new coefficients are proposed for all steel deck components (Upper flange, Web, Lower flange) and the reinforcing bars, which are important for the load-bearing fire capacity (R).

1.3. Dissertation structure

The work is categorized into eight chapters, and four additional sections relating to references and data sheets are presented in Appendix A, B, C and D.

In the first chapter, a contextualization and motivation for the study on the fire behaviour of composite slabs with steel deck is presented, as well as the objectives to be accomplished with the work.

The second chapter presents the literature review, where fields of application and geometric characteristics characterize the composite slabs with steel decking. In addition, it discusses the development of fire resistance criteria and the parameters to be met by each type of criterion and describes the thermal properties associated with the materials considered in the research. Furthermore, the formulations and parameters proposed by Eurocode for the ISO 834 standard fire and natural fire curves are addressed. Some studies performed in recent years on the fire behaviour of composite slabs with steel decks are also presented. The works presented were used as a reference for preparing and corroborating the concepts and procedures used in developing this work.

Chapter 3 describes and details the materials and methods used to prepare the study and the numerical models, as well as the methodology followed for the preparation of the parametric studies. As well, discusses the methodology used in the advanced calculation model applied in the MATLAB programs for the thermal simulations to estimate the fire resistance of composite slabs, regarding to the insulation (I) criteria and load bearing capacity (R).

The fourth chapter describes the simplified calculation methods proposed by Eurocode 4 for calculating the fire resistance of composite slabs with steel plates. The formulations presented for the insulation criteria (I) and load bearing capacity (R) are valid only for elements subjected to the ISO 834 curve.

Chapter 5 presents the advanced calculation methods. This chapter describes how the finite element model was developed using MATLAB software to develop a parametric analysis and all the boundary conditions and parameters applied in the programs to prepare the models.

As well demonstrates the details of the heat transfer process, the associated concepts, the existing transfer modes, and how these occur. It also contains the analytical and numerical results which were performed with MATLAB Toolbox, describing the study cases and how the numerical model was designed. This chapter describes the proposed methodology used to obtain the results, refining the new calculation methods. This chapter also describes the optimization method of the Generalized Reduced Gradient (GRG), used to minimize the sum of the quadratic deviations between the numerical and analytical temperatures to obtain the new coefficients. The comparison of the analytical and numerical results is also presented. Based on the general evaluation of the results, new calculation proposals and new coefficients for Annex D of EN 1994-1-2, regarding the calculation of the fire resistance (I) and the temperatures of the steel components, are also given.

In chapter sixth, the accuracy comparison of the results of the parametric studies is outlined. A discussion around the influence of each studied parameter is given in this chapter as well. The validation of the thermal models and comparisons between the outcome of the numerical simulations and existing calculation rules is also presented in this chapter.

Finally, chapter 7 presents the main conclusions of this work about the results achieved through the parametric study, highlighting the effects of the new calculation proposal on the temperature of the components of composite slabs and suggestions for investigation in future studies.

The appendices comprise the following information:

- Appendix A: Data Sheet for trapezoidal geometry
- Appendix B: Data Sheet for re-entrant geometry
- Appendix C: Relationship between the temperature of the flanges of the steel deck θ_a for numerical analysis (N) and the New Proposal (NP)
- Appendix D: Relationship between the temperature of the flanges of the steel deck θ_a for EN-1994-1-2 (S) and the New Proposal (NP)

2. LITERATURE REVIEW

In this chapter, relevant literature is presented. There is a distinction between existing calculation rules, experimental investigation, and numerical research.

Understanding the various heat transfer methods and the various modes of transmission is crucial before analysing the fire behaviour of composite structural parts. The most critical fire safety engineering concepts, heat transmission, thermal properties of materials, fire resistance standards, and other important elements for the fire behaviour of structures during fire exposure are covered in this chapter.

2.1. State of art

The behaviour of composite structures, more specifically composite slabs concrete and steel has been developing as an important research area since a series of experimental studies of isolated elements and numerical models in the analysis of composite slabs were and still are developed. Based on this research, several methodologies have been developed where it is possible to make a prevision about the resistance time of these elements under the action of standard fire to contribute to the understanding and consequently to the improvement of structural projects. This increases the safety of human lives and property.

With the evolution of computational technology, several methods for structural analysis have been developed because the analysis by advanced calculation methods has a better cost-benefit besides presenting satisfactory results when compared to experimental tests; thus, the development of new numerical methods is extremely important to add knowledge and provide improvements in the analysis methods of structural elements.

The following segment is intended to present, in a summarized way, a literature review of several studies on concrete/steel composite slabs under fire conditions. Thus, the background and current knowledge on the subject will be presented according to numerical and experimental investigations developed throughout history.

2.1.1. Experimental tests descriptions

In 1961, a committee was appointed by the International Standards Organization to develop a study of specifications for fire resistance tests. Through this, the first model version for the standard temperature-time curve was created, resulting from a standardization between the American ASTM E119 (1918) and British BS 476 (1932) curves [11].

In 1975, the standard fire curve was introduced by the publication of ISO 834 "Fire Endurance Testing - Building Elements". This standard underwent a revision and was replaced in 1999 by the first edition of ISO 834-1 [1], in which some test requirements were changed, such as the tolerance applied to the deviation of the average furnace temperature curve from the standard fire curve and other instructions related to measurement equipment and instrumentation.

Three criteria are imposed by the standard time-temperature fire resistance test specified in ISO 834. These are the load bearing (R) fire resistance time under load, the Integrity (E) to prevent the passage of smoke or flame, and thermal Insulation (I) which consists of a limit to the temperature on the unexposed side of the composite slab in order to prevent the spread of the fire. According to Cooke, G. M. E. [6], the fire tests are relatively expensive and are time-consuming due to the drying time of the concrete.

In Europe, the organization responsible for introducing calculation methods was the European Convention for Steel Construction (ECCS) [12], where in 1983, published some calculation rules applied to the practical design of composite concrete slabs with a steel profile exposed to a standard fire. The performance criteria are based on a simplification of the general fire resistance criteria as specified in ISO 834. As a result, several studies have emerged from developing and improving simplified and numerical calculation models.

In 1980, these composite slabs became very popular in the United Kingdom. Although these types of composite structures had been in use in North America since the 1970s, regulatory authorities in Europe were concerned because of the amount of data on the fire resistance of composite slabs was insufficient to meet the fire safety criteria established by European standards. [13] Thus, after 1982, considerable large-scale testing of composite slabs was performed .

Following the fire resistance studies, in 1988, G. Cooke et al.[6] tried to show the possibility of composite slabs presenting a fire resistance of 90 minutes so that there would be no need to include additional insulation on the exposed face of the slab, only applying a steel

grid reinforcement on the top of the composite slab. In conclusion, until then, for this fire resistance criterion, it was necessary to use reinforcing bars. These studies were based on tests developed by the Construction Industry Research & Information Association (CIRIA) and the British Steel Corporation (BSC), carried out in 1983/1985 and 1984/1986, respectively. Thus, with the data obtained from these tests, it was possible to prove that the slabs reached the 90 minutes fire resistance level only with the inclusion of the negative moment reinforcement grids at the top of the slab. Furthermore, with the experimental test, it was also possible to conclude that the slabs with recessing geometry offer better insulation as well as thermal shielding properties than trapezoidal slabs.

Between the years 1995 and 2003, the Building Research Establishment (BRE) carried out real scale fire tests in the Cardington laboratory. The detailed explanation of each test was presented in 1999 [9]. Several full-scale tests of an 8-story building were developed, made by steel and composite structures and subjected to different fire scenarios. The building had dimensions of 21 x 45 m and a total height of 33 m. The simulation of the mechanical loading was performed by placing sandbags in addition to the self-weight of the structure. As the collapse of the structure was not achieved, the tests confirmed the conservatism of the Eurocode Fire design. The tests aimed to collect data representative of real fires to enable the verification and validation of advanced calculation programs for performing numerical analysis of structures under fire. They concluded that the arrangement presented an adequate fire safety condition, meaning that a standard office (the building model for which the load distribution arrangement was made) has these same resistance characteristics under fire conditions. In addition, the experimental test results were used to study the behaviour of the connections between slabs, beams, and columns, helping to refine the analytical and numerical calculation models.

In 1998, C. Both [10] carried out a full-scale experimental study where the main objective was to introduce easy-to-follow calculation rules and provide more information about fire behaviour and failure mechanisms, mainly of continuous composite slabs. As such, the author concluded that the thermal model was able to describe the two- and three-dimensional heat flows in composite slabs during fire exposure and that the fire resistance evaluation rules given in Eurocode 4 at that time could be significantly improved.

In 1999, Abdel-Halim et al. [14] studied the behaviour of composite slabs exposed to fire. The tests concentrate on the investigation of the effect of additional bars on fire resistance, as well as on the comparison of the fire resistance of the samples concerning integrity and

insulation. In the first test, the failure by insulation occurred at 86 minutes and for the second test at 80 minutes. Slab integrity failed after 192 minutes in the first test and 180 minutes in the case of the second test. The conclusions were that since the metal cover separates from the concrete, it can be assumed that it has no contribution to the slab's thermal resistance during a fire.

Also in 1999, Bailey et al. [15] presented the results of two full-scale experimental tests performed by the Building Research Establishment (BRE) in the UK, demonstrating that the performance of the structure under fire effect was different from what is expected by fire resistance codes, convincing that these were conservative. After the two tests, it was demonstrated that the element's behaviour differs from what is normally obtained in standard small-scale fire resistance tests. They also concluded that this type of slab has good fire resistance.

Piloto P. et al. [13] investigated in 2019 the standard fire behaviour of composite slabs with a steel plate. The slab structure consists of a profiled steel plate covered by a concrete layer to resist negative bending and avoid cracking in the concrete, a steel mesh was used in the upper part. To resist positive bending, individual rebars were placed between their ribs. The steel plate also acts as reinforcement and can be directly exposed to fire conditions. This composite solution is widely used in all types of buildings, which require a certain level of fire resistance according to regulations and standards. The classification of the resistance of these elements was determined by the fire test standard ISO834. In this investigation, two samples were tested under these conditions to evaluate the integrity (E) and insulation (I) and deal objectively with the classification of the insulation resistance (I). This analysis showed that EN 1994-1-2 overestimates the fire resistance providing unsafe results.

In 2021 Bolina F. [16], studied the thermal behaviour of reinforced concrete composite slabs in fire, intending to make a comparison of the temperature distribution in the cross-section through various methods, including experimental. The authors carried out eight full-scale fire tests. With these experimental tests, the numerical models developed using the ABAQUS software were calibrated. These two methods were compared with the analytical method provided by EN 1994-1-2 [4]. The conclusions presented by the authors were: during the experimental tests, the steel deck detachment was observed in the first 5 minutes of exposure to the ISO-834 fire curve, implying that the benefits of the composite slab effect do not occur throughout much of the fire exposure period, the need for a review in Table D.6. of EN 1994-1-2 was also mentioned.

2.1.2. Numerical simulations

Between 1983 and 1985, the Construction Industry Research & Information Association conducted a test programme on behalf of the leading steel deck producers in the United Kingdom (CIRIA). One large-scale and five smaller-scale loaded composite slabs with reinforcement meshes were used for the fire testing. The inquiry revealed, among other things, that design suggestions were typically conservative and that slabs with dovetail profiles typically offered superior fire protection than slabs with trapezoidal profiles [6].

Considering that the experimental structural analysis based on ISO 834 was assumed expensive and time-consuming, and the calculation model provided by ECCS 1984 [17] was very conservative regarding structural safety, in 1990, Hamerlinck et al. [18] developed a simulation model that predicts the behaviour of composite concrete and steel slabs. Where this research developed a thermal and mechanical analysis, and the model was verified through experimental tests. These tests were conducted on twelve specimens, using several types of steel profiles, and evaluating the effect of the steel profile for slabs with the same thickness of concrete. The design comprises thermal and mechanical models for the cross-section analysis and a structural analysis model for the composite slabs. The model was validated by experiments at the Institute for Building Materials and Structures (TNO). The numerical results showed satisfactory values that can predict temperature evolution compared to the experimental measurements.

Later, in 1991, Hamerlinck [19] described separately all the methods used in his development of calculation models, where a model describing the behaviour of composite slabs exposed to fire was used. Experimental verification was performed to validate the results. The models that are being used include both computation of temperature changes over time and the mechanical reactions of the slab. In this study, the author concludes that the predicted data did not significantly differ from the actual data. The heat transfer model is tested in two sections, separating the effect of two key factors. One of these parameters explains conduction in the slab, while the other defines heat transfer (convection and radiation).

Both [20], in 1996, developed a numerical model to predict the evolution of temperatures in a concrete and steel composite slab. In this study, twelve tests were performed with different profiles to determine the influence of the concrete thickness and the steel deck on the thermal performance of the section. The effects of the fusion of the zinc layer, present in the steel deck was considered, where this effect was simulated employing the temperature-

dependent emissivity of the profile, and the evaporation of moisture was taken into consideration through a relationship of temperature with the specific heat of the concrete. According to the author, the model presented satisfactory results since it showed similarities with the results obtained in the experimental tests.

Later, in 1997, C. Both [21] developed a finite element model to determine the temperature and mechanical response of Slim Floor systems exposed to fire using DIANA software. The author realised that for temperatures above 100°C, when evaporation of the moisture process occurs in the concrete, there is a loss of contact between the steel deck and the concrete. Therefore, a heat transfer by radiation and convection to the void layer between the steel and concrete was introduced.

In 2001, S. Lamont et al. [22] used the finite element software HADAPT to develop numerical heat transfer models to perform a 2D non-linear transient thermal analysis compared to Cardington fire simulations. Thus, the authors demonstrated that the parameters selected, and the software effectively simulated the temperature evolution in the concrete up to a certain period. Furthermore, they verified that when the concrete reached a temperature of 100 °C, the experimental tests showed a brief temperature stabilisation reducing the heating rate. On the other hand, numerical modelling showed greater temperature stability in the heating phase. The authors concluded with their analyses that this difference in the structure's response was due to the inequality between the moisture of the concrete used in the modelling compared to the concrete used in the Cardington test.

Later, in 2004, S. Lamont et al. [8] performed a numerical study on finite elements using ABAQUS to study the element behaviour during a fire modelled in a five-story high structure. The structure was initially submitted to a short-duration fire with high temperature and later to a second fire with a long duration and with the maximum temperature lower than the first. The numerical models were validated with Cardington test data. In the analysis of the results, the authors realised that the most destructive fire from a structural safety point of view is a short-duration fire with high intensity. In this case, large deformations arise quickly, resulting in a premature failure of the structure, thus going against the direction employed in the analysis of the area under the fire Temperature-Time curves. It was also concluded that a fire with long duration and lower intensity results in higher temperatures in the steel and concrete, as expected. However, these values are reached after a longer period of exposure, thus ensuring that even if there are larger displacements for the short fire duration, these will occur later in the structure.

In 2017, Jian Jiang et al. [23] developed a numerical analysis incorporating several elements that might affect the fire resistance of composite slabs with regards to the thermal insulation criteria (I). Whereas a revised algebraic equation that explicitly considers the moisture content of the concrete was provided for calculating the fire resistance. These authors concluded that the characteristics that most affected the fire resistance were the concrete thickness and moisture content after the parametric analysis of 54 composite slabs.

In recent years, various finite element software programs have developed a wide range of thermal and structural models to predict the structural and thermal behaviour of steel-concrete composite slabs under fire conditions.

In 2018, Piloto et al. [24] analysed the fire resistance of composite concrete slabs with profiled steel decks with steel mesh on top containing rebars between ribs. The main purpose of this study was to develop the two-dimensional numerical model using the programs MATLAB and ANSYS to evaluate the fire resistance of various composite slabs configurations according to insulation standards. For the development of this study, the fire resistance criteria (I) ability to insulation was evaluated using numerical and simple computational methods and verified by experimental fire tests. The results demonstrate that fire resistance (I) increases with concrete thickness for both calculation methods. However, using the numerical method, the simulation predicts a lower fire resistance (I) compared to fundamental standards, so this method guarantees higher stability. Therefore, a new and better approach was proposed that considers the quadratic variation between fire resistance and the effective thickness of composite slabs.

In 2019, P.A.G. Piloto et al. [25] [26] used ANSYS and MATLAB programs to perform numerical simulations on a standard fire-based thermal solution with 3D numerical validation models of load bearing (R) and insulation (I) criteria. The authors wanted to investigate the effect of load on the resistance criterion (R) and the effect of concrete thickness on the insulation criterion (I). For the thermal model, when the slab is exposed to fire, the steel plate heats up and expands rapidly, causing separation from the concrete, so they used an alternative model with air gaps between the steel and the concrete. This effect is called "air gap". The authors concluded that the formulation proposed by the standard overestimates the actual resistance of the composite slab. However, model results simulating perfect contact between steel plate and concrete underestimate the resistance. This is due to the 'air gap' effect, which increases the fire resistance of the composite deck. On the other hand, the new formula for calculating the fire resistance according to the insulation criterion (I) shows a quadratic

dependence between fire resistance and the effective thickness of the slab.

In 2019, Balsa et al. [27] performed improvements in the validation of thermal and mechanical numerical models with the help of ANSYS software, where the technique of using solid elements to simulate the air layer between the steel plate and the concrete was replaced by shell finite elements. This new proposal allowed the reduction of the thermal model processing time due to a decrease in the number of nodes created in the model. Even more accurate results were achieved for the prediction of fire resistance according to the insulation criterion (I), being the difference only 3.88% for the application of an air layer with 0.50 mm of thickness.

In 2021, P.A.G. Piloto and Balsa et al. [28] developed a study where different steel deck geometry in the common fire was used in a number of computational simulations of the thermal effects on composite slabs. Using the Matlab Partial Differential Equations Toolbox, 3D finite elements were used to simulate the full-scale testing (PDE Toolbox). The results were utilised to develop a new proposal as an alternative to the EN 1994-1-2 standard for the assessment of the temperatures in the slab components (lower and upper flange, web, and rebar). The suggested analytical method enables more precise estimation of the temperatures for various time values by using the numerical results as reference values (45, 60, 90 and 120 minutes). However, since the coefficients of the new proposal are obtained by fitting the numerical data using the Generalised Reduced Gradient (GRG) optimisation method, there is no certainty that the solution is optimal or quasi-optimal.

Bolina et al. [16] evaluated the thermal behaviour of composite steel-concrete slabs exposed to a typical fire in 2021. The objective was to compare the temperature distribution throughout the cross-section using various experimental, numerical, and analytical approaches. The numerical models created using the ABAQUS software were calibrated using eight full-scale fire tests that the authors conducted. The analytical method offered by EN 1994-1-2 [4] was compared with the numerical methods. The analytical method and the numerical and experimental methods did not converge well for the temperature in the steel deck. As a result, a novel analytical method for calculating temperature was presented. The authors noticed a convergence of the analytical method with the numerical and numerical and experimental method only for the steel deck, but not for the concrete, the reinforcement bars and the thermal insulation. Therefore, a new approximation for determining the temperature inside the rebar was developed, including a new factor for evaluating thermal insulation performance.

In the present thesis, new coefficients are proposed for the analytical method. In order to obtain the coefficients and new proposals, the linear least squares method is used instead of an optimization method in the thermal analysis of composite slabs to determine the fire resistance EN 1994-1-2 [4], taking into account the load resistance criterion (R) and also the thermal insulation (I) .

2.2. Characterization of composite slabs

A Composite steel-concrete slab consists of a structural solution composed of elements that contribute to the ability to sustain load and, where two or more materials are linked together and work as a composite solution. In general composite slabs consist of a steel decking (thin-walled cold-formed steel panels), rebars, a light reinforcement mesh, and concrete. The steel and concrete composite slabs can be described by joining a reinforced concrete layer found above a steel deck, which may or may not be reinforced by steel rebar within the ribs (see Figure 1.1). The steel deck provides three essential functions: as a temporary working platform, as formwork, including as positive moment reinforcement. This configuration ensures lightness to the structure, more efficiently and economically than conventional slabs. Composite slabs play an important role in the overall stability of buildings during a fire and must be designed following regulations and standards [15].

Among the advantages presented by composite slabs is the reduction in the use of concrete, which results in a lower self-weight of the structure, besides the decrease in execution time, since the steel plate acts as permanent formwork. However, the presence of the steel plate in the composite slabs may present a disadvantage to the fire resistance, due to the sensitivity of the thermal and mechanical properties of steel at elevated temperatures.

2.2.1. Application fields

Composite slabs are generally used in the following types of buildings: commercial, industrial, office, leisure, hospital and residential buildings, single and multiple family structures, renovation of existing buildings, sectors that demand speed of construction and general structural economy. Although most are used on steel-framed buildings, masonry or concrete components may also support composite slabs [15].

Generally composite slabs are typically combined with multi-story steel-framed buildings the most. Composite slabs have recently been implemented in structures with

concrete, masonry, and wooden frames. Under typical environmental conditions, composite slabs are ideal for interior applications. In other cases, the specification of composite slabs should consider any potential adverse effects from environment.

2.2.2. Fire safety verification of composite slabs with steel decking

As part of understanding the evolution of concern for structural safety in the event of a fire, its introduction in Europe was first published by ECCS (European Convention for Constructional Steelwork). Then, thanks to the contributions of researchers such as Hamerlinck R., and Booth K. [18], the EN 1994-1-2[4] was published and presents the rules for determining the fire resistance of structural elements. Structural elements need to meet fire-safety requirements according to building codes. Regarding the latter point, it is mentioned that traditionally fire resistance is assessed based on combustion tests of single structural elements such as beams and columns. The fire rating of composite slabs is usually made using standard fire tests and should consider the criteria of insulation (I), integrity (E) and load bearing (R). Usually, the fire resistance is expressed in classes ranging from 15 to 240 minutes with intervals of 30 minutes, for the case of higher fire ratings [29].

The European Standard EN 13501-2 [29] defines these criteria and the fire rating classification of building products and elements. The three criteria (REI) being the classification period during which all criteria loadbearing capacity, integrity and thermal insulation are satisfied. Additionally, it clarifies that, depending on the structural component, the three conditions need not be met simultaneously. Occasionally two (RE) or just one (R) may be sufficient, depending on the function of the studied element. For proper structural design and to avoid both structural collapse and component integrity in the event of a fire, experimental tests shall be performed according to the standard heating curve, usually following ISO 834 [1].

This test standard defines the fire resistance of a structural member to a standard fire, measured in minutes, until failure occurs. The laws of each country specify the minimum fire resistance for each building element. The standard EN 13501-2 [29] presents the most used fire rates, which act as a standard guide to help both in commercial design development and in the development of studies to optimize processes currently used in design, as in this thesis.

In this work, the focus is given to the fire resistance according to the thermal insulation criterion (I) and to the other components affected by temperature in case of fire, regarding the ability to sustain the load. The following sub-sections present a description of the three different criteria of fire resistance for composite slabs.

2.3. Fire resistance criteria

Composite slabs must meet fire protection requirements according to building codes. Fire protection requirements are usually specified by fire resistance times of 30, 60, 90 minutes or more. The fire rating of this building element is usually based on standard fire resistance tests [2]-[10] and should consider the criteria for stability (R), Integrity (E) and insulation (I).

The time required for failure in any of the cases presented (RE and I) is given as the fire resistance rating of the slab, even if the failure criterion of another category has not been met until long afterwards [19].

2.3.1. Load-bearing Capacity (R)

The ability to support structural loads without collapsing or presenting large deformations is known as load-bearing resistance (R). Three distinct failure modes, flexural failure, longitudinal shear failure, and vertical shear, come into play when membrane effect is ignored [19]. The performance standards for flexural elements are provided below and are based on the international standard EN 1363-1 [2] for maximum deflection D_{limit} given in [mm] and maximum deflection rate $\left(\frac{dD}{dt}\right)$ given in [mm/min].

The following equations in EN 1363-1 [2] describe the guidelines that guarantee the structure will function satisfactorily concerning this criterion:

$$D_{limit} = \frac{L^2}{400d} \text{ [mm]} \quad (2.1)$$

$$\left(\frac{dD}{dt}\right)_{limit} = \frac{L^2}{9000d} \text{ [mm/min]} \quad (2.2)$$

where t represents the fire-exposure time [min], L represents the span of the slab [mm], d represents the distance between the extreme fibre in the compression zone to the extreme fibre of the cold design tensile zone of the element cross-section. The updated 2020 version of EN 1363-1 [2] introduces a new definition to this criterion (R), which is expressed in the following requirements. Failure is deemed to have occurred when one the maximum displacement reaches $1.5 \times D_{limit}$, or when both, the maximum displacement reaches D_{limit} and the maximum rate of displacement reaches $(dD/dt)_{limit}$.

2.3.2. Thermal Insulation (I)

The basis of the current calculation rules for the fire resistance of composite slabs regarding thermal insulation is the schematisation of the profiled shape of the cross-section for a flat concrete slab. Therefore, the fire resistance analysis employing the thermal insulation criterion (I) in concrete/steel composite structures without additional protection by thermal insulators on the surface exposed to fire depends on specific factors to each slab, in particular its geometry. The criterion used for this condition is based on the temperature evolution of the unexposed surface.

This limiting condition is based on the increment of 140°C for the average temperature (θ_{AVE}) or the increment of 180°C for the maximum temperature (θ_{MAX}) above the initial average temperature (θ_0) of the element [2].

The equations (2.3) and (2.4) express this behaviour.

$$\theta_{MAX} = 180 + \theta_0 \text{ [}^\circ\text{C]} \quad (2.3)$$

or

$$\theta_{AVE} = 140 + \theta_0 \text{ [}^\circ\text{C]} \quad (2.4)$$

2.3.3. Integrity (E)

The integrity criterion (E) refers to the ability of the slab to withstand hot gases or flames penetrating through openings (e.g., cracks). This criterion is usually verified because the floor slab is cast in situ, being the joints adequately sealed. For composite steel/concrete slabs, it is assumed that the steel sheet satisfies the integrity condition. If the test specimen fractures or sustains burning on the unexposed face, it is deemed to have failed in integrity.

2.4. Heat transfer and thermal actions

Heat transfer is a process that studies the transfer of energy between material elements caused by differences in temperature. Heat can be transferred by three methods: conduction, convection, and radiation. Thus, the temperature distribution in a system depends on the combined effects of these three modes of heat transfer.

The action of fire on a structure increases the temperature of the elements, decreasing their stiffness and resistance capacity, which may cause their collapse. Therefore, it is essential to determine the evolution of the thermal field in the transient regime and, simultaneously, to

determine the fire resistance time.

When analysing the rate of the temperature evolution in structural elements, it is fundamental to determine the amount of heat affecting these components. The Eurocode 1 – Part 1-2 [3] presents thermal actions for the temperature analysis, This effect is defined in terms of an incident heat flux density on the boundary surface of the element (\dot{h}_{net} [W/m^2]) comprising two methods, one due to radiation ($\dot{h}_{net,r}$) and another due to convection ($\dot{h}_{net,c}$) from the fire environment.

In the case of the design for the standard fire situation, the standard curve is the curve of temperature versus time (ISO 834), for which the heat flux density absorbed is made by the two methods of heat transfer.

The surface heat fluxes are calculated using the expressions for heat transfer by convection, and radiation; the terms are, respectively:

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} \quad (2.5)$$

The following subsections present the formulations used to determine each component of the above equation and briefly describe the three modes of heat transfer.

2.4.1. Conduction

Heat conduction is fundamentally related to atomic and molecular activity as it is the process responsible for this type of heat transfer at these levels. Interparticle interactions result in energy transfer from a higher-energy object to a lower-energy particle of another material [21].

Heat conduction can occur in solids, gases, or liquids. In gases and liquids, conduction occurs through collisions and diffusion as molecules move randomly. In solids, it happens through a combination of molecular vibrations and the free transport of electronic energy. The heat transfer rate, therefore, depends on the medium's temperature difference, shape, thickness, and material. In other words, the thermal conductivity through the plane is proportional to the temperature difference between the layer and the heat transfer area but inversely proportional to the thickness of the layer [22]. This phenomenon is governed by Fourier's law, introduced in 1822, which describes this heat conduction phenomenon and is expressed in its differential form by the equation (2.6):

$$\dot{h}_{cd} = -\lambda \cdot \frac{d\theta}{dx} \quad (2.6)$$

In equation (2.6) $d\theta/dx$ is the temperature gradient in the direction of heat flow [K/m], which means the material's ability to conduct heat in the x-direction and is the thermal conductivity of the material [W/m·K]. Since heat flow is a vector quantity, the three-dimensional form of Fourier's law is given by:

$$\vec{h}_{cd} = -\lambda \cdot \vec{\nabla}\theta \quad (2.7)$$

$\nabla\theta$ is the temperature gradient vector giving the temperature variation in the three 3D axes.

2.4.2. Convection

Convection is the transfer of heat by the movement of the medium, defined as the mode of energy transfer between a solid surface and a fluid (i.e., advection and diffusion of a gas or liquid) in movement on its boundaries. It depends on fluid conduction's effects and motion [8].

Convection transfer can also be divided into groups based on the flow type. It is classified as forced convection when the fluid flow is brought about by machinery (fans, pumps, or atmospheric winds) or by some other external force. As attributed to that, it can also be referred to as natural (or free) convection when the flow is brought on by density variations brought on by changes in the fluid's temperature [30]. Regarding the convection effect's complexity, Newton's equation provides a concise expression for the convective heat transfer rate, which is proportional to the temperature difference.

According to Eurocode 1 - Part 1-2 [3], the convective heat flux of the fluid should be calculated according to the equation:

$$\dot{h}_{net,c} = \alpha_c(\theta_s - \theta_\infty) \quad (2.8)$$

where, α_c is the convection coefficient [W/m²K], relevant for nominal temperature-time curves; θ_s is the body surface temperature and θ_∞ is the temperature of the gas, or the fluid in [°C].

According to EN 1994-1-2 [4], the net convective heat flux on the unexposed surface of separating elements should be considered $\alpha_c = 4 \left[\frac{W}{m^2} \right]$. Otherwise, this value should be taken as $\alpha_c = 9 \left[\frac{W}{m^2} \right]$ when assuming it contains the effects of radiation heat transfer. The coefficient of heat transmission via convection should be used as follows regarding the fire-exposed surface as $\alpha_c = 25 \left[\frac{W}{m^2} \right]$ if the element is exposed to the standard fire curve ISO 834 [1]

or the external fire curve and $\alpha_c = 50 \left[\frac{W}{m^2} \right]$ in the case of surfaces exposed to the hydrocarbon curve.

2.4.3. Radiation

The definition of radiation heat transfer is the transmission of energy by electromagnetic waves as a result of alterations in atomic or molecular electronic structures. Each body constantly produces energy through electromagnetic radiation. Still, the amount of this energy depends on the temperature of the body in question and the type of surface it has [24]. The Stefan-Boltzmann law specifies the maximum amount of energy that a surface can irradiate E [W/m^2].

The model for the perfect thermal radiator is called "blackbody" (ideal thermal radiator) which emits thermal radiation proportionally to the fourth power of the absolute temperature, thus the upper limit for the emissive power is described by the Stefan-Boltzmann law:

$$E_b = \sigma \cdot \theta^4 \quad (2.9)$$

where θ is the absolute temperature [K] of the surface and σ is the Boltzmann constant ($\sigma = 5.67 \cdot 10^{-8} [W/m^2 \cdot K^4]$) and describes the ideal surface referring to a blackbody.

The black body's thermal radiation is of utmost significance for heat transfer by radiation. Although the black body has numerous unique qualities, its excellent emission quality is the most significant. To calculate the emission of radiation by other bodies, it is necessary to introduce a new parameter in the equation. This variable, the element's emissivity (ϵ), is used to estimate the heat flux brought on by radiation.

The emissivity of a surface is usually related to the emission wavelength energy, surface temperature, and beam angle; for simplicity, whether the emissivity depends on these factors, the surface is called a "grey body" appearance.

Ash radiation is used in fire engineering approaches and calculations. The ability of a body to emit or absorb thermal energy throughout all its wavelengths can be quantified using this adimensional parameter [-], whose coefficient ranges from 0 to 1, with 1 being the value attributed to the blackbody. Thus, equation (2.10) can be rewritten as:

$$E_b = \epsilon \sigma \cdot \theta^4 \quad (2.10)$$

According to Eurocode 1 - Part 1-2 [3] the equation of heat flux by radiation on the surface exposed to fire was used to analyse the temperature of structural elements $\dot{h}_{net,r}$ in [W/m^2] is defined according to the Equation below:

$$\dot{h}_{net,r} = \Phi \varepsilon_f \cdot \varepsilon_m \cdot \sigma [(\theta_r + 273)^4 - (\theta_m + 273)^4] \quad (2.11)$$

Where Φ is the view factor, ε_f is the emissivity of the fire, ε_m represents the emissivity of the exposed structural element, θ_r is the effective radiation temperature in the burning environment given in [°C], and θ_m is the surface temperature of the element receiving the radiation also in [°C].

2.4.3.1. View factor

Radiation is the primary heat transfer method that raises the slab's temperature in fire heat analysis, especially when high temperatures are attained. The placement of the flame and the element receiving the thermal energy, or the "view factor," must be considered when calculating the transfer through radiation (Φ).

The view factor (Φ) is a dimensionless term that expresses the proportionality of the heat absorbed in the form of radiation by a surface exposed to fire so that it is directly dependent on the geometric arrangement of the element. In other words, depends on the area and orientation of the surface-emitting radiation relative to the surface receiving radiation and between them [7]. Despite the complexity in determining the view factor, simplifications are provided in the literature for the specific case of the surface elements of composite slabs with collaborating steel decks exposed to fire due to the high variability of situations.

The view factor defined in EN 1994 1-2 [4], is based on Hottel's crossed-string method developed in 1950 [31]. For composite slab geometries, the view factor of the lower flange of steel decking is typically taken as unity $\Phi_{low} = 1.0$.

The view factors for the web and upper flange of steel decking are less than unity due to obstruction by the ribs. Equations (2.12) and (2.13) provide the mathematical relations to determine this view factor as a function of the geometric characteristics of the profiles presented in Figure 2.1.

$$\Phi_{upper} = \frac{\sqrt{h_2^2 + \left(l_3 + \frac{l_1 - l_2}{2}\right)^2} - \sqrt{h_2^2 + \left(\frac{l_1 - l_2}{2}\right)^2}}{l_3} \quad (2.12)$$

$$\Phi_{web} = \frac{\sqrt{h_2^2 + \left(\frac{l_1 - l_2}{2}\right)^2} + (l_3 + l_1 - l_2) - \sqrt{h_2^2 + \left(l_3 + \frac{l_1 - l_2}{2}\right)^2}}{2\sqrt{h_2^2 + \left(\frac{l_1 - l_2}{2}\right)^2}} \quad (2.13)$$

Following this rule, Figure 2.1 shows the parameters required to determine the view factor in composite slabs.

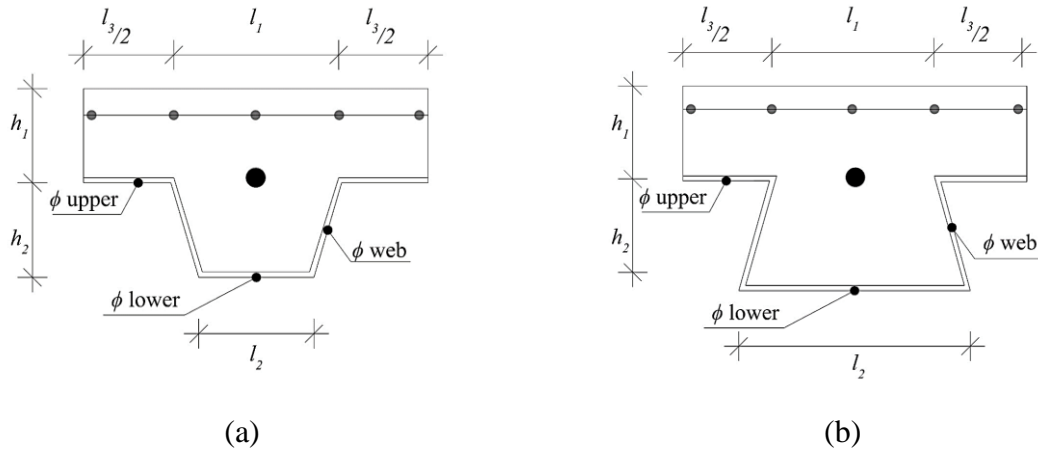


Figure 2.1: Parameters for determining the view factors: (a) Trapezoidal profile, (b) Re-entrant profile.

2.5. Thermal properties of materials

Heat transfer studies require thermal properties such as density, thermal conductivity, and specific heat. Given that the study aims to numerically simulate the solution of the second-order differential heat equation to predict the temperature distribution in composite slabs of composite elements, it is the understanding of the thermal properties and boundary conditions that interfere with the thermal performance of these elements.

Thus, to obtain the best possible results in the thermal model, the thermal properties of the materials should be regarded as close as possible to reality and temperature dependant. Assuming that the composite slab is a globally and locally heterogeneous structure considering specific elements, the nonlinearity of heat transfer along the cross section can be regarded as the main characteristic of this type of slab, so that the temperature modification during the fire period implies changes in the material's specific heat, thermal conductivity, and density.

The thermal properties of each material describe its mechanical responses when subjected to a temperature variation and have an important influence on the results of numerical simulations, as this determines the responses of the structure to temperature variation. The properties used in the numerical model follow the formulas of Eurocode 2 and 3, being the steel and concrete properties specified in EN 1993-1-2 [32] and EN 1992-1-2 [33], respectively. The development of the analytical model obeyed the recommendations of EN 1994-1-2 [4]. As the air gap is regarded between the steel plate and the concrete, it is also

required to know the air's thermal properties.

2.5.1. Steel

The thermal properties stand for both steel elements (steel deck and rebars). This variation may be determined through equations available in Eurocode 3 Part 1-2 [32].

The variation of the specific heat of steel (C_p), the variation of the thermal conductivity of steel (λ_a) and as a function of temperature θ_a of steel is presented in Figure 2.2, according to EN 1993-1-2 [32]. The density of steel is independent of temperature variation, taking a constant value so that: $\rho_a=7850 \text{ kg/m}^3$, as shown in Figure below:

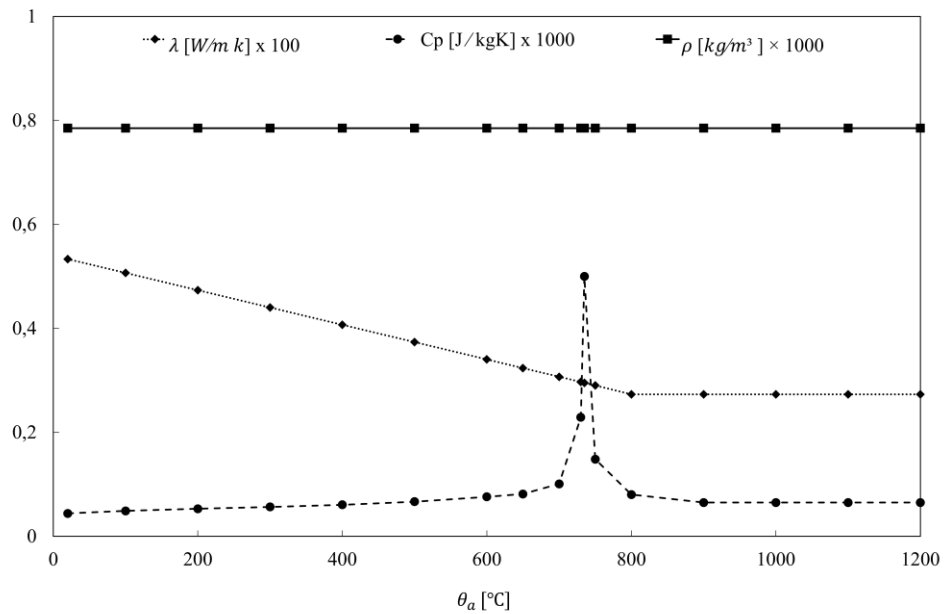


Figure 2.2: Thermal properties of carbon steel.

2.5.2. Concrete

This study will comprise the normal weight concrete (NWC) type, also named conventional concrete. The thermal properties of this material were obtained according to the EN 1992 part 1-2.

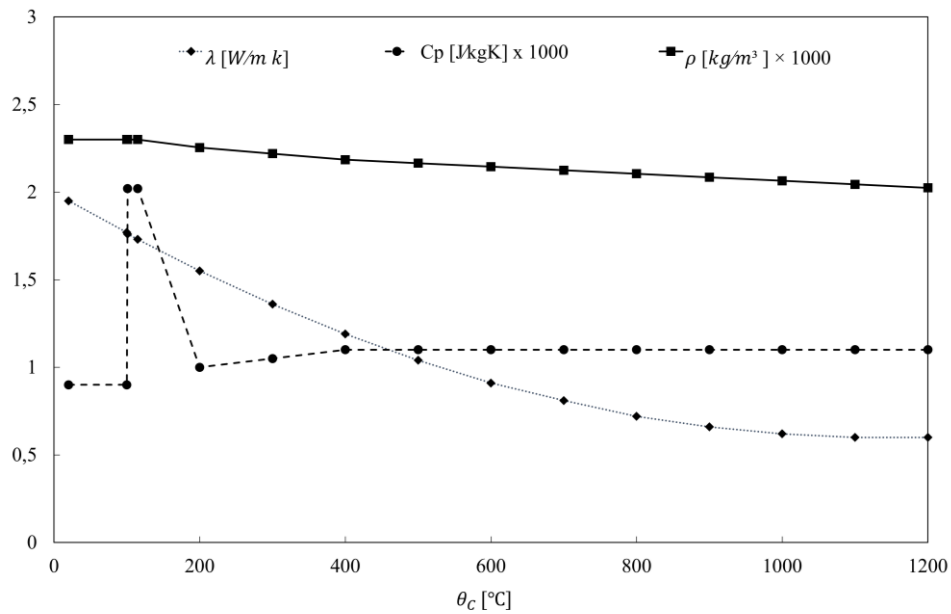


Figure 2.3: Thermal properties of concrete as a function of temperature.

In Figure 2.3, the specific heat c_p of the material in [J/kgK] changes with temperature and depends on the moisture of the concrete. For dry concrete ($u = 0\%$). The density of the concrete ρ_c varies as a function of temperature. The standard also provides two equations that reflect the upper limits of the thermal conductivity (λ_c) [W/mK] of NWC that depends on the temperature, allowing for estimating any value falling within this range. However, EN 1994-1-2 [2] suggests using the highest limit in the case of composite elements, where θ_c corresponds to concrete temperature in [°C].

For the calculation of the specific heat, referring to other percentages of moisture, the standard includes the values of the peak specific heat ($C_{p,max}$) in which, it is constant between temperatures between 100 °C and 115 °C and decreases linearly between 115 °C and 200 °C, the values for these constants are shown in Table 2.1.

Table 2.1: Correlation between the maximum specific heat for NWC and moisture content.

| Moisture Content [%] | $C_{p,max}$ [J/Kg K] |
|----------------------|----------------------|
| 0.0 | 900 |
| 1.5 | 1470 |
| 3.0 | 2020 |

2.5.3. Air

The analysis of the air-gap effect, which consists of a thin layer of air rising between the concrete and the steel deck during the heating process, should be included in the behaviour of composite slabs under fire. This effect occurs due to the thermal expansion variation between the two materials, which significantly impacts the heat transfer in composite slabs.

The thermal properties of air were selected from the work developed by Y. A. Congel and A. J. Ghajar [15], who identified that the specific heat, thermal conductivity, and density vary with temperature. Therefore, the properties of air are required to simulate the effect between the steel deck and the specific "air gap".

Figure 2.8 presents the variation of the thermal properties of air with temperature for a pressure of 1 atm.

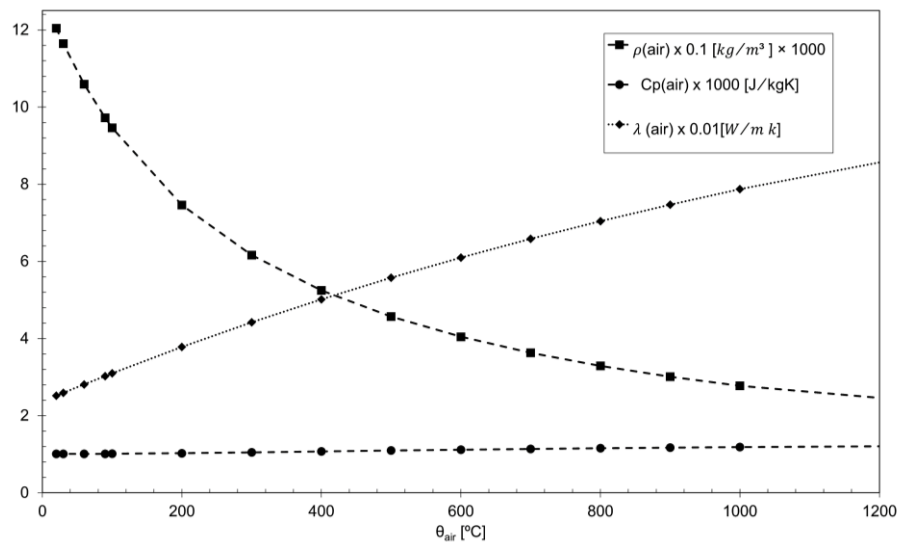


Figure 2.4: Air thermal properties as a function of temperature variation.

2.6. Fire Curves

The development of fire requires a source of heat, fuel, and oxygen all at the same time. They can be caused by flaws in the building, specifically in the electrical or gas installations. They can also be initiated by users inadvertently. If the fire is not controlled, it spreads, and a fire begins, endangering the structure and the safety of the residents.

Being the representation of accurate fire models is complicated due to all the variables involved, it is necessary to use simplified models, but adequate with reality, such as nominal

curves or parametric curves. The nominal curves are defined by simple equations and the parametric curves are defined by equations that depend on several physical parameters.

2.6.1. Natural fire curves

Fire is the result of a very exothermic thermochemical process of oxidation. For this to occur, it requires an organic chemical compound susceptible to oxidation (the fuel), a reducing/oxidizing substance (the oxidizing agent) and activation energy. Once the oxidation reaction is initiated, also known as combustion, or burning, the heat released by the reaction keeps the process going. According to Paulo Vila Real [34], a natural fire model, schematically shown in Figure 2.5, is composed of four phases: the initial phase or the ignition, the propagation phase, the full development phase, and the extinguishing or cooling phase.

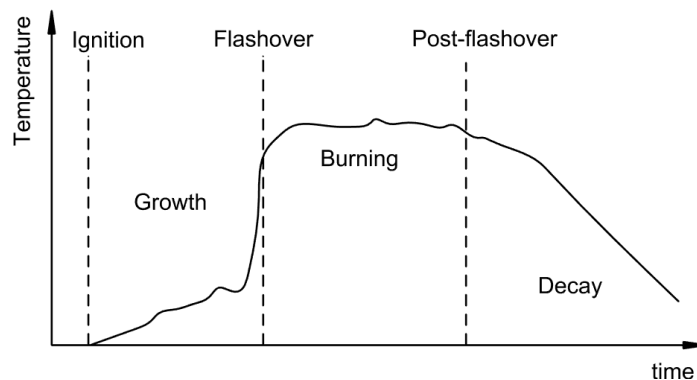


Figure 2.5: Fire curve for the complete process of fire development.

So, the first phase corresponds to the beginning of the fire with low-temperature values, not yet influencing the structural behaviour. The second phase occurs with the generalized propagation of the fire in which the fuel will be consumed, leading to a rapid temperature rise called the "Flashover". This phenomenon usually occurs for temperatures between 450°C and 600°C on the ceiling or by an incident heat flux of 20 kW/m² at the floor level. The third phase of full development occurs during the burning of the fuel. The temperature is maintained at roughly constant values by the generalized spreading of the fire and by the rapid evolution of temperature values.

Finally, there is cooling, characterized by the progressive decrease in temperature due to lack of fuel, combustible, or even human action related to firefighting.

Regulatory requirements such as Eurocode allow us to create two types of fire curves to specify maximum temperatures achieved and assess structural fire resistance ISO 834 fire

and parametric fire. The following sections describe the distinctions between these approaches to calculating fire curves.

2.6.2. Nominal standard fire curves

A standard fire is defined as a nominal fire with a monotonically increasing temperature throughout the test and was designed to represent a worst-case flashover fire. Due to the lack of cooling, standard fires have historically been considered conservative for most purposes.

The EN 1991-1-2 [3] indicates three distinct nominal fire curves: the ISO 834 [1] standard fire curve, the hydrocarbon fire curve, the American standard ASTM E119 [11], and the external element fire curve, see Figure 2.9.

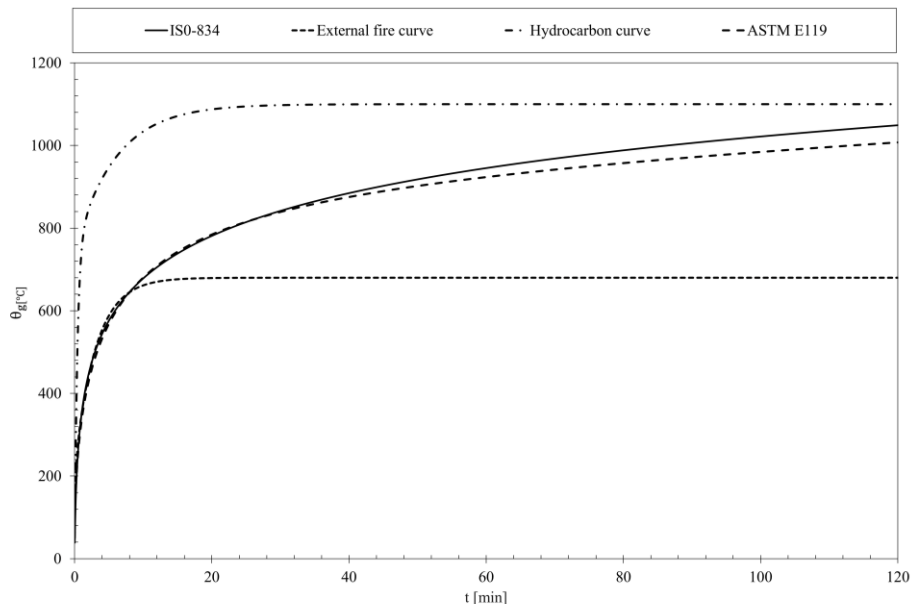


Figure 2.6: Nominal time-temperature fire curves.

The fire curves shown above are independent of all the building's exposed characteristics, such as the fire load and ventilation conditions. These curves don't accurately depicts how the temperature changes over time. The engineering community considers them unrealistic because the temperature seems to increase without any reduction. However, this type of curve is only used as a means of comparison to assess the severity of the fire over a given element.

The value of the fire resistance established by employing these curves will never be the natural fire curve. The numerical model developed in this investigation exclusively applies to the ISO 834 standard fire curve.

2.6.3. Standard Fire curve ISO-834

Modern building codes for fire safety may take either a prescriptive or performance-based approach. It is commonly acknowledged that performance-based approaches have significant advantages over prescriptive methods because they let designers evaluate structural fire safety using real fire engineering methodologies.

The bulk of current fire regulations still takes either a prescriptive approach or a combination of prescriptive and performance-based techniques because it is difficult to evaluate the performance of complete structures [35].

The fire resistance of a building element is defined as the time during standard exposure to fire, expressed in completed minutes, until failure occurs under one of the criteria applicable to the element, according to ISO 834 [1].

$$\theta \cong 345 \cdot \log_{10} \cdot (8t + 1) + 20 \quad (2.26)$$

where θ is the temperature in [°C], and t is the time elapsed in minutes.

3. METHODOLOGY FOR THERMAL ANALYSIS

To determine the fire resistance of the composite slabs regarding the thermal insulation criterion (I) and to calculate the temperature of the steel components regarding the load capacity criterion (R), two different solution methods are used: the simplified calculation method following the recommendations of EN 1994-1-2 [4] and the advanced calculation method. The later is based on a three-dimensional finite element model that includes the effect of additional steel reinforcement bars (rebars) using the MATLAB Toolbox.

This model was developed to evaluate the thermal behaviour of composite slabs with steel decks subjected to standard fire exposure. The numerical temperatures are compared with those obtained by the simplified method provided in the standard. The numerical temperatures are then used to derive a new analytical method, an alternative to the simplified method provided in the standard, to determine the temperatures in reinforced concrete bars accurately.

The fitting of the analytical model to the numerical data was done by solving a linear least squares problem using singular value decomposition. This method guarantees to obtain a solution that minimizes the square of the deviations.

3.1. Geometric characteristics of steel profiles

The study of the thermo-mechanical behaviour of steel parts subjected to the action of fire is a complex problem due, on the one hand, to the thermal and mechanical properties of steel strongly dependent on temperature and, on the other hand, to the geometric complexity of the parts [35].

The geometry of composite slabs can be represented by the dimensions illustrated in Figures 3.1 to 3.4: h_1 , h_2 , h_3 , l_1 , l_2 and l_3 , which denote, respectively, the height of the top continuous part of the slab, the height of the rib, the width at the top of the rib, the width of the bottom edge of the decking and the width of the top decking flange.

The most significant geometric factor influencing the fire resistance of composite slabs is the height of the concrete upper portion of the slab, h_1 . The l_1 and l_2 parameters have similar effects to the one caused by parameter h_2 , since the concrete mass is also directly related to

the variation of l_1 and l_2 . Its difference is in the distribution of the lower temperatures in the upper part of the slab, but the variation in the thinner part of the section is not affected by the variation of these parameters. Regarding the length of the upper part of the slab recess, defined as l_3 , it directly affects the heat transfer in the thinnest part of the slab because that is where the highest temperature occurs. However, it has little influence on the largest section of the slab [23].

The numerical analyses were conducted for trapezoidal and variable re-entrant steel decks profiles. The following table resumes the ranges of the investigated parameters.

Table 3.1: Geometric characteristics of steel profiles.

| Steel deck profile | h_1 [mm] | h_2 [mm] | l_1 [mm] | l_2 [mm] | l_3 [mm] |
|-------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Polideck 59S (Trapezoidal) | 50,70,90,110,125 | 59 | 126 | 61 | 84 |
| Cofraplus 60 (Trapezoidal) | 50,70,90,110,125 | 58 | 101 | 62 | 106 |
| Multideck 50 (Re-entrant) | 60,70,90,110,125 | 50 | 110 | 135 | 40 |
| Bondeck (Re-entrant) | 60,70,90,110,125 | 52 | 168 | 187 | 32 |

The Polydeck 59S model of the trapezoidal profile is the first one chosen. ArcelorMittal oversees producing this profile with a steel deck that is (1.0 mm, 1.25 mm) thick and made with a S350 steel grade. The geometrical characteristics are illustrated in Figure 3.1.

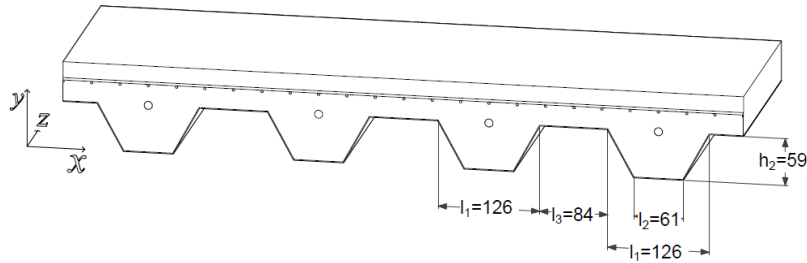


Figure 3.1: Polydeck 59S geometric characteristics [mm].

The second trapezoidal model profile developed by ArcelorMittal is designated Cofraplus 60. The model with a thickness of (1.0 mm and 1.25 mm) has been selected for the collaborating steel deck, and is made with a S350 steel grade. Figure 3.2 depicts its geometry.

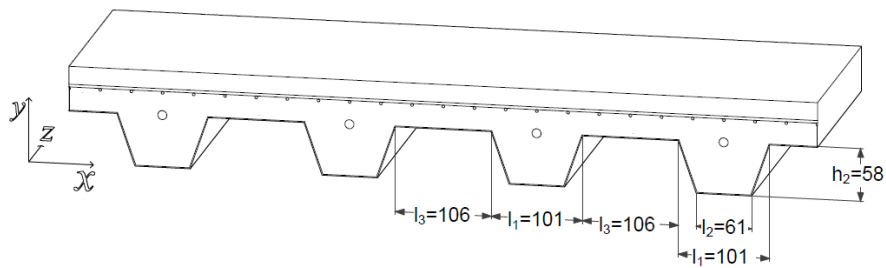


Figure 3.2: Cofraplus 60 geometric characteristics [mm].

The first re-entrant model presented is the Multideck 50, produced by Kingspan Structural Products. This product has a steel profile with steel grade S350 and (1.0 mm, 1.25) of thickness. The geometry is depicted in Figure 3.3.

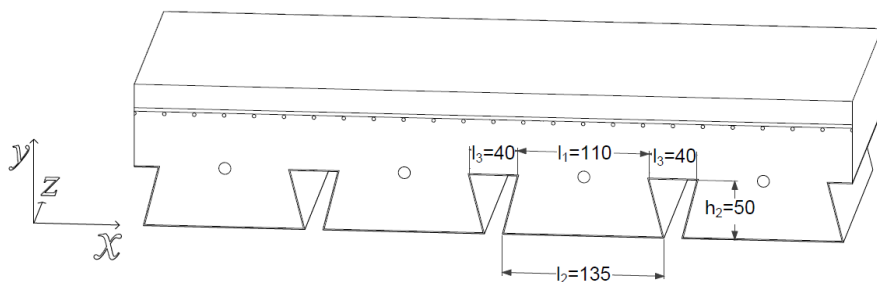


Figure 3.3: Multideck geometric characteristics [mm].

The last re-entrant model is Bondek, which is developed and produced by the Lysaght company. The steel deck is usually made with a steel grade S350, and the model with 1 mm thickness has been selected. The geometry is presented in Figure 3.4.

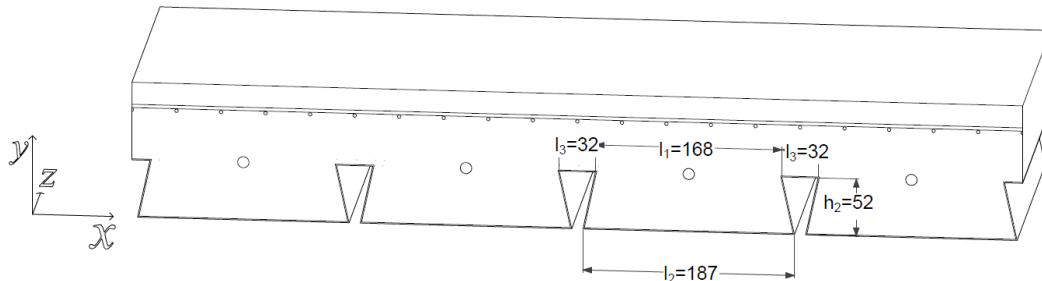


Figure 3.4: Bondek geometric characteristics [mm].

3.2. Parameters for the Simulations in MATLAB

In the last years, different finite element software has been used for an extensive range of thermal and structural analyses to predict the behaviour of composite slabs under fire conditions. MATLAB (MATrix LABoratory) is a well-known high-performance numerical software used for numerical calculations. Due to its simplicity and high dissemination, this program was used to perform non-linear transient thermal analysis.

The MATLAB PDE Toolbox is a widely used tool for solving partial differential equations (PDEs) involving problems of heat transfer, and structural mechanics, among others. This software uses the finite element method to solve the energy equation. The thermal analyses in MATLAB PDE Toolbox require the definition of a thermal model, material properties, and boundary conditions.

3.2.1. Computational Solution with MATLAB

To create the model of the composite slabs in MATLAB, it is necessary to define a transient thermal element model responsible for solving the partial differential equations involving heat transfer. To perform this calculation, it is necessary to create the mesh of the composite slab with the respective parts, thermal properties, and the number of finite elements of the mesh. The boundary conditions require the definition of the gas temperature over time. The algorithm used by the software uses the principles of the finite element method. Thus, to generate the geometry of the composite slab, the following steps were followed: 1-Create a

transient thermal element model with the "thermal model" command; 2-Generate a simple mesh to create the geometry of the slab and for this, the "makeMesh" function was used.

In the case of including the air gap layer at the interface between the concrete and the steel deck, t_s and t_a represent, respectively, the thickness of the steel deck of the slab and the thickness of the air layer, see Figure 3.5.

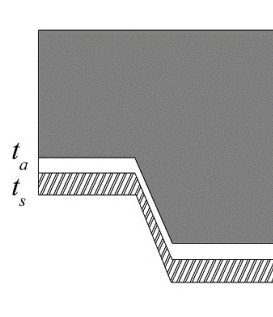


Figure 3.5: Parameters for dimensioning steel sheet thickness and air layer MATLAB.

This last parameter can take a value of zero when it is intended to consider perfect contact (airgap = 0), although the case under study considered ($t_a = 0.5$) between the steel plate and the bottom surface of the concrete [36]. The third dimension w represents the width of the structure element. The parameter $nbCell$ is the number of cells used to create the slab as illustrated in Figure 3.6.

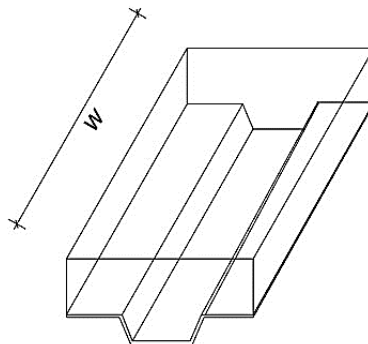


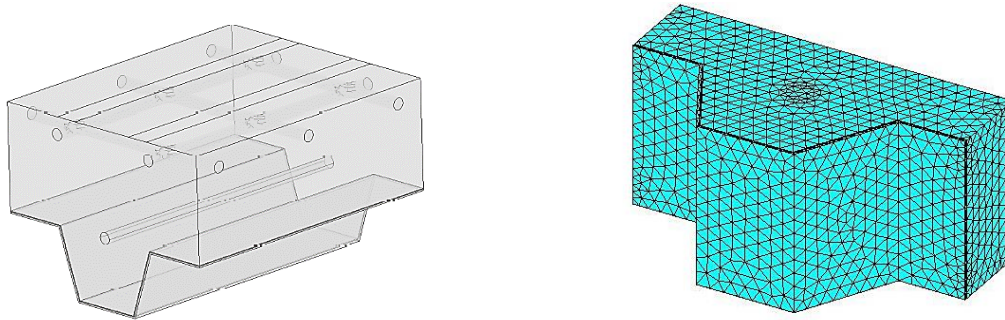
Figure 3.6: Parameters for dimensioning the rib length of the MATLAB composite slab.

For 3D geometry, the PDE toolbox uses uniform meshing with tetrahedral elements, using quadratic geometric order by default offering the option to switch to linear geometric order, but meshes with different element types (mixed mesh) are not supported [37].

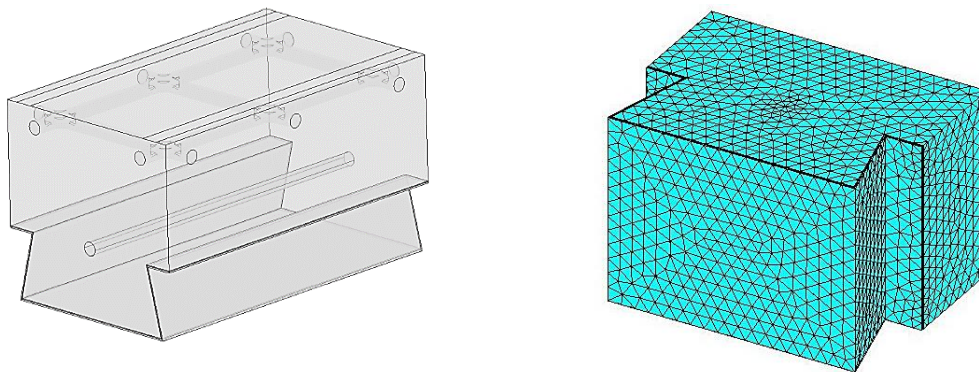
Tetrahedral elements are defined by four nodes (at the corners) for linear elements or ten nodes (at their corners and midside) for quadratic interpolation elements. The mesh of the composite (multidomain) geometry is generated through the function *generateMesh* and stored in the thermal model object. This function allows the use of either linear or quadratic elements,

and provides a few options for mesh-size control, namely the mesh growth rate ($Hgrad$), and the maximum and minimum mesh edge length ($Hmax$, $Hmin$).

In this investigation, the full model was developed, using the mesh presented in Fig. 3.7. In the numerical simulations, the maximum mesh edge length $Hmax$ varies from analysis to analysis, usually standing between 0.015 and 0.02. These values have been selected according to convergence tests using different mesh sizes. The finite element has linear interpolation functions and uses full integration method.



(a) Composite slab Geometry volumes and Finite Element Mesh – Trapezoidal Profile



(b) Composite slab Geometry and Finite Element Mesh – Re-entrant Profile

Figure 3.7: Finite element models

Generally, quadratic elements result in more accurate solutions, however, require higher computational power in comparison to linear elements.

3.2.2. Solution method

The solution method used by the MATLAB PDE Toolbox is incremental in time and iterative in each time step due to the non-linear thermal properties of the material. Following equation below:

$$\mathbf{C}(\boldsymbol{\theta})\dot{\boldsymbol{\theta}} = \bar{\mathbf{F}}(\boldsymbol{\theta}) \quad (3.1)$$

where $\bar{\mathbf{F}}(\boldsymbol{\theta}) = \mathbf{F} - \mathbf{K}(\boldsymbol{\theta})$. The solution of Equation (3.1) is achieved by the built-in function `ode15s` [38]. The solution method implemented in this function is based on the discretisation of the time derivative by numerical differentiation formulas (NDFs) of orders 1 to 5.

The accuracy of the solution can be explicitly controlled through the absolute or relative tolerance parameters. The absolute tolerance is a threshold parameter, below which the value of the solution component is disregarded. This property determines the accuracy when the solution approaches zero.

The relative tolerance is nothing more than a measure of the error concerning the size of each component of the solution. The absolute tolerance is set to 10^{-6} and the relative tolerance is set to 10^{-3} [37]. At each step, the non-linear system of algebraic equations is solved using the Gauss-Newton method, whose stopping criterion can be monitored through the maximum number of iterations (25), the tolerance (10^{-4}), and the minimum damping of search direction (10^{-3}).

4. SIMPLIFIED CALCULATION METHODS

Simplified computational models from the standards are usually derived from experimental fire tests and numerical analyses. These models allow simple analytical formulas to calculate important parameters related to the response of composite slabs under fire, such as the fire resistance for insulation (I) and the temperature of steel members as the fire resistance for load bearing (R).

The simplified calculation method for composite slabs with profiled steel deck, Annex D of EN 1994 Part 1-2 [4], is presented.

4.1. EN 1994 – 1-2

This sub-section describes the processes required in the annex D of EN 1994-1-2 [4] simplified temperature calculation method. When exposed to an ISO834 standard fire [1], the simpler calculation approach for the load-bearing criterion (R) and the thermal insulation criterion (I) described in EN 1994 -1-2 can be used with supported composite slabs.

This simple calculation model (EN 1994-1-2, 4.3) applies to unprotected slabs and the bending resistance shall be determined by the plastic theory. Only simply supported concrete slabs with steel deck (Figure 4.1), heated from below, and subjected to the typical standard temperature-time curve, are covered by the following guidelines [4].

The tables found in EN 1994-1-2 annex D are used to determine the temperature of both materials. Direct actions caused by interactions with other parts of the structure are not considered (isolated member analysis).

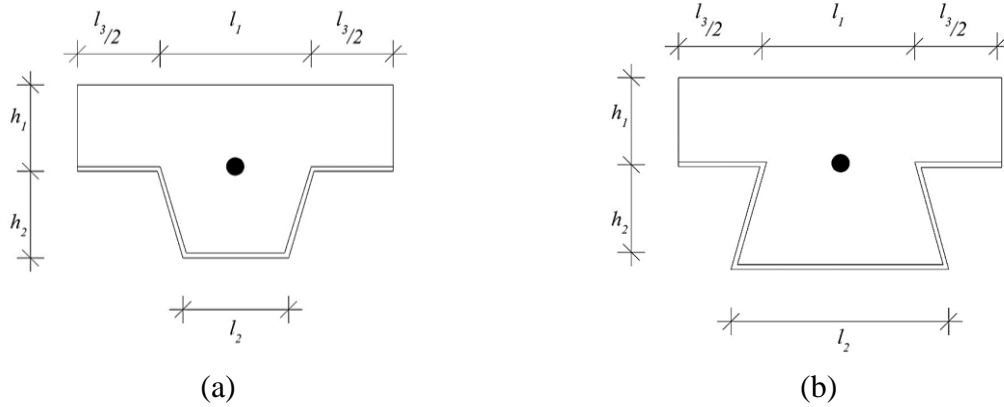


Figure 4.1: Composite slabs parameters: (a) Trapezoidal, (b) Re-entrant.

Therefore, Table 4.1 presents the geometric limits for the application of the simplified method present in annex D of EN 1994-1-2 to verify the fire resistance concerning criterion I and criterion R.

Table 4.1: Field of application for simplified calculation methods (EN 1994-1-2).

| Trapezoidal steel decking profiles [mm] | Re-entrant steel decking profiles [mm] |
|---|--|
| $80 \leq l_1 \leq 155$ | $77 \leq l_1 \leq 135$ |
| $32 \leq l_2 \leq 132$ | $110 \leq l_2 \leq 150$ |
| $40 \leq l_3 \leq 115$ | $38.5 \leq l_3 \leq 97.5$ |
| $50 \leq h_1 \leq 125$ | $50 \leq h_1 \leq 130$ |
| $50 \leq h_2 \leq 100$ | $30 \leq h_2 \leq 60$ |

4.1.1. Analytical Analysis of Insulation (I) criterion

Based on the results of fire tests of flat concrete slabs, a rule has been developed that relates the minimum required thickness to the fire resistance. In principle, the thickness of the flat concrete slab is equal to the arithmetic mean thickness of the composite profiled slab and is referred to as the so-called effective thickness.

Besides ensuring the geometric limits, EN 1994-1-2 provides two formulations to evaluate the Insulation criterion (I). The first is through equation (4.1), which determines the fire resistance relative to insulation t_{fi} in [min]. Both methods are using the insulation criteria for the unexposed slab temperature, when it reaches an average temperature increase of 140°C or a maximum of 180°C, concerning the initial average temperature

$$t_{fi} = a_0 + a_1 \cdot h_1 + a_2 \cdot \phi_{up} + a_3 \cdot \frac{A}{L_r} + a_4 \cdot \frac{1}{l_3} + a_5 \cdot \frac{A}{L_r} \cdot \frac{1}{l_3} \quad (4.1)$$

In the above equation, h_1 is the concrete thickness (mm); ϕ_{up} is the top flange view factor [-] that is based on the distance between the emitting radiation surface and the receiving surface, as well as the area and direction of both surfaces. The rib geometry factor $\frac{A}{L_r}$ is defined as the ratio between the concrete volume and exposed area A (mm^3/m) per meter of rib length L_r (mm^2/m) of the steel deck, it is given in [mm] and its calculations is conducted through the following formulation:

$$\frac{A}{L_r} = \frac{h_2 \left(\frac{l_1 + l_2}{2} \right)}{l_2 + 2 \sqrt{h_2^2 + \left(\frac{l_1 + l_2}{2} \right)^2}} \quad (4.2)$$

The partial factors a_i are tabulated coefficients that are differentiated for normal-weight concrete (NWC) and lightweight concrete (LWC). These coefficients are shown in the following table.

Table 4.2: Coefficients for the determination of the fire resistance of composite slabs with NWC and LWC (adapted from EN 1994 -1-2[4]).

| Concrete type | a_0 [min] | a_1 [min/mm] | a_2 [min] | a_3 [min/mm] | a_4 [min/mm] | a_5 [min] |
|---------------|----------------|-------------------|----------------|-------------------|-------------------|----------------|
| NWC | -28.80 | 1.55 | -12.6 | 0.33 | -735 | 48.0 |
| LWC | -79.2 | 2.18 | -2.44 | 0.56 | -542 | 52.3 |

The second method defined in the EN 1994-1-2, considers the definition of the effective thickness of a composite slab, h_{eff} (mm), that should be determined using Eqs. 4.3 a and 4.3 b.

$$h_{eff} = h_1 + 0.5 \cdot h_2 \cdot \left(\frac{l_1 + l_2}{l_1 + l_3} \right) \quad \text{for } h_2/h_1 \leq 1.5 \text{ and } h_1 > 40 \text{ [mm]} \quad (4.3 \text{ a})$$

$$h_{eff} = h_1 \cdot \left[1 + 0.75 \cdot \left(\frac{l_1 + l_2}{l_1 + l_3} \right) \right] \quad \text{for } h_2/h_1 > 1.5 \text{ and } h_1 > 40 \text{ [mm]} \quad (4.3 \text{ b})$$

The relationship between the minimum effective slab thickness and the minimum fire

resistance (I) is shown in Table 4.3. The parameter “ h_3 ” represents the thickness of the screed layer, if any on top of the composite slab, see Figure 4.2.

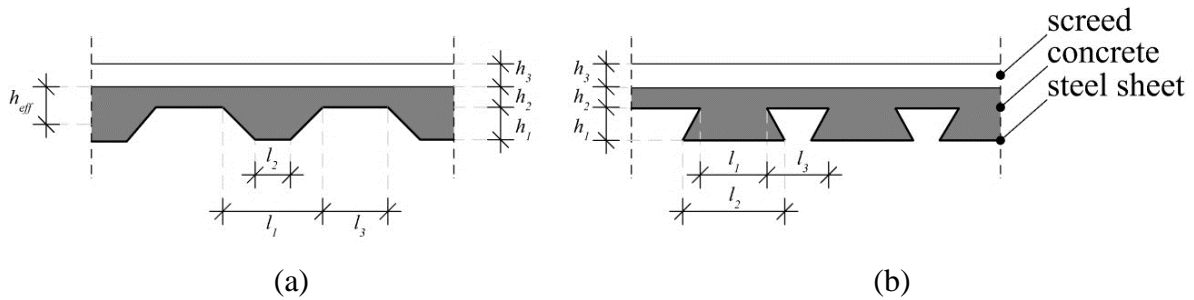


Figure 4.2: Symbols for (a) trapezoidal and (b) re-entrant sheeting (adapted [4]).

Table 4.3: Minimal effective thickness of the slab h_{eff} to satisfy the thermal insulation criteria.

| Standard fire resistance | Minimum effective thickness h_{eff} [mm] |
|--------------------------|--|
| I 30 | $60 - h_3$ |
| I 60 | $80 - h_3$ |
| I 90 | $100 - h_3$ |
| I 120 | $120 - h_3$ |
| I 180 | $150 - h_3$ |
| I 240 | $175 - h_3$ |

Due to the presence of ribs, which produce orthotropic profiles with significant temperature gradients, measuring the temperature field in the cross-section of composite slabs during fire exposure a challenge. The temperatures at the unexposed surface and the fire resistance of composite slabs represent difficult challenges in fire design, see Figure 4.3.

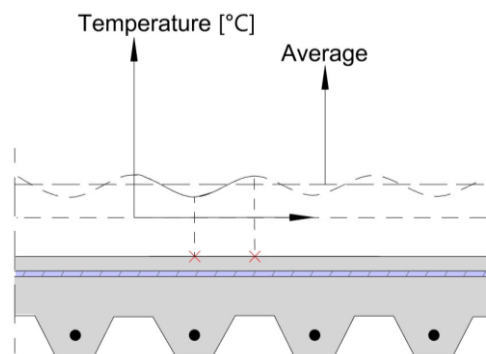


Figure 4.3: Theoretical temperature distribution at the unexposed surface of a fire exposed composite slab.

Temperature measurement points on the slab surface were looked at for the thermal insulation analysis of the slab.

4.1.2. Analytical Analysis of Load bearing (R) criterion

According to EN 1994-1-2 item D.2, the analytical steel decking temperature maybe estimated, as shown in Eq. (4.4):

$$\theta_a = b_0 + b_1 \cdot \frac{1}{l_3} + b_2 \cdot \frac{A}{L_r} + b_3 \cdot \Phi + b_4 \cdot \Phi^2 \text{ [}^\circ\text{C]} \quad (4.4)$$

where b_0 , b_1 , b_2 , b_3 , and b_4 are tabulated empirical coefficients only valid for the ISO 834 [1] and for fire ratings of 60, 90, and 120 minutes. The temperature θ_a in each of the steel deck components (Upper flange, Web and, Lower flange) can be predicted in $^\circ\text{C}$. The Φ corresponds to the view factor of the upper flange, and the partial coefficients b_i are coefficients dependent on the type of concrete, the fire rating under analysis and the component of the steel sheeting, whether it is the upper flange, lower flange, or web. Table 4.4, provided by Eurocode 4, is used for the determination of the partial coefficients b_i .

Table 4.4: Coefficients for the determination of the temperatures of the parts of the steel deck for slabs with NWC (adapted from EN 1994 – 1-2 [4]).

| Standard fire resistance | Part of the steel deck | b_0 [$^\circ\text{C}$] | b_1 [$^\circ\text{C mm}$] | b_2 [$^\circ\text{C mm}^{-1}$] | b_3 [$^\circ\text{C}$] | b_4 [$^\circ\text{C}$] |
|--------------------------|------------------------|-------------------------------|----------------------------------|---------------------------------------|-------------------------------|-------------------------------|
| R60 | Lower flange | 951 | -1197 | -2.32 | 86.4 | -150.7 |
| | Web | 661 | -833 | -2.96 | 537.7 | -351.9 |
| | Upper flange | 340 | -3269 | -2.62 | 1448.4 | -679.8 |
| R90 | Lower flange | 1018 | -839 | -1.55 | 65.1 | -108.1 |
| | Web | 816 | -959 | -2.21 | 464.9 | -340.2 |
| | Upper flange | 618 | -2786 | -1.79 | 767.9 | -472.0 |
| R120 | Lower flange | 1063 | -679 | -1.13 | 46.7 | -82.8 |
| | Web | 925 | -949 | -1.82 | 344.2 | -257.4 |
| | Upper flange | 770 | -2460 | -1.67 | 592.6 | -379.0 |

Annex D of EN 1994-1-2 [4] still defines the possibility to determine the rebar temperature, (θ_s) following Equation (4.5).

$$\theta_s = c_0 + c_1 \cdot \frac{u_3}{h_2} + c_2 \cdot z + c_3 \cdot \frac{A}{L_r} + c_4 \cdot \alpha + c_5 \cdot \frac{1}{l_3} \text{ [}^\circ\text{C]} \quad (4.5)$$

where the temperature θ_s is given in [°C]. The parameter l_3 is the distance within the ribs, u_3 represents the distance from the middle of the rebar to the lower flange in [mm], h_2 is the height of the rib in [mm], the z-factor represents the average position of the rebar concerning the rib geometry in [$mm^{\mp 0.5}$],

$$\frac{1}{z} = \frac{1}{\sqrt{u_1}} + \frac{1}{\sqrt{u_2}} + \frac{1}{\sqrt{u_3}} \quad (4.6)$$

α corresponds to the angle formed between the web component of the steel deck and the horizontal direction in degrees. To facilitate the visualisation of these geometric factors, Figure 4.4 is presented.

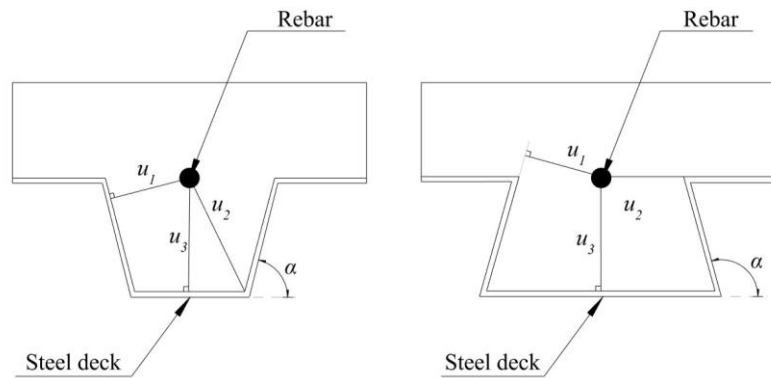


Figure 4.4: Parameters u_i for the z-factor calculation.

Also concerning Equation (4.5), the calculation factors c_i are defined according to the type of concrete used and the fire resistance class to be analyzed. These factors are presented in Table 4.5, as presented in Annex D of EN 1994-1-2 [4].

Table 4.5: Coefficients for the determination of the temperatures of the rebars for slabs with NWC (adapted from EN 1994 – 1-2 [4]).

| Standard fire Resistance | c_0 [°C] | c_1 [°C] | c_2 [°C $mm^{-0.5}$] | c_3 [°C mm^{-1}] | c_4 [°C/°] | c_5 [°C mm] |
|--------------------------|---------------|---------------|----------------------------|--------------------------|-----------------|------------------|
| R60 | 1191 | -250 | -240 | -5.01 | 1.04 | -925 |
| R90 | 1342 | -256 | -235 | -5.30 | 1.39 | -1267 |
| R120 | 1387 | -238 | -227 | -4.79 | 1.68 | -1326 |

After determining the temperatures of the elements that provide resistance to tensile forces, i.e., the steel deck and rebar, the neutral axis (X_{pl}) that is located in the cross section of the composite slab can be determined using equation (4.7) provided by EN 1994-1-2.

$$\sum_{i=1}^n A_i K_{y, \theta, i} \left(\frac{f_{y,i}}{\gamma_{M, f_{i,a}}} \right) + \alpha_{slab} \sum_{j=1}^m A_j K_{c, \theta, j} \left(\frac{f_{c,j}}{\gamma_{M, f_{i,c}}} \right) = 0 \quad (4.7)$$

Were $f_{y,i}$ is the nominal yield strength f_y for the element steel area A_i . This value should be taken as positive if it is in the compressed region (above the plastic neutral axis) and negative otherwise.

The term $f_{c,j}$ refers to the design strength for the elemental concrete area A_j at 20°C under compression, and α_{slab} is the reduction coefficient regarding the rectangular tension block hypothesis for concrete elements. Finally, the terms $K_{y, \theta, i}$ and $K_{c, \theta, j}$ refer to the reduction factors for stress-strain relationships of structural steel and concrete respectively, at elevated temperatures, in particular the term $K_{y, \theta, i}$ is related with the temperatures θ_s and θ_a . The reduction factors for steel ($K_{y, \theta, i}$) EN 1994-1-2 [4] are presented. However, for concrete, the same standard suggests the adoption of $K_{c, \theta, j} = 1$.

Thus, after obtaining the plastic neutral axis position values (X_{pl}), it becomes possible to calculate the design sagging moment resistance ($M_{f_{i,t}, R_d}$) for composite slabs according to equation (4.8).

$$M_{f_{i,t}, R_d} = \sum_{i=1}^n A_i Z_i K_{y, \theta, i} \left(\frac{f_{y,i}}{\gamma_{M, f_{i,a}}} \right) + \alpha_{slab} \sum_{j=1}^m A_j Z_j K_{c, \theta, j} \left(\frac{f_{c,j}}{\gamma_{M, f_{i,c}}} \right) \quad (4.8)$$

Where z_i and z_j indicate the distance between the gravity centres of the regions A_i and A_j and the neutral axis.

Regarding the bending resistance reduction factor ($\frac{M_{f_{i,t}, R_d}}{M_{rd}}$) represents the relationship between the sagging moment for each fire resistance class ($M_{f_{i,t}, R_d}$), and the slab's sagging moment at room temperature (M_{rd}).

As a result, it depicts the decline in flexural strength for each time corresponding to the fire resistance classification as a function of temperature increase.

5. ADVANCED CALCULATION METHOD

This section explains the methodology to create the finite element thermal model that will be used to solve the non-linear transient thermal problems under standard fire conditions.

The heat transfer problem in this study must be solved in the multi-domain body corresponding to the composite slab. Note that the heat flux applied to non-exposed surfaces is determined by the ambient temperature, while the heat flux applied to exposed surfaces is determined by the ISO-834 fire curve [1].

A description of boundary conditions and convergence criterion, element type and physical domains, thermal model and a brief description of the finite elements is presented.

The incremental and iterative numerical solution will be used to solve the non-linear problems in the context of fire. Compared with simple calculation models, the advanced calculating methods provide a more realistic approach of the real element performance under fire conditions.

5.1. FEM for thermal analysis

The 3D transient heat transfer problems will be solved on four composite slabs with different geometries, as shown in Figures 3.1 to 3.4. As such, the 3D models were created following a realistic representation of the physical model of the slabs where the geometry of the models considers the approximation shape of the surfaces based on a representative volume of the slab.

The cross-section was selected as the side edges bounded by the centroid of the top flange and comprised a rib with a sample length of 200 mm.

The developed multi-domain consists of four sub-domains: the steel deck, the airgap, the concrete, and the rebar. Thus, the materials that make up the slabs' physical subdomains are the Carbon steel (steel deck and rebars), the Concrete (concrete topping) and the Airgap (to simulate the debonding effect between the steel deck and concrete).

The energy conservation equation mathematically models the heat conduction inside this physical domain.

$$\rho(\theta)C_p(\theta)\frac{\partial\theta}{\partial t} = \nabla \cdot (\lambda(\theta)\nabla\theta) \quad (5.1)$$

Where θ represents the temperature [$^{\circ}\text{C}$], $\rho(\theta)$ is the specific mass [kg/m^3], $C_p(\theta)$ is the specific heat [J/kgK], $\lambda(\theta)$ is the thermal conductivity [W/mK], t is the time in [s] and $\nabla = (\partial_x, \partial_y, \partial_z)$ is the gradient.

Equation (5.1) is temperature-dependent and holds a transient thermal state for the slab once the heat flux on the surface exposed to fire changes with time. Therefore, the incremental and iterative solution to Equation (5.1) is needed to calculate the temperature field over time.

Additionally, the ISO-834 [1] fire curve boundary conditions must be used in the physical domain to handle the issue effectively.

5.1.1. Physical Domains

The physical subdomains corresponding to the various materials are used to discretize Equation (5.1). Figures 5.4a and 5.4b, produced by the MATLAB PDE Toolbox, demonstrate the geometries of a representative volume of a composite slab (trapezoidal slab polydeck and re-entrant slab multideck) and the corresponding mesh.

Finite element modelling was performed to investigate the behaviour of the tested composite slabs in detail. The energy equations are produced from solving Equation (5.1) using the finite element technique.

$$C(\theta)\dot{\theta} + K(\theta)\theta = F \quad (5.2)$$

Where K is the conductivity matrix, F is the vector of the thermal loads, including the boundary conditions, $\dot{\theta}$ is the vector of the time derivatives of the nodal temperatures, and C is the capacitance matrix.

The solution of the second order non-linear system of partial differential equation, given by Equation (5.2), needs to consider the initial condition $\theta(t_0)=\theta^0$, in order to determine the temperature at each node using the relevant boundary conditions, as shown in Figures 5.1a and 5.1b, over the time of simulation $[t_0, t_f]$.

The non-linear transient thermal analysis was developed and solved using the MATLAB (R2021a) PDE toolbox. Only the tetrahedron finite element type is used in the composite slab's finite element model. Four nodes make up this finite element, which employs linear interpolation techniques. The final mesh comprises four sub-domains, each with unique thermal properties: concrete, steel deck, rebar, and anti-crack mesh.

5.1.2. Boundary conditions

The boundary conditions in any numerical analysis are crucial in limiting the temperature and locations of actions and responses sparked by thermal loads. This work includes boundary conditions that affect how heat is transferred through composite slabs. The composite slabs are exposed to three main boundary conditions: exposed surfaces, unexposed surfaces, and insulating surfaces. They follow Eurocode guidelines EN 1991-1.2 [3].

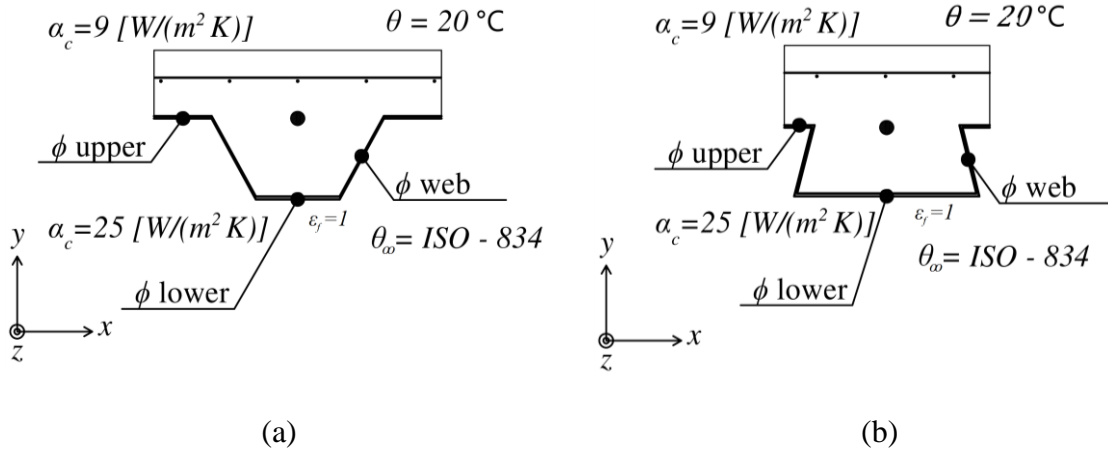


Figure 5.1: Boundary conditions: (a) Trapezoidal profile, (b) Re-entrant profile.

In the exposed side of the composite slab, the boundary conditions comprise the heat transfer by convection and radiation and are given by

$$\lambda(\theta)\nabla\theta \cdot \vec{n} = \alpha_c (\theta_\infty - \theta) + \Phi \varepsilon_m \varepsilon_f \sigma (\theta_\infty^4 - \theta^4) \quad (5.3)$$

where \vec{n} is the unitary vector normal to the external face, Φ is the view factor, α_c is the convection coefficient, ε_m is the emissivity of the material, ε_f is the emissivity of fire, σ is the Stefan-Boltzmann constant and θ_∞ is the gas temperature of the fire compartment.

Equation (5.3) represents the amount of heat flux that arrives at the steel deck by radiation and convection based on the gas bulk temperature, which will be transferred through the slab by convection and radiation. An initial uniform temperature is applied to all the nodes (20°C). The lower part of the deck is submitted to standard fire conditions, using a convection coefficient $\alpha_c = 25[\text{W}/\text{m}^2\text{K}]$, the emissivity of steel is $\varepsilon_m = 0.7$, and the fire emissivity is $\varepsilon_f = 1$.

Equation (5.3) includes the gas temperature θ_∞ , of the fire compartment, which follows the standard fire curve ISO-834 ($\theta_\infty = \theta_g$ ISO) given by equation (2.26) in section 2.6.3 where θ_g ISO is given in [$^{\circ}\text{C}$] and t in [min][1].

According to the recommendations of standard EN 1991-1-2 [3], the top part of the slab (unexposed side) is submitted to a convective coefficient of 9 [$\text{W}/\text{m}^2\text{K}$] to include the radiation effect, the unexposed surface of the composite slab is also an important side to determine the temperature evolution. After all, it will determine the heat transfer from the compartment below the composite slab to the above compartment.

These parameters are depicted in Figure 5.1. The boundary condition in the unexposed surface of the composite slab is given by the Equation:

$$\lambda(\theta)\nabla\theta \cdot \vec{n} = \alpha_c (\theta - \theta_\infty) \quad (5.4)$$

The θ_∞ is the bulk (room) temperature. The other four surfaces of the slab (front, back, left, right) are considered as isolated surfaces. That is, the adiabatic boundary conditions applied to these surfaces are given by equation (5.5),

$$\lambda(\theta)\nabla\theta \cdot \vec{n} = 0 \quad (5.5)$$

5.2. Development of the Numerical Model

Numerous non-linear phenomena emerge during fire exposure, which makes it challenging to perform numerical analysis to determine the fire resistance of the composite slab. For example, the dependence of all and thermal material properties on temperature and the convective and radiant heat exchange at the exposed side of the composite slab, are all examples of non-linear effects.

A parametric study is then carried out to investigate the influence of concrete thickness on the thermal behaviour of the composite slab. A realistic 3D finite element-based thermal model has been developed to evaluate the thermal behaviour of composite decks using the temperature field for every standard fire rating. The numerical results are verified, and parametric studies on the effect of concrete thickness on the rebars (reinforcing bars) are carried out.

The numerical temperature is compared with the simplified procedure specified in the standard. The numerical values of the temperatures are then used to obtain a new analytical proposal. Thus, by adapting analytical models, new coefficients were generated by solving a

linear least squares problem using singular value decomposition. This method is guaranteed to give the solution to minimise the errors of the deviations.

Regarding validating the numerical model through experimental tests, it should be mentioned that the thermal models used have already been validated against experimental results by several works developed by Piloto P. et al. and Balsa et al. [13], [24].

5.2.1. Parametric study

Parametric simulations were developed using non linear thermal analyses, comprising composite slabs with commercial steel deck profiles. The parametric study is concerned with the influence of different parameters on the temperatures of the steel deck parts (lower flange, web, upper flange) and the rebars. Furthermore, attention is paid to the influence of the steel components of the slab on the insulation criterion (I).

The cross-section was selected by the side edges, delimited by the centre of the upper flange, comprising one rib and part of the anti-crack mesh. The length of the specimens is 200 mm and this dimension is not affecting the results. The geometries of the two profiles (trapezoidal and re-entrant) are modelled by volumes in MATLAB, and are depicted in Figure 3.7.

Regarding the concrete type, the NWC from C20/25 class is considered to fulfill the composite slabs with 3.00% moisture content. The steel grade for the deck changes in accordance with each steel deck type. All composite slabs were submitted to numerical simulations of fire exposure for 7200 seconds (120 min), aim to verify if the insulation fire resistance criteria (θ_{AVE} and θ_{MAX}) were achieved or not. The following table resumes the range of the investigated parameters.

Table 5.1: Parameters of parametric study.

| Steel deck profile | h_1 [mm] | t_d [mm] | Φ_{reb} [mm] | Steel mesh [mm//mm] |
|--|------------------|---------------|----------------------|------------------------|
| ArcelorMittal Polydeck 59S (Trapezoidal) | 50,70,90,110,125 | 1.00,1.25 | 10,16 | $\Phi 6//50$ |
| ArcelorMittal Cofraplus 60 (Trapezoidal) | 50,70,90,110,125 | 1.00,1.25 | 10,16 | $\Phi 6//50$ |
| Kingspan Multideck (Re-entrant) | 60,70,90,110,125 | 1.00,1.20 | 10,16 | $\Phi 6//50$ |
| Lysaght Bondeck (Re-entrant) | 60,70,90,110,125 | 0.75,1.00 | 10,16 | $\Phi 6//50$ |

The commonly used values of concrete thickness h_1 , rebar diameters ϕ_{reb} , and steel deck thickness t_d are selected for the range of parameters studied. Eighty numerical simulations were performed in MATLAB using the thickness of the "air gap" ($t_a=0.5$ mm), and all parameters were compared separately. The diameters and spacing of the anti-crack mesh were determined from technical catalogues.

The numerical model validation was essential and used as a base to develop different models of slabs. Table 5.2 presents the view factors calculated according to Eqs. (2.12) and (2.13), for each steel deck profile. As discussed before, the view factor of the lower flange is always assumed as 1.

Table 5.2: View factors (ϕ) according to each slab geometry.

| Slab Geometry | Deck Component | View Factor (ϕ [-]) |
|---------------------------------------|----------------|---------------------------|
| Polydeck 59 S (Trapezoidal) | Lower flange | 1 |
| | Web | 0.64 |
| | Upper flange | 0.75 |
| Cofraplus 60 (Trapezoidal) | Lower flange | 1 |
| | Web | 0.56 |
| | Upper flange | 0.73 |
| Multideck 50 (Re-entrant) | Lower flange | 1 |
| | Web | 0.09 |
| | Upper flange | 0.14 |
| Bondek (Re-entrant) | Lower flange | 1 |
| | Web | 0.09 |
| | Upper flange | 0.12 |

The view factors of trapezoidal and re-entrant profiles can be seen to differ significantly from one another. The significant restriction from the ribs is the cause of the lower values for re-entrant profiles.

5.3. Numerical and Analytical Results

The results of the analytical methods, EN 1994-1-2 [4], and the numerical methods described above are discussed in sequence.

The results of the three-dimensional analysis obtained through MATLAB are presented besides the new proposal to determine the fire resistance of composite slabs by the insulation (I) and load-bearing criteria (R). The temperature of each component has been determined by the average of the nodal temperatures, using their characteristic length .

5.3.1. Fire resistance according to thermal insulation (I)

Regarding the first parametric study, composite slabs' fire resistance (I) is predominantly governed by the average temperature rise criterion. The results are given for slabs with the same parameters but only for the thinnest concrete thickness for each steel deck family, which is the critical case (highest temperature), see Figure 4.3.

The temperature rise at the unexposed surface of composite slabs is a significant concern from the thermal insulation standpoint. It is crucial to control the temperature rise to avoid igniting of any material located on the unexposed surface of the slab and thus prevent the spread of fire.

This temperature is predicted by the model for a total simulation time that can guarantee fire resistance predictions according to standards. Weighted average and maximum temperatures are calculated on the non-exposed side of the composite slab and compared to the criteria used for the fire resistance (insulation).

Figure 6.1 depicts the fire insulation rating (I) obtained through the numerical models (MATLAB) at the unexposed side; see Figures 6.1 a), b), c) and d), for an example of the simulation during 2h ($t_i = 120$ minutes). The maximum temperature of the unexposed surface is always expected to match the area corresponding to the upper flange. The curves " θ_{AVE} " and " θ_{MAX} " refer to the average and maximum temperature, respectively.

The fire resistance is presented in completed minutes, see table 6.1. The results in the table exemplify the values obtained for a steel platform thickness $t_s = 1.00$ [mm] and for rebar diameter $\phi_{rebar} = 10$ [mm].

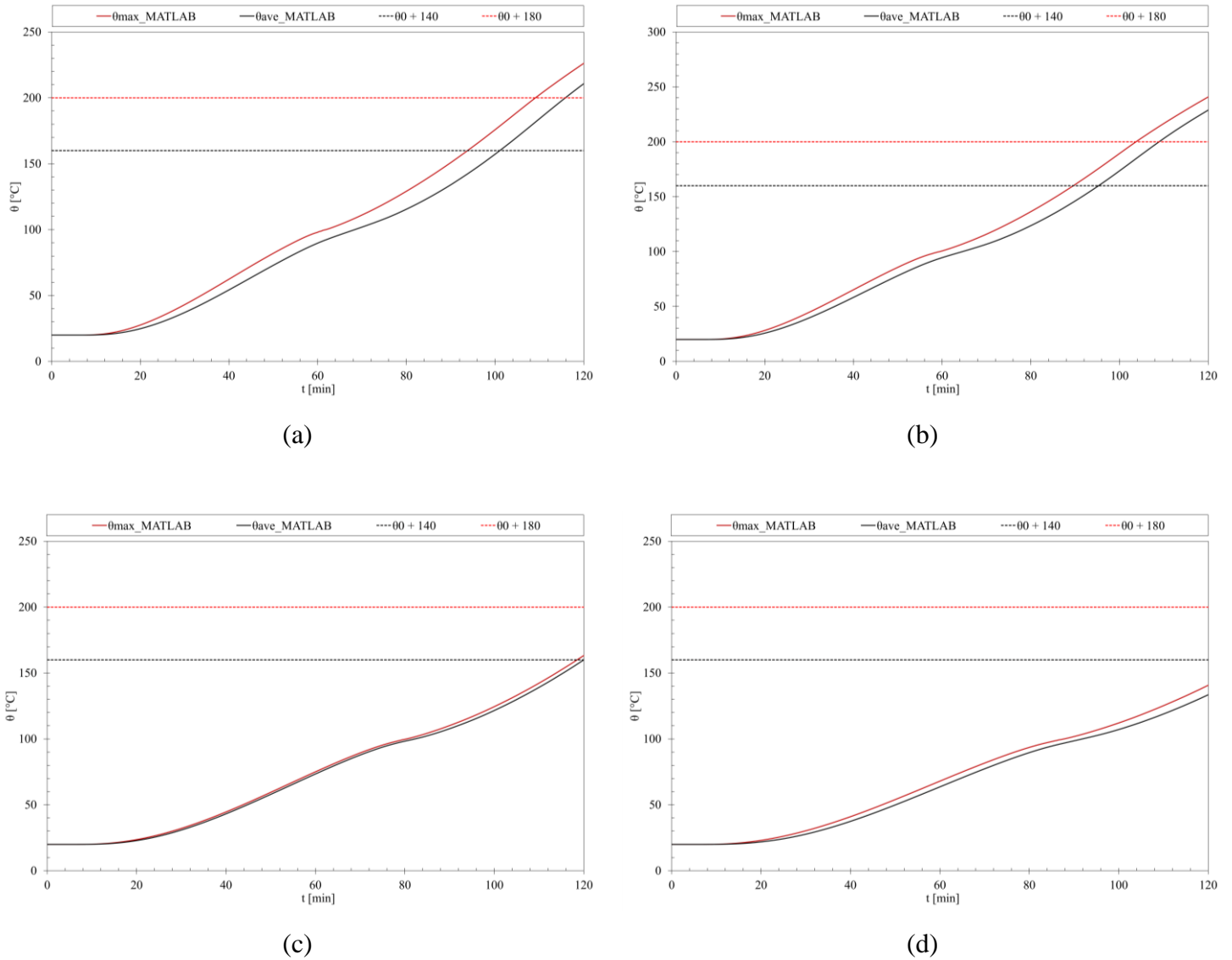


Figure 5.2: Unexposed temperature evolution, (a) Polydeck (b) Cofraplus 60 (c) Multideck and (d) Bondeck.

The results show that while the concrete thickness is increased, both the mean temperature and maximum temperature curves are translated horizontally, thus increasing the fire resistance time of the composite slab.

Furthermore, a slight plateau is evident at around 100 °C for all the curves due to moisture evaporation. Notably, the composite slabs with a re-entrant profile show a less pronounced temperature development than those with the trapezoidal profile. The composite slabs with re-entrant shapes show a higher fire resistance than those with trapezoidal profiles.

These differences in fire resistance for both geometries (TRA) and (REE) are between 41 min and 84 min, approximately for $h_1 = 50$ mm. This is explained by the fact that the

recessing profiles allow the use of a more uniform volume of concrete along the cross-section, resulting in more homogeneous temperature distributions. See Table 6.1.

Table 5.3: Fire resistance in completed minutes (insulation criterion).

| Profile (TRA) | Geometry | h_1 [mm] | 50 | 70 | 90 | 110 | 125 |
|----------------------|--------------------|------------------------------|-----------|-----------|-----------|------------|------------|
| Polydeck | $l_1/l_2 = 126/61$ | t_{fi} [min] | 43 | 71 | 101 | - | - |
| Cofraplus 60 | $l_1/l_2 = 101/62$ | t_{fi} [min] | 41 | 66 | 95 | - | - |
| Profile (REE) | Geometry | h_1 [mm] | 60 | 70 | 90 | 110 | 125 |
| Multideck | $l_1/l_2 = 135/40$ | t_{fi} [min] | 74 | 88 | 119 | - | - |
| Bondeck | $l_1/l_2 = 187/32$ | t_{fi} [min] | 84 | 100 | - | - | - |

The fire resistance for insulation is directly proportional to the parameters h_1 , l_1 and l_2 . The thickness of the continuous top layer of the slab (concrete thickness h_1) as the most significant geometric factor influencing fire resistance (I). This can be explained since when these parameters increase, consequently, the concrete in the slab section also increases. As the maximum time for the simulations was set as 7200 s, some slabs did not reach the fire resistance criteria during this period ($t_{fi} > 120$ min).

Figure 6.2 presents the comparison between numerical results and results obtained with the simplified calculation method of EN 1994 - Part 1.2 (EC4) for fire resistance (I), when changing the value of the concrete layer h_1 .

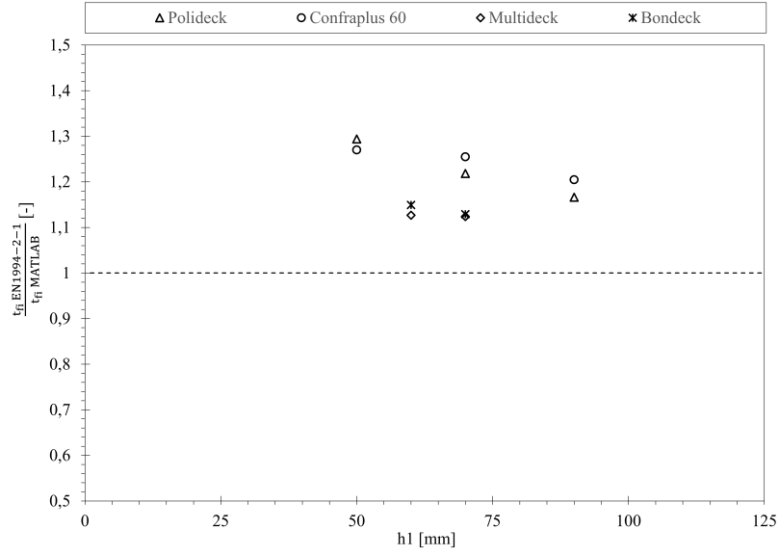


Figure 5.3: Comparison between the numerical results from MATLAB and the EN 1994-1-2 for the fire resistance (I).

According to the numerical results, there is a non-linear dependence between the fire resistance t_{fi} and the concrete thickness h_1 which is not considered in the simplified calculation methods of EN 1994-1-2 standard. In addition, the thickness of the air gap t_a is an important parameter which can significantly affect the fire resistance and may be considered in calculation methods. Moreover, the current version of EN 1994-1-2 is over-predicting the value of the fire resistance by a value between 10 and 30 %.

5.3.1.1. New Proposal for Insulation Criterion

The fire resistance obtained by numerical simulation of all the cases is smaller than the other results. This means that the current proposal from Eurocode 4 may be unsafe. According to the numerical results, there is a non-linear dependence between the fire resistance and the effective thickness, which is not included in the Equation (4.1).

A model with quadratic dependence between the fire resistance t_{fi} and the effective thickness h_{eff} is chosen to fit the results of the numerical simulations. A linear relationship between the effective thickness and the thickness of the air gap t_a increased fire resistance is considered in the analysis. The new proposal equation for the fire resistance of composite slabs is given in Eq.(6.1).

$$t_{fi} = 0.0059 \cdot h_{eff}^2 + 0.1127 \cdot h_{eff} - 5.8065 + (0.1424 \cdot h_{eff} + 2.4672) \cdot t_a \quad (6.1)$$

The estimation of the fire resistance (I) of the slab t_{fi} , is given in minutes, and h_{eff} and t_a are given in millimetres; with the following limits: $70 \leq h_{eff} \leq 150$ mm and $0 \leq t_a \leq 3$ mm. In this scope, the thickness of the air gap was considered to be $t_a = 0.5$ mm. After all, a layer of low thermal conductivity between steel and concrete affects the thermal energy that reaches the concrete and the rebar region. The new results are presented in Table 6.2, when using the Eq. (6.1)

Table 5.4: Fire resistance in completed minutes for the new proposal (6.1).

| Profile (TRA) | Geometry | h_1 [mm] | 50 | 70 | 90 | 110 | 125 |
|---------------|--------------------|----------------|----|----|----|-----|-----|
| Polydeck | $l_1/l_2 = 126/61$ | t_{fi} [min] | 43 | 68 | 96 | - | - |
| Cofraplus 60 | $l_1/l_2 = 101/62$ | t_{fi} [min] | 40 | 64 | 92 | - | - |
| Profile (REE) | Geometry | h_1 [mm] | 60 | 70 | 90 | 110 | 125 |
| Multideck | $l_1/l_2 = 135/40$ | t_{fi} [min] | 74 | 89 | - | - | - |
| Bondeck | $l_1/l_2 = 187/32$ | t_{fi} [min] | 82 | 97 | - | - | - |

Figure 6.3 shows that, in general, the results from MATLAB and the new proposal (6.1) are quite similar, with a variation smaller than 5 %, being most of the results on the safe side.

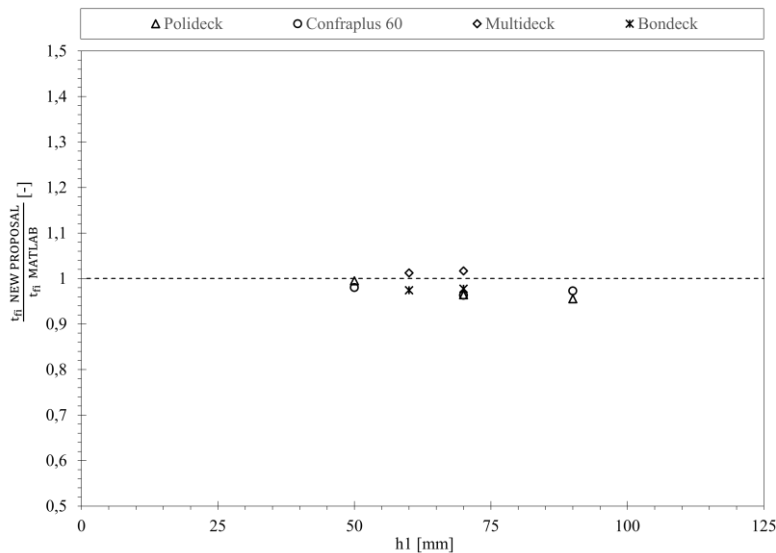


Figure 5.4: Comparison between the numerical results from MATLAB and the New Proposal for the fire resistance (I).

5.3.1.2. Comparison results according to criterion (I)

The fire resistance was defined by the temperature rise in the unexposed side of the slab. Table 6.3 presents the t_{fi} fire resistance time results obtained with MATLAB, as well as the results obtained by the simplified methods. The relative differences between the simplified methods and the numerical results are also presented.

Table 5.5: Comparison of fire resistance results according to thermal insulation.

| Fire Resistance [min] - Thermal Insulation | | | | | | | |
|---|-------------------------|---|----------------|--|--|-------------------------------|-------------------------|
| Steel Deck | | Numerical (N) simulation t_{fi} [min] | | Analytical Analysis t_i [min] | | Relative difference [%] | |
| Profile | h_1 | $t_{fi_{AVE}}$ | $t_{fi_{MAX}}$ | Simplified Method (EC4) | Simplified Method (new proposal (NP)) | Error EC4 N | Error NP N |
| Polydeck 59S $e = 1.00 ; \varphi = 10$ | 50 | 46 | 43 | 55 | 43 | 29.40 | 1.37 |
| | 70 | 71 | 73 | 86 | 68 | 21.82 | 3.57 |
| | 90 | 101 | 109 | 117 | 96 | 16.63 | 4.44 |
| | 110 | - | - | - | - | - | - |
| | 125 | - | - | - | - | - | - |
| Cofraplus 60 $e = 1.00 ; \varphi = 10$ | 50 | 43 | 41 | 52 | 40 | 26.99 | 2.00 |
| | 70 | 66 | 69 | 83 | 64 | 25.49 | 3.67 |
| | 90 | 95 | 103 | 114 | 92 | 20.46 | 2.73 |
| | 110 | - | - | - | - | - | - |
| | 125 | - | - | - | - | - | - |
| Multideck $e = 1.00 ; \varphi = 10$ | 60 | 74 | 81 | 83 | 74 | 12.67 | 1.24 |
| | 70 | 88 | 98 | 98 | 89 | 12.38 | 1.66 |
| | 90 | - | 119 | - | - | - | - |
| | 110 | - | - | - | - | - | - |
| | 125 | - | - | - | - | - | - |
| Bondeck $e = 1.00 ; \varphi = 10$ | 60 | 84 | 90 | 97 | 82 | 14.93 | 2.59 |
| | 70 | 100 | 108 | 112 | 97 | 12.92 | 2.25 |
| | 90 | - | - | - | - | - | - |
| | 110 | - | - | - | - | - | - |
| | 125 | - | - | - | - | - | - |

According to the above results in Table 6.3, it is observed that the fire resistance (I) increases considerably with concrete thickness for all composite slab specimens. Moreover, the composite slabs with re-entrant steel deck profiles show an almost linear increase with respect to h_1 .

The smallest and largest relative error between the MATLAB results and those obtained with the new proposal are 1.24% and 4.44% respectively. In contrast, the minimum and maximum values of relative error using the simplified Eurocode method are 12.38% and 29.40%. With this, it is demonstrated that the Eurocode method is not very accurate considering that the new proposal presents a considerable reduction in the predicted difference.

5.4. Temperature estimation according to Load-Bearing criterion (R)

The criterion (R) is verified assuming a specific fire rating for the element. Then one needs to verify if the effect of the load is smaller or equal than the bending resistance determined by the reduction of the plastic moment due to the effect of the temperature. The simulations were developed for 120 minutes of fire exposure. The current version of EN 1994-1-2 presents a simplified method to find the temperature for each fire rating. The numerical results are averaged and compared for each component affected by temperature (lower flange, web, upper flange and rebar). Other parameters are also reported and are related to several phenomena during the test (variation of the view factors, creation of the air gap effect between the steel deck and the concrete, geometric parameters not considered by the standard, such as concrete thickness, among others).

A parametric analysis was developed, regarding the evolution of temperature and the fire resistance. The critical temperatures of the steel components were determined based on fire resistance criteria.

Figures 6.4 to 6.7 show the temperature field in the composite slab after 120 [min] and the time average temperatures of the trapezoidal and re-entrant load-bearing components with NWC thickness and with concrete cover h_1 equal to 90 [mm]. The numerical results are identified by the name of the components and the results determined by the simplified method are identified by the additional (S) for each load-bearing component affected by temperature.

The results presented in this subsection are related to slabs with rebar diameter $\varnothing_{\text{rebar}}$ of 10 [mm] and thickness of steel deck t_s of 1.0 [mm].

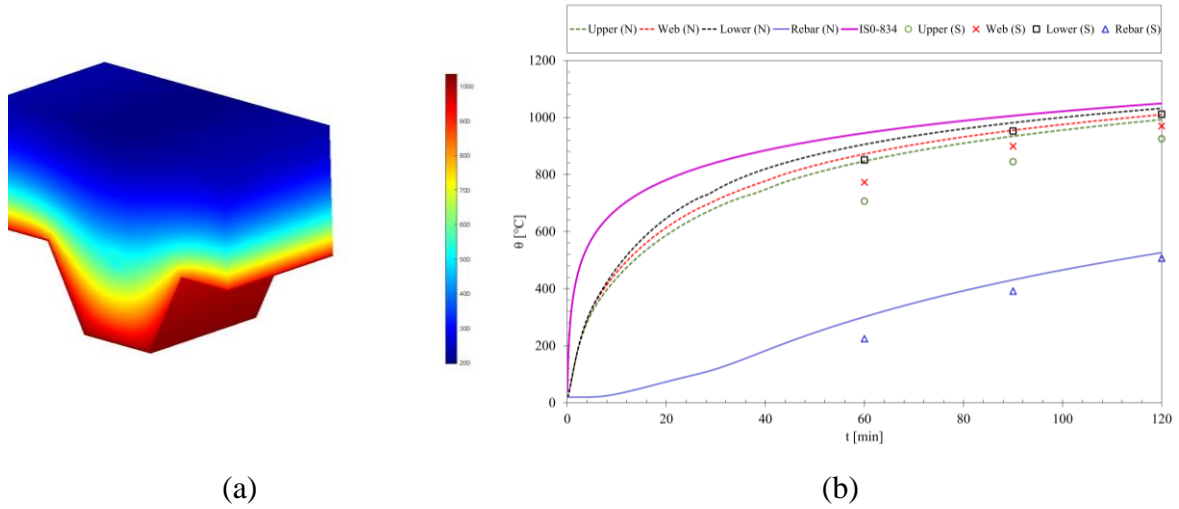


Figure 5.5: Polydeck 59S. (a) Final temperature distribution. (b) Temperature evolution: (N) stands for numerical and (S) for simplified method.

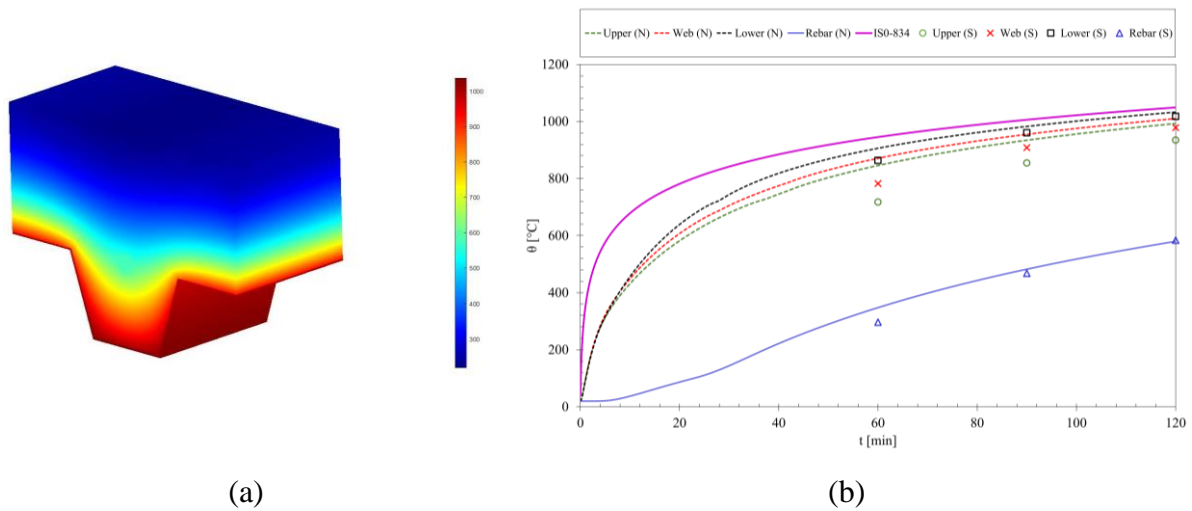


Figure 5.6: Cofraplus 60. (a) Final temperature distribution. (b) Temperature evolution: (N) stands for numerical and (S) for the simplified method.

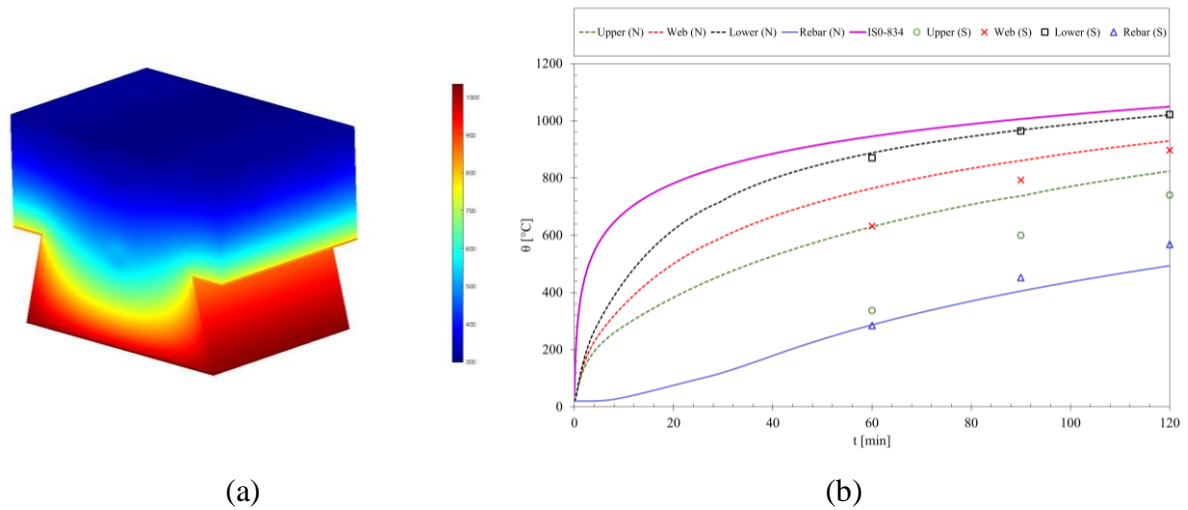


Figure 5.7: Multideck 50. (a) Final temperature distribution. (b) Temperature evolution: (N) stands for numerical and (S) for simplified method.

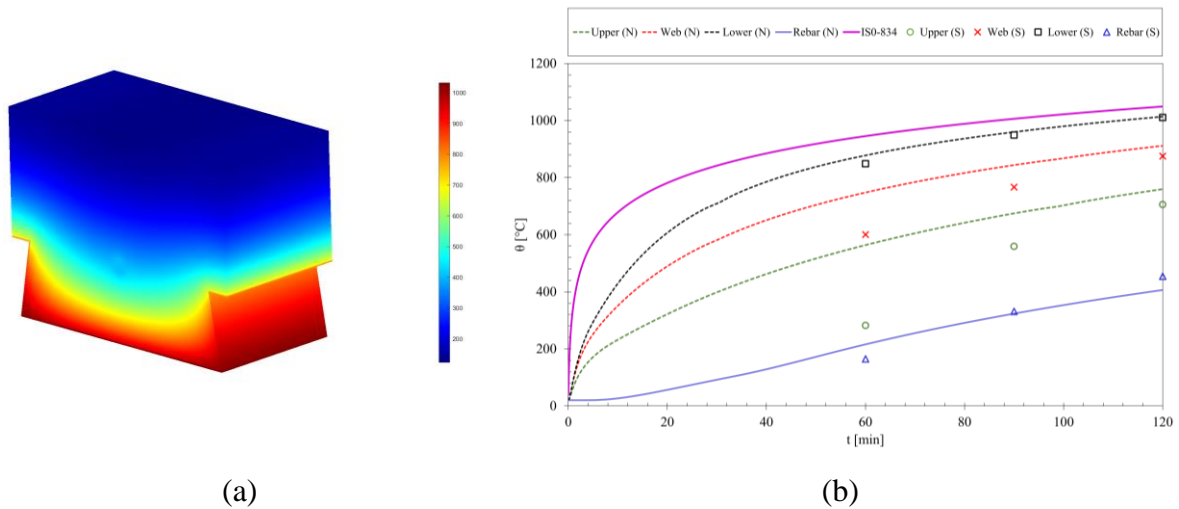


Figure 5.8: Bondeck. (a) Final temperature distribution. (b) Temperature evolution: (N) stands for numerical and (S) for the simplified method.

Several aspects of the composite slab heating process can be observed from the heat curves shown in Figures 6.4 to 6.7. First, the heating rate of steel profiles decreases slightly between 600°C and 800°C. This effect is almost invisible due to the small value of the steel deck. This behaviour is because steel undergoes a phase transition in this temperature range.

This analysis shows the difference between the parametric results and the simplified calculation method of EN 1994-1-2 [4]. The non-linear transient thermal analysis results show higher temperatures for all load bearing components affected by temperature, when compared for each fire rating. Secondly, it can be proved that the current version of EN 1994-1-2 from a static point of view, as thermal effects directly affect the mechanical behaviour of the slabs.

5.4.1. Comparison results according to criterion (R)

This subsection presents the differences between the results proposed by the simplified model (S) presented in EN 1994-1-2 [4] and the numeric results (N) for concrete topping h_1 and different fire ratings, namely R60, R90 and R120 used the mechanical response.

Figure 6.8 presents the relationship between the temperature of the lower flange of the steel deck θ_a for numerical analysis (N) and the simplified method (S) presented in EN 1994-1-2 [4]. This comparison shows that the simplified method is underpredicting the temperature of each load bearing component, which may compromise the mechanical behaviour.

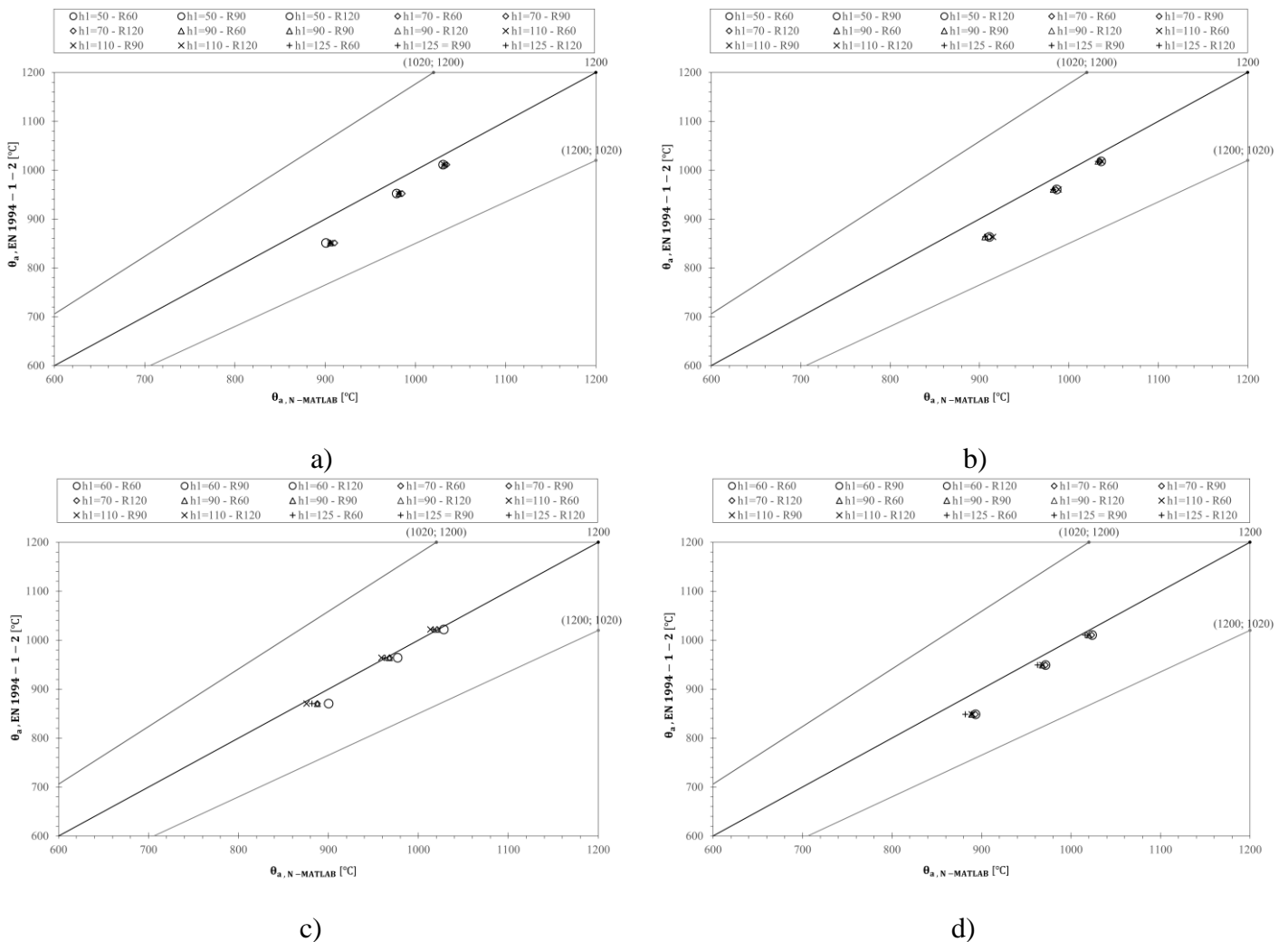


Figure 5.9: Temperatures of the lower flange for different classes of fire resistance (R) for trapezoidal
a) Polydeck, b) Cofraplus and re-entrant profile c) Multideck, d) Bondeck.

Figure 6.9 presents the difference between the temperature of the web flange of the steel deck θ_a for numerical results (N) and the simplified method (S) for concrete topping h_1 and for different classes of fire resistance for all slabs.

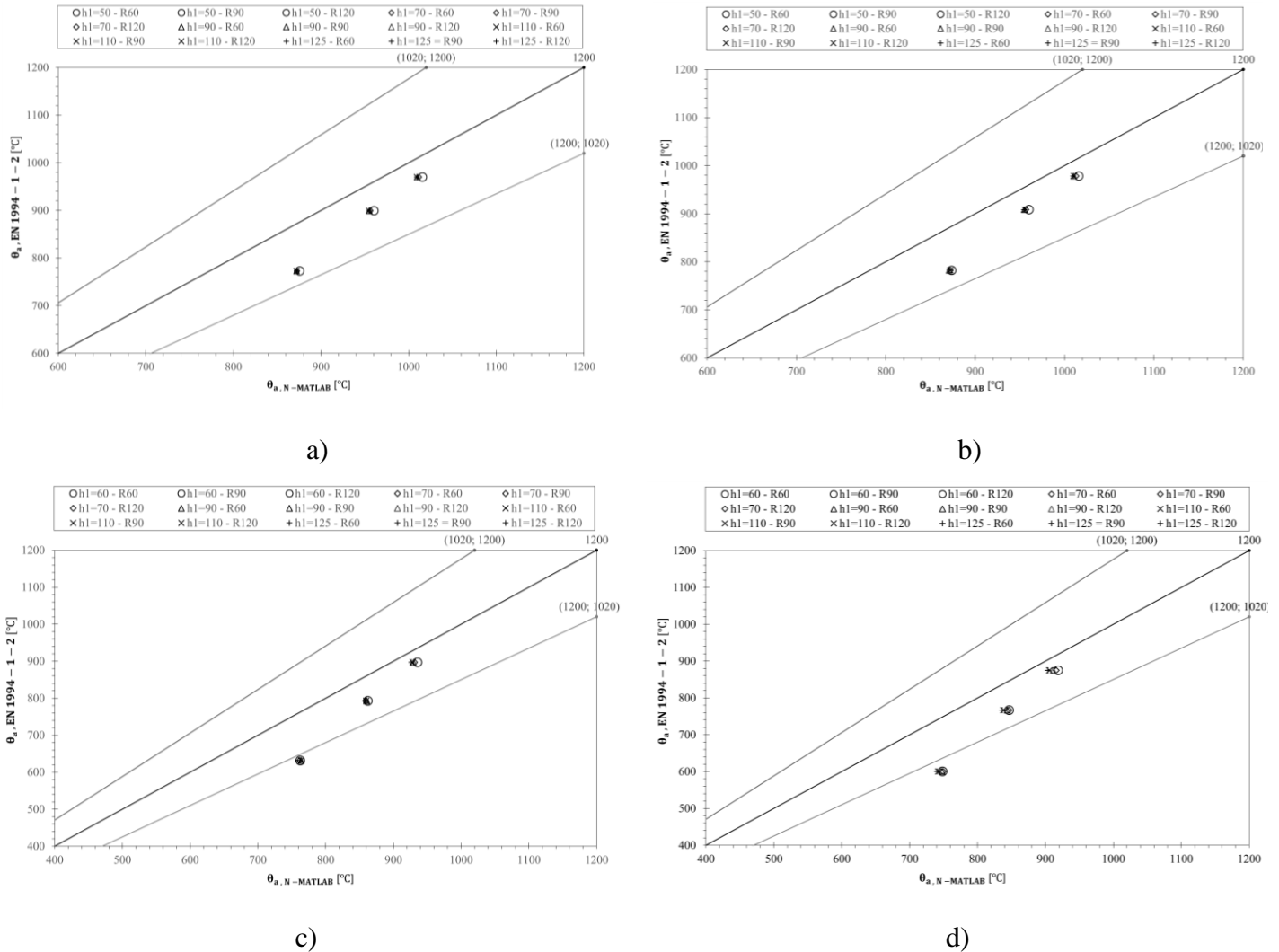


Figure 5.10: Temperatures of the web for different classes of fire resistance (R) for trapezoidal a) Polydeck, b) Cofraplus and re-entrant profile c) Multideck, d) Bondeck.

The comparison for the web component reveals a higher difference between both calculation methods. The simplified results are smaller than they should be.

Figure 6.10 presents the difference between the temperature of the upper flange of the steel deck θ_a for numerical results (N) and for the simplified method (S) for the concrete topping h_1 and for different classes of fire resistance.

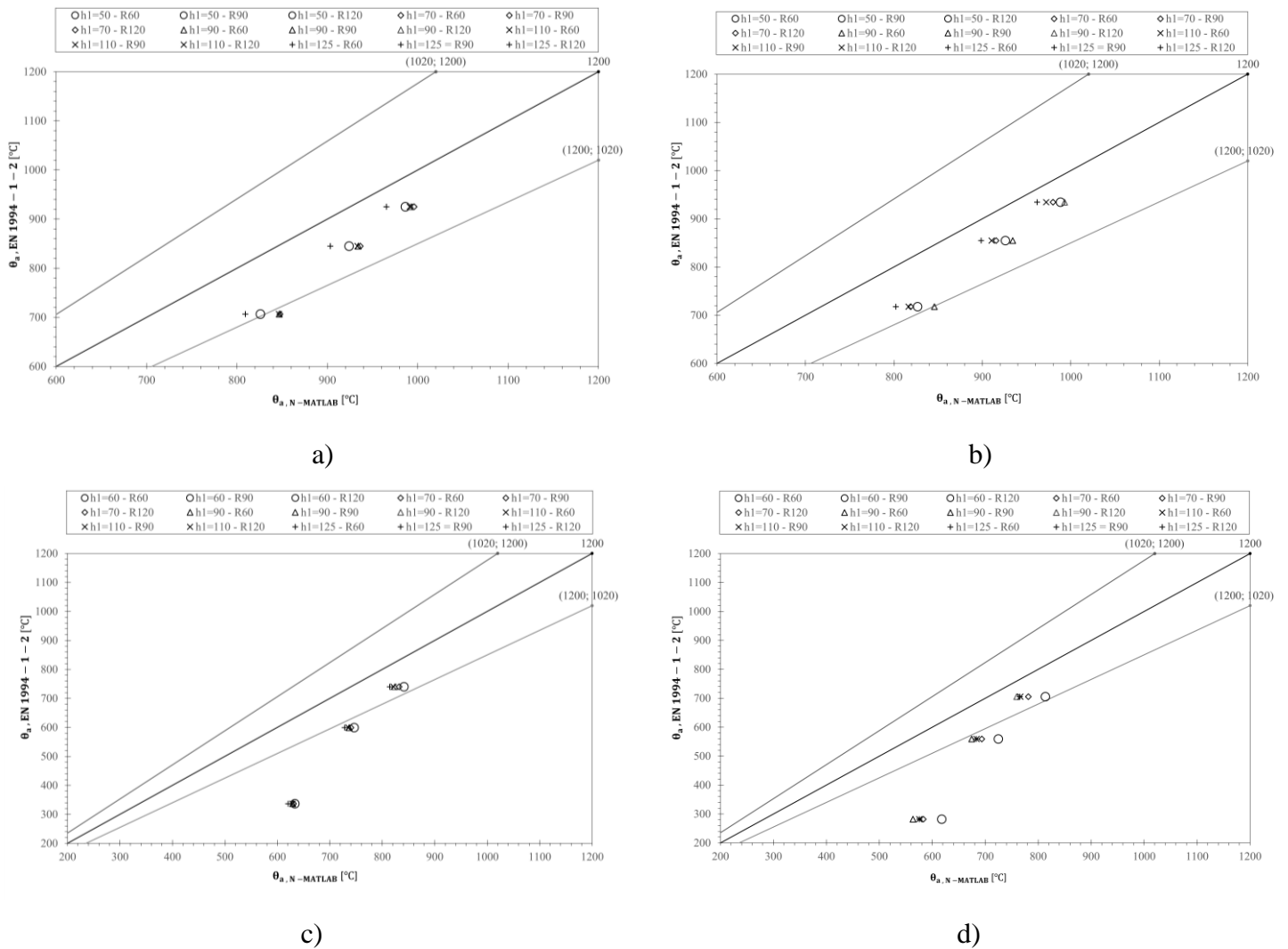


Figure 5.11: Temperatures of the upper flange for different classes of fire resistance (R) for trapezoidal a) Polydeck, b) Cofraplus and re-entrant profile c) Multideck, d) Bondeck.

From the results, one can see that the difference for the upper flange component is even higher, which can compromise the ability of the composite slab to sustain the load (R).

Figure 6.11 presents the difference between the temperature of the reinforcement bar of the steel deck θ_s for numerical analysis (N) and the simplified method (S) for concrete cover h_1 and for different fire ratings.

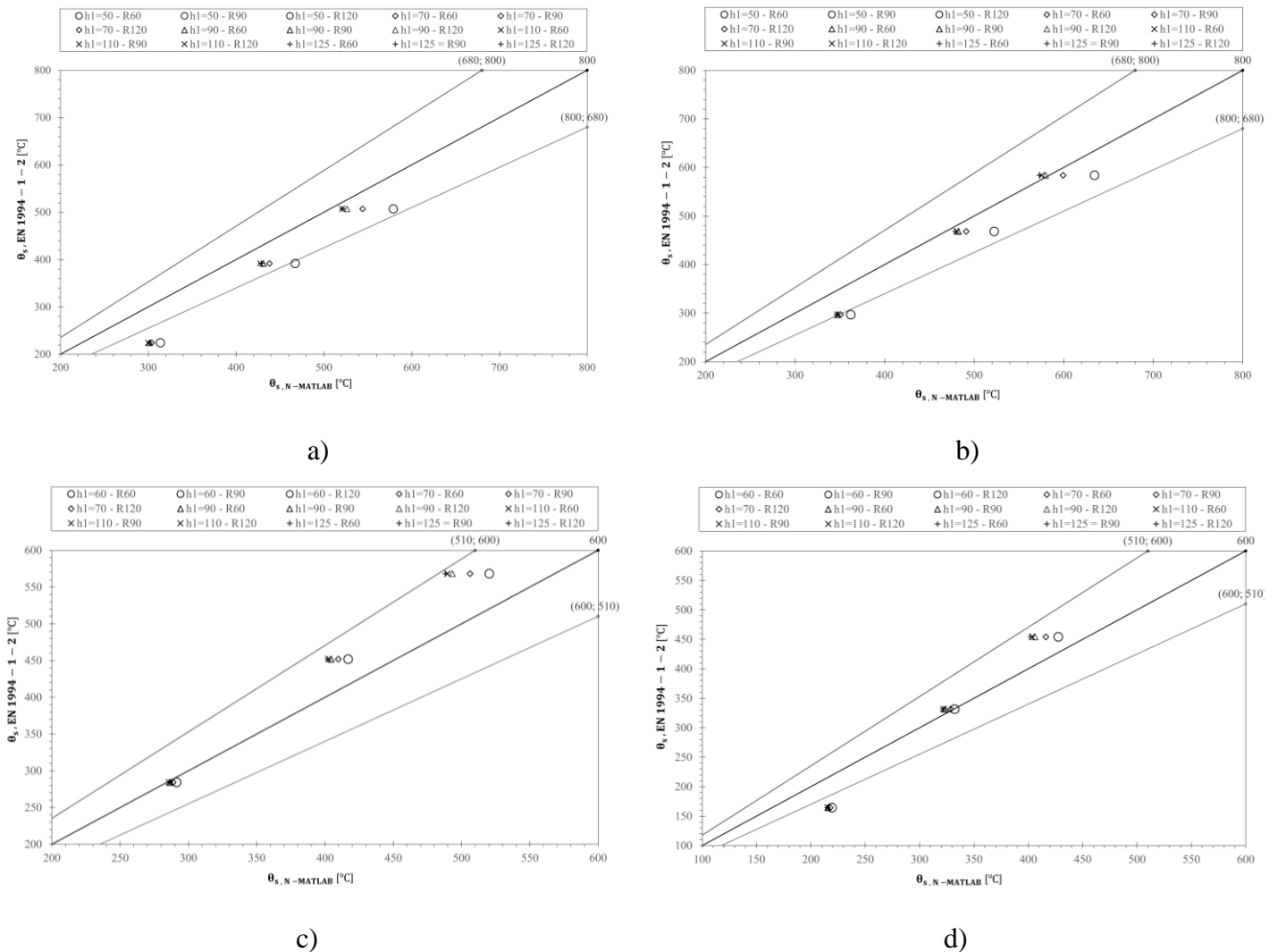


Figure 5.12: Temperatures of the reinforcement bar for different classes of fire resistance (R) for trapezoidal a) Polydeck, b) Cofraplus and re-entrant profile c) Multideck, d) Bondeck.

It should be mentioned that only some of the parametric results are presented in this section. However, each the remaining simulations are presented in the annexes. Thus, Appendix A refers to the trapezoidal geometry and NWC slabs, Appendix B refers to the re-entrant geometry and NWC slabs. The annex C refers to the data comparison according to criterion (R) results between numerical analysis (N) and the New Proposals (NP). Appendix D refers to a comparison according to criterion (R) results between EN 1994-1-2 (S) and the New Proposals (NP).

In general, it is observed that the results from the EN 1994 – Part 1-2 for the temperature of the components of the steel deck θ_a and in reinforcement bars θ_s are considerably lower concerning the numerical results. It can also be noted that the temperatures of the trapezoidal slabs are usually higher than the temperatures of the re-entrant slabs.

For both types of slabs, trapezoidal and re-entrant, one can see the difference between the parametric results and the simplified calculation method of EN 1994-1-2 [4]. In this case, the results obtained through non-linear transient thermal analysis have a higher temperature in all load bearing components and during the complete fire simulation. This means that the calculation rules of the European standard are on the unsafe side. It is possible to verify that the current Eurocode produces unsafe results from a structural viewpoint since the thermal results directly influence the mechanical response of the slabs.

5.4.2. Improving New Proposals with linear least square method

After proving the difference between the results obtained, new calculation proposals, based on the numerical results, were developed to estimate the temperatures in the load bearing components affected by temperature (steel deck components and the rebars). To preserve some similarity to the methodology presented by the EN 1994-1-2 [4], the new proposals were based on the current recommendation, promoting a modification of the current coefficients (b_i and c_i) of Annex D, and inserting new coefficients that enable a better approximation to the temperature as a function of the profile geometry.

As mentioned before, this research was developed to determine the influence of concrete thickness h_1 on the temperatures used to determine the fire resistance of composite slabs according to the load-bearing criterion (R), with a focus given to the influence of the load-bearing components of the slab on the fire resistance (I).

The coefficients relative to reinforcing bar (rebar) for each fire rating $c_j, j=0,1, 2, \dots, 6$, for these new proposals methods were determined by fitting the mathematical model represented by Equations (6.9),(6.11) and (6.13). The coefficients relative to steel components $b_j, j=0,1, 2, \dots, 7$ are given by the Equations (6.8),(6.10) and (6.12). All the new results are approximately equal to the corresponding numerical temperatures θ_i , with $i=1,2, \dots, 80$, for the four different types of steel deck geometries and for the five different values of h_1 . The total number of simulations done is 80.

In the following, the method for obtaining the coefficients (c_i) for the reinforcing bars (rebars) is presented. However, the coefficients for the steel components (b_i) were obtained using the same method.

To obtain the coefficients, an approximate solution is required for the overdetermined system of linear equations.

$$\begin{cases} c_0 + c_1 a_{1.2} + c_2 a_{1.3} + c_3 a_{1.4} + c_4 a_{1.5} + c_5 a_{1.6} + c_6 a_{1.7} \approx \theta_1 \\ c_0 + c_1 a_{2.2} + c_2 a_{2.3} + c_3 a_{2.4} + c_4 a_{2.5} + c_5 a_{2.6} + c_6 a_{2.7} \approx \theta_2 \\ \vdots \\ c_0 + c_1 a_{80.2} + c_2 a_{80.3} + c_3 a_{80.4} + c_4 a_{80.5} + c_5 a_{80.6} + c_6 a_{80.7} \approx \theta_{80} \end{cases} \quad (6.1)$$

where $a_{i.2}=u_3/h_2$, $a_{i.3} = z$, $a_{i.4} = A/L_r$, $a_{i.5} = \alpha$, and $a_{i.6} = 1/l_3$ represents the geometrical parameters of the composite slabs (Cofraplus 60, Polydeck 59S, Multideck 50, or Bondek), and $a_{i.7} = h_1$ is the corresponding concrete thickness.

The solution of the system (6.1), in the least squares sense, corresponds to the solution $\mathbf{x} = [c_0, c_1, \dots, c_6]^T \in \mathbb{R}^7$, which minimises the sum of the squared difference between the two sides of the 80 equations, viz,

$$\min_{\mathbf{x}} \sum_{i=1}^{80} \left(\theta_i - \sum_{j=0}^6 c_j a_{ij} \right)^2 \quad (6.2)$$

The system (6.1) can be written in the matrix form as

$$\begin{bmatrix} 1 & a_{1.2} & a_{1.3} & a_{1.4} & a_{1.5} & a_{1.6} & a_{1.7} \\ 1 & a_{2.2} & a_{2.3} & a_{2.4} & a_{2.5} & a_{2.6} & a_{2.7} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & a_{80.2} & a_{80.3} & a_{80.4} & a_{80.5} & a_{80.6} & a_{80.7} \end{bmatrix} \cdot \begin{bmatrix} c_0 \\ c_1 \\ \vdots \\ c_6 \end{bmatrix} \approx \begin{bmatrix} \theta_0 \\ \theta_1 \\ \vdots \\ \theta_{79} \end{bmatrix} \Leftrightarrow \mathbf{Ax} \approx \mathbf{b} \quad (6.3)$$

where $\mathbf{A} \in \mathbb{R}^{80 \times 7}$ and $\mathbf{b} \in \mathbb{R}^{80 \times 1}$. The condition given by Equation (6.2) is equivalent to the minimization of the squared norm of the residual, $\|\mathbf{r}\| = \|\mathbf{b} - \mathbf{Ax}\|$ of the system $\mathbf{Ax} \approx \mathbf{b}$, i.e.,

$$\min_{\mathbf{x}} \|\mathbf{b} - \mathbf{Ax}\|^2 \quad (6.4)$$

This least square problem could be solved in different ways if \mathbf{A} had full column rank, but \mathbf{A} had only rank 5. In all four composite slab models, $u_3 = h_2$ is verified so that the second column of \mathbf{A} is equal to the first ($a_{i,2} = 1$ for $i = 1, \dots, 80$). As a result, the least squares problem has multiple solutions. However, from all the solutions to the equation (6.4), there is only one that also minimises the norm of \mathbf{x} .

This solution can be obtained by decomposing it into singular values. The singular value decomposition of \mathbf{A} is

$$\mathbf{A} = \mathbf{U}\mathbf{D}\mathbf{V}^T \quad (6.5)$$

where $\mathbf{U} \in \mathbb{R}^{80 \times 80}$, $\mathbf{D} \in \mathbb{R}^{7 \times 7}$ and $\mathbf{V} \in \mathbb{R}^{7 \times 7}$. The matrix \mathbf{D} is a diagonal matrix with the singular values of the matrix \mathbf{A} . Two of them are zeros because of the rank of the matrix \mathbf{A} . These matrices can be decomposed to separate the singular values that are not zero:

$$\mathbf{U} = [\mathbf{U}_1 \quad \mathbf{U}_2], \quad \mathbf{D} = \begin{bmatrix} \mathbf{D}_1 & 0 \\ 0 & 0 \end{bmatrix}, \quad \text{and } \mathbf{V} = \begin{bmatrix} \mathbf{V}_1^T \\ \mathbf{V}_2^T \end{bmatrix} \quad (6.6)$$

where $\mathbf{U}_1 \in \mathbb{R}^{80 \times 5}$, $\mathbf{D} \in \mathbb{R}^{5 \times 5}$ and $\mathbf{V}_1 \in \mathbb{R}^{5 \times 5}$. The matrix \mathbf{D}_1 includes the non-singular values of \mathbf{A} . The solution of the least squares problem (6.4) is then given by

$$\mathbf{x} = \mathbf{V}_1 \mathbf{D}_1^{-1} \mathbf{U}_1^T \mathbf{b} \quad (6.7)$$

As mentioned before, the temperature-dependent load bearing capacity criteria for the steel deck components and the rebar component, as well as the insulation criterion that defines the value of the average or maximum temperature in the unexposed part of the composite slab, can be determined through the simplified calculation method proposed by EN 1994-1-2 [4]. Although this model has not been modified for a long time and needs to be improved.

The proposed methodology is based on the numerical solution of the incremental and non linear thermal analysis. This solution method has been applied for different thicknesses of the concrete cover (h_1), comparing the results with the simplified solution method.

5.4.2.1. New Proposal I

Based on the numerical results, new coefficients b_i and c_i are proposed for the simplified calculation model. In addition, the original model given by equations (4.4) and (4.5) was modified by including a new term that depends on h_1 to consider the effect of concrete pavement thickness on temperature.

The thickness h_1 was explicitly included in the mathematical model multiplied by coefficient b_5 , in the case of the steel deck temperatures, and by c_6 , in the case of the rebar temperature. Therefore, the New Proposal for the steel deck temperature is

$$\theta_{\alpha,New I} = b_0 + b_1 \cdot \frac{1}{l_3} + b_2 \cdot \frac{A}{L_r} + b_3 \cdot \Phi + b_4 \cdot \Phi^2 + b_5 \cdot h_1 \quad (6.8)$$

and for the rebar is:

$$\theta_{s,New I} = c_0 + c_1 \cdot \frac{u_3}{h_2} + c_2 \cdot z + c_3 \cdot \frac{A}{L_r} + c_4 \cdot \alpha + c_5 \frac{1}{l_3} + c_6 \cdot h_1 \quad (6.9)$$

The coefficients for these first new proposal were determined by fitting the mathematical model represented by the Equations (6.8) and (6.9) to the numerical results of the parametric study with different values of h_1 considering the four different composite slab geometries. The coefficients were determined using the non-linear least-squares method.

The resulting coefficients for the calculation of temperatures on parts of the steel deck through Equations (6.8) are presented in Table 6.4. It is worth mentioning that, in addition to the standard fire resistance ratings of 60, 90, and 120 min, the proposal also comprises the coefficients for the fire rating of 45 min.

Table 5.6: Coefficients of the New Proposal I for estimating the temperature of the steel deck components.

| Fire Rating [min] | Flange | b_0 | b_1 | b_2 | b_3 | b_4 | b_5 |
|-------------------|--------|--------|----------|-------|--------|---------|-------|
| 45 | Upper | 718.31 | -1.91 | -6.12 | 67.13 | 301.4 | -0.23 |
| | Web | 706.96 | -22.82 | -1.93 | 444.61 | -310.15 | -0.02 |
| | Lower | 296.03 | -1534 | -0.46 | 296.03 | 296.03 | -0.15 |
| 60 | Upper | 789.74 | -1.46 | -6.23 | 138.15 | 217.71 | -0.26 |
| | Web | 784.99 | -22.10 | -2.15 | 437.54 | -313.07 | -0.04 |
| | Lower | 314.22 | -1321.44 | -0.43 | 314.22 | 314.22 | -0.12 |
| 90 | Upper | 897.64 | -0.55 | -6.16 | 172.92 | 150.07 | -0.30 |
| | Web | 886.35 | -18.79 | -2.06 | 391.27 | -284.97 | -0.06 |
| | Lower | 337.31 | -1034.5 | -0.37 | 337.31 | 337.31 | -0.09 |
| 120 | Upper | 1028.8 | 0.60 | -7.05 | 63.46 | 223.15 | -0.37 |
| | Web | 981.05 | -12.96 | -2.58 | 310.46 | -209.96 | -0.12 |
| | Lower | 352.77 | -845.3 | -0.34 | 352.77 | 352.77 | -0.08 |

The next resulting coefficients may be used to determine the average temperature on the rebar, through Equations (6.9). The coefficients are presented in Table 6.5.

Table 5.7: Coefficients of the New Proposal I obtained for estimating the rebar temperature.

| Fire Rating [min] | c_0 | c_1 | c_2 | c_3 | c_4 | c_5 | c_6 |
|-------------------|---------|---------|----------|--------|-------|----------|-------|
| 45 | 1027.10 | 1027.10 | -1816.60 | 108.76 | -2.33 | -1694.40 | -0.05 |
| 60 | 1302.00 | 1302.00 | -2271.4 | 136.73 | -3.21 | -2129.60 | -0.12 |
| 90 | 1702.40 | 1702.40 | -2944.20 | 179.11 | -4.50 | -2769.7 | -0.36 |
| 120 | 1893.30 | 1893.30 | -3194.70 | 194.47 | -5.10 | -3033.38 | -0.61 |

5.4.2.2. New Proposal II

The second New Proposal presented for the calculation of the fire resistance, consider the thickness of the concrete topping h_1 and the reinforcement bar diameter ϕ_{reb} for the estimation of the temperature in the steel deck components (θ_a) and in the rebars (θ_s), for the specific time defined by fire rating.

The thickness h_1 was explicitly included in the mathematical model multiplied by the coefficient b_5 , in the case of the steel deck temperatures, and by c_6 , for the case of the rebar temperature. The rebar diameter ϕ_{reb} is multiplied by coefficient b_6 in the case of the steel deck temperatures, and by c_7 , in the case of the rebar temperature. Therefore, the New Proposal II for the steel deck temperature is defined by:

$$\theta_{\alpha,NewII} = b_0 + b_1 \cdot \frac{1}{l_3} + b_2 \cdot \frac{A}{L_r} + b_3 \cdot \Phi + b_4 \cdot \Phi^2 + b_5 \cdot h_1 + b_6 \cdot \Phi_{reb} \quad (6.10)$$

and for the rebar:

$$\theta_{s,New,II} = c_0 + c_1 \cdot \frac{u_3}{h_2} + c_2 \cdot z + c_3 \cdot \frac{A}{L_r} + c_4 \cdot \alpha + c_5 \frac{1}{l_3} + c_6 \cdot h_1 \cdot c_7 \cdot \Phi_{reb} \quad (6.11)$$

The coefficients were determined by the same approximation method, see the next tables.

Table 5.8: Coefficients of the New Proposal II for estimating the temperature of the steel deck components.

| Fire Rating [min] | Flange | b_0 | b_1 | b_2 | b_3 | b_4 | b_5 | b_6 |
|-------------------|--------|---------|----------|-------|--------|---------|-------|-------|
| 45 | Lower | 297.61 | -1440.60 | -0.86 | 297.61 | 291.61 | -0.11 | 0.16 |
| | Web | 707.51 | -22.49 | -1.96 | 440.20 | -303.86 | -0.02 | 0.01 |
| | Upper | 741.89 | -1.83 | -6.48 | -20.97 | 395.08 | -0.23 | -0.28 |
| 60 | Lower | 315.58 | -1245.80 | -0.75 | 315.58 | 315.58 | -0.10 | 0.10 |
| | Web | 785.28 | -22.03 | -2.16 | 436.45 | -311.88 | -0.04 | -0.02 |
| | Upper | 801.23 | -1.32 | -6.37 | 133.51 | 215.99 | -0.27 | -0.47 |
| 90 | Lower | 338.36 | -980.75 | -0.60 | 338.36 | 338.36 | -0.08 | 0.05 |
| | Web | 884.62 | -19.72 | -1.88 | 404.58 | -299.46 | -0.10 | -0.26 |
| | Upper | 907.70 | -0.45 | -6.30 | 159.95 | 159.26 | -0.31 | -0.34 |
| 120 | Lower | 353.68 | -801.91 | -0.53 | 353.68 | 353.68 | -0.07 | 0.04 |
| | Web | 981.31 | -12.89 | -2.59 | 309.31 | -208.64 | -0.12 | -0.02 |
| | Upper | 1044.50 | 0.61 | -7.36 | -22.53 | 317.73 | -0.34 | -0.02 |

The resulting coefficients for the calculation of temperatures on the rebar, through Equations (6.11), are presented in Table 6.7.

Table 5.9: Coefficients of the New Proposal II obtained for estimating the rebar temperature.

| Fire Rating [min] | c_0 | c_1 | c_2 | c_3 | c_4 | c_5 | c_6 | c_7 |
|-------------------|---------|---------|----------|--------|-------|----------|-------|-------|
| 45 | 1021.00 | 1021.00 | -1804.10 | 108.02 | -2.31 | -1683.30 | -0.05 | -0.09 |
| 60 | 1297.00 | 1297.00 | -2257.80 | 135.90 | -3.20 | -2118.60 | -0.13 | -0.25 |
| 90 | 1693.80 | 1693.80 | -2920.50 | 177.58 | -4.48 | -2750.50 | -0.35 | -0.38 |
| 120 | 1811.90 | 1881.90 | -3164.10 | 192.50 | -5.08 | -3008.90 | -0.60 | -0.44 |

5.4.2.3. New Proposal III

In the New Proposal III, two different sets of coefficients were determined as a function of the slab geometry (Trapezoidal or Re-entrant profiles). The concrete thickness h_1 multiplied by coefficient b_5 , in the case of the steel deck temperatures, and by c_6 , in the case of the rebar temperature. The rebar diameter ϕ_{reb} is multiplied by coefficient b_7 in case of the steel deck temperatures and by the c_8 coefficient in case of the rebar temperature. This new proposal allows performing the analysis in a way to include the fire rating time t , which makes the analysis even more simplified since it is and straightforward. This novelty requires new coefficients to be used for the load bearing components affected by the temperature. This parameter is multiplied by coefficient b_6 for steel deck and by c_7 in case of the rebar.

The analysis can be performed considering different coefficients for the slab geometry, trapezoidal and re-entrant.

$$\theta_{a,NewIII} = b_0 + b_1 \cdot \frac{1}{l_3} + b_2 \frac{A}{L_r} + b_3 \cdot \Phi + b_4 \cdot \Phi^2 + b_5 \cdot h_1 + b_6 \cdot t + b_7 \cdot \phi_{reb} \quad (6.12)$$

and for the rebar

$$\theta_{s,New,III} = c_0 + c_1 \frac{u_3}{h_2} + c_2 \cdot z + c_3 \frac{A}{L_r} + c_4 \cdot \alpha + c_5 \frac{1}{l_3} + c_6 \cdot h_1 + c_7 \cdot t + c_8 \cdot \phi_{reb} \quad (6.13)$$

The resulting coefficients for the calculation of temperatures on the steel deck, through Equations (6.12), are presented in Table 6.8.

Table 5.10: Coefficients of the New Proposal III for estimating the temperature of the steel deck components.

| Profile | Flange | b_0 | b_1 | b_2 | b_3 | b_4 | b_5 | b_6 | b_7 |
|-------------|--------|--------|-------|-------|---------|---------|--------|-------|-------|
| Trapezoidal | Lower | 279.01 | -4.30 | -1.49 | 279.01 | 279.01 | -0.002 | 2.06 | -0.03 |
| | Web | 489.29 | -7.71 | 17.23 | -132.97 | -330.37 | -0.05 | 2.27 | -0.02 |
| | Upper | 438.00 | -6.94 | 2.05 | 230.10 | 100.74 | -0.23 | 2.54 | -0.68 |
| Re-entrant | Lower | 277.16 | -0.76 | -1.83 | 277.14 | 277.16 | -0.20 | 2.20 | 0.21 |
| | Web | 59.50 | -0.14 | 22.26 | 6.74 | -194.19 | -0.09 | 2.67 | -0.20 |
| | Upper | 668.94 | -1.83 | -7.50 | 153.03 | 28.05 | -0.36 | 3.09 | 0.13 |

The resulting coefficients for the calculation of temperatures on the rebar, may be used in combination with Equation (6.13), and are presented in Table 6.9.

Table 5.11: Coefficients of the New Proposal III obtained for estimating the rebar temperature.

| Profile | c₀ | c₁ | c₂ | c₃ | c₄ | c₅ | c₆ | c₇ | c₈ |
|--------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Trapezoidal | -0.05 | -0.05 | -0.28 | -3.28 | 3.91 | 0.01 | -0.37 | 3.73 | 0.37 |
| Re-entrant | 0.32 | 0.32 | 0.88 | -17.91 | 7.98 | -0.02 | -0.17 | 3.16 | -0.22 |

5.4.2.4. New Proposal IV

The New Proposal IV establishes new optimized coefficients for both trapezoidal and re-entrant slabs. This proposal includes all the parameters that were presented before, but can be classified as a general proposal concerning the New Proposal III. That is, it allows the analysis to be performed independently of the slab geometry.

Table 5.12: Coefficients of the New Proposal IV for estimating the temperature of the steel deck components.

| Profile | Flange | b₀ | b₁ | b₂ | b₃ | b₄ | b₅ | b₆ | b₇ |
|--------------------|---------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Trapezoidal | Lower | 271.56 | -1865.90 | 1.20 | 271.56 | 271.56 | -0.09 | 2.08 | -1.23 |
| | Web | 777.23 | -21.44 | -5.33 | 194.38 | -18.33 | -0.07 | 2.47 | -0.07 |
| Re-entrant | Upper | 1212.30 | 550.22 | -15.65 | -2824.10 | 3619.40 | -0.29 | 2.76 | 0.99 |

The resulting coefficients for the calculation of temperatures on the steel deck and rebar, through Equations (6.12) and (6.13) is presented in Table 6.11, respectively.

Table 5.13: Coefficients of the New Proposal IV obtained for estimating the rebar temperature.

| Profile | c₀ | c₁ | c₂ | c₃ | c₄ | c₅ | c₆ | c₇ | c₈ |
|--------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Trapezoidal | | | | | | | | | |
| or | 1366.20 | 1366.20 | -2565.40 | 155.36 | -3.90 | -2340.70 | -0.28 | 3.44 | -0.29 |
| Re-entrant | | | | | | | | | |

6. ACCURACY AND COMPARISON OF THE DIFFERENT PROPOSALS

This chapter presents the differences between the results proposed by the simplified method (S) presented in EN 1994-1-2 [4], the numeric results (N), and the new calculation method proposals (NP), in order to compare the accuracy of the new coefficients. The numerical model was already validated against experimental results based on the previous investigations (Balsa et al.; Piloto et al.,2022) available in the literature [39].

In Table 7.1 to 7.4, the values obtained by the analytical methods y_i for $i = 1, 2, \dots, 80$ given by the simplified method or by the New Proposals are compared with the numerical results \mathcal{X}_i for $i = 1, 2, \dots, 80$, (right-hand side of the system (6.3)). According to the recommendations of Chai and Draxler [40], the Root Mean-Squared Error (RMSE) is used as an error measure to compare the results:

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \mathcal{X}_i)^2}, \quad (7.1)$$

and the Bias, given by:

$$\text{Bias} = \frac{1}{n} \sum_{i=1}^n (\mathcal{X}_i - y_i) \quad (7.2)$$

To complement the RMSE and Bias metrics, the Standard Deviation of the Error (SDE) is also considered. The SDE simply corresponds to:

$$\text{SDE} = \sqrt{\text{RMSE}^2 - \text{Bias}^2} \quad (7.3)$$

Considering the Bias as a basic indicator of the *systematic error* in a prediction, then the SDE is the equivalent indicator of the *random error* [39].

Table 6.1: Errors measures of the different Proposals for the Lower flange.

| Fire Rating | 45 [min] | | | 60 [min] | | | 90 [min] | | | 120 [min] | | |
|---------------------------|---------------------------------|------|------|-------------|-------|------|----------|-------|------|------------|-------|------|
| | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE |
| EN 1994-1-2 | - | - | - | 95.26 | 95.57 | 7.74 | 57.26 | 57.51 | 5.36 | 42.30 | 42.52 | 4.29 |
| NP - I | 0 | 6.83 | 6.83 | 0 | 5.50 | 5.50 | 0 | 3.97 | 3.97 | 0 | 3.18 | 3.18 |
| NP - II | 0 | 7.52 | 7.52 | 0 | 6.08 | 6.08 | 0 | 4.42 | 4.42 | 0 | 3.57 | 3.57 |
| NP - III (Trapezoidal) | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 38.69 | | | | | | 38.69 | | |
| NP - III (Re-entrant) | 0 | | | 41.74 | | | | | | 41.74 | | |
| NP - IV | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 44.58 | | | | | | 44.58 | | |

Table 6.2: Errors measures of the different Proposals for the Web.

| Fire Rating | 45 [min] | | | 60 [min] | | | 90 [min] | | | 120 [min] | | |
|---------------------------|---------------------------------|------|------|-------------|--------|-------|----------|-------|-------|------------|-------|------|
| | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE |
| EN 1994-1-2 | - | - | - | 130.46 | 133.35 | 27.62 | 70.78 | 73.10 | 18.25 | 38.88 | 39.84 | 8.70 |
| NP - I | 0 | 1.48 | 1.48 | 0 | 1.51 | 1.51 | 0 | 1.50 | 1.50 | 0 | 1.71 | 1.71 |
| NP - II | 0 | 1.52 | 1.52 | 0 | 1.56 | 1.56 | 0 | 3.16 | 3.16 | 0 | 1.73 | 1.73 |
| NP - III (Trapezoidal) | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 42.57 | | | | | | 42.57 | | |
| NP - III (Re-entrant) | 0 | | | 46.96 | | | | | | 46.96 | | |
| NP - IV | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 45.29 | | | | | | 45.29 | | |

The errors are below the limit for the temperature variation of the plate thermocouple, during an experimental tests [2]. At any time after the first 10 min of the test, the temperature recorded by any thermocouple in the furnace shall not differ from the corresponding temperature of the standard temperature/time curve by more than 100 K.

Table 6.3: Errors measures of the different Proposals for the Upper flange.

| Fire Rating | 45 [min] | | | 60 [min] | | | 90 [min] | | | 120 [min] | | |
|----------------------------------|---------------------------------|-------------|------------|-----------------|-------------|------------|-----------------|-------------|------------|------------------|-------------|------------|
| Error | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE |
| EN 1994-1-2 | - | - | - | 72.53 | 203.19 | 189.8 | 101.63 | 108.5 | 38.0 | 65.15 | 68.52 | 21.21 |
| NP - I | 0 | 14.41 | 14.41 | 0 | 12.46 | 12.46 | 0 | 9.91 | 9.91 | 0 | 9.38 | 9.38 |
| NP - II | 0 | 13.36 | 13.36 | 0 | 11.42 | 11.42 | 0 | 9.25 | 9.25 | 0 | 9.17 | 9.17 |
| NP – III (Trapezoidal) | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 48.19 | | | | | | 48.19 | | |
| NP – III (Re-entrant) | 0 | | | 52.46 | | | | | | 52.46 | | |
| NP - IV | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 54.06 | | | | | | 54.06 | | |

Table 6.4: Errors measures of the different Proposals for the Reinforcement bar.

| Fire Rating | 45 [min] | | | 60 [min] | | | 90 [min] | | | 120 [min] | | |
|----------------------------------|---------------------------------|-------------|------------|-----------------|-------------|------------|-----------------|-------------|------------|------------------|-------------|------------|
| Error | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE | Bias | RMSE | SDE |
| EN 1994-1-2 | - | - | - | 45.07 | 51.67 | 25.27 | 1.36 | 32.52 | 32.49 | 26.42 | 47.91 | 39.97 |
| NP - I | 0 | 1.23 | 1.23 | 0 | 2.50 | 2.50 | 0 | 6.98 | 6.98 | 0 | 8.49 | 8.49 |
| NP - II | 0 | 1.35 | 1.35 | 0 | 2.58 | 2.58 | 0 | 6.96 | 6.96 | 0 | 8.45 | 8.45 |
| NP – III (Trapezoidal) | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 65.20 | | | | | | 65.20 | | |
| NP – III (Re-entrant) | 0 | | | 53.13 | | | | | | 53.13 | | |
| NP - IV | 45 60 90 120 [min] | | | | | | | | | | | |
| | Bias | | | RMSE | | | | | | SDE | | |
| | 0 | | | 50.37 | | | | | | 50.37 | | |

The results represented in Tables 7.1 to 7.4 show that the temperatures for the four different proposals obtained by the Least Squares method fit the numerical results satisfactorily.

In all New Proposals, smaller errors are noted for all fire classes, including a value of zero for the bias. It can also be observed that the temperatures estimated by the simplified method of EN 1994-1-2 are generally lower than the numerical temperatures because the bias is always positive.

Proposals III and IV include more parameters and for that reason have larger errors. This results from the fact that these two proposals are much more complete in terms of the inclusion of parameters, allowing a much more straightforward analysis for the designer.

Although the errors of proposal III and New Proposal IV are larger when compared to New Proposals I and II, they still meet the values according to EN 1363-1:2020 [2] , and the results are within this reference range. Therefore, all proposals are following a good estimation.

The following sub-sections 7.1 to 7.4 show the percentage relative errors for the four slabs for different heating times, 45, 60, 90 and 120 min at the different combinations of heat input from the bottom flange, web, top flange and also at the reinforcing bar comparing the analytical results from EN 1994-1-2 as well as the four New Proposals with the numerical results.

6.1. Comparison between EN 1994-1-2 and Numerical Results

A measurement of the relative errors between the numerical results and those obtained by Annex D of EN 1994-1-2 [4] is presented first in this section.

Figure 7.1 illustrates a comparison between the results obtained numerically (MATLAB) and those obtained by the EN 1994-1-2 (EC4) for the fire resistance (R).

The results were selected for the concrete cover $h_1 = 70$ [mm].

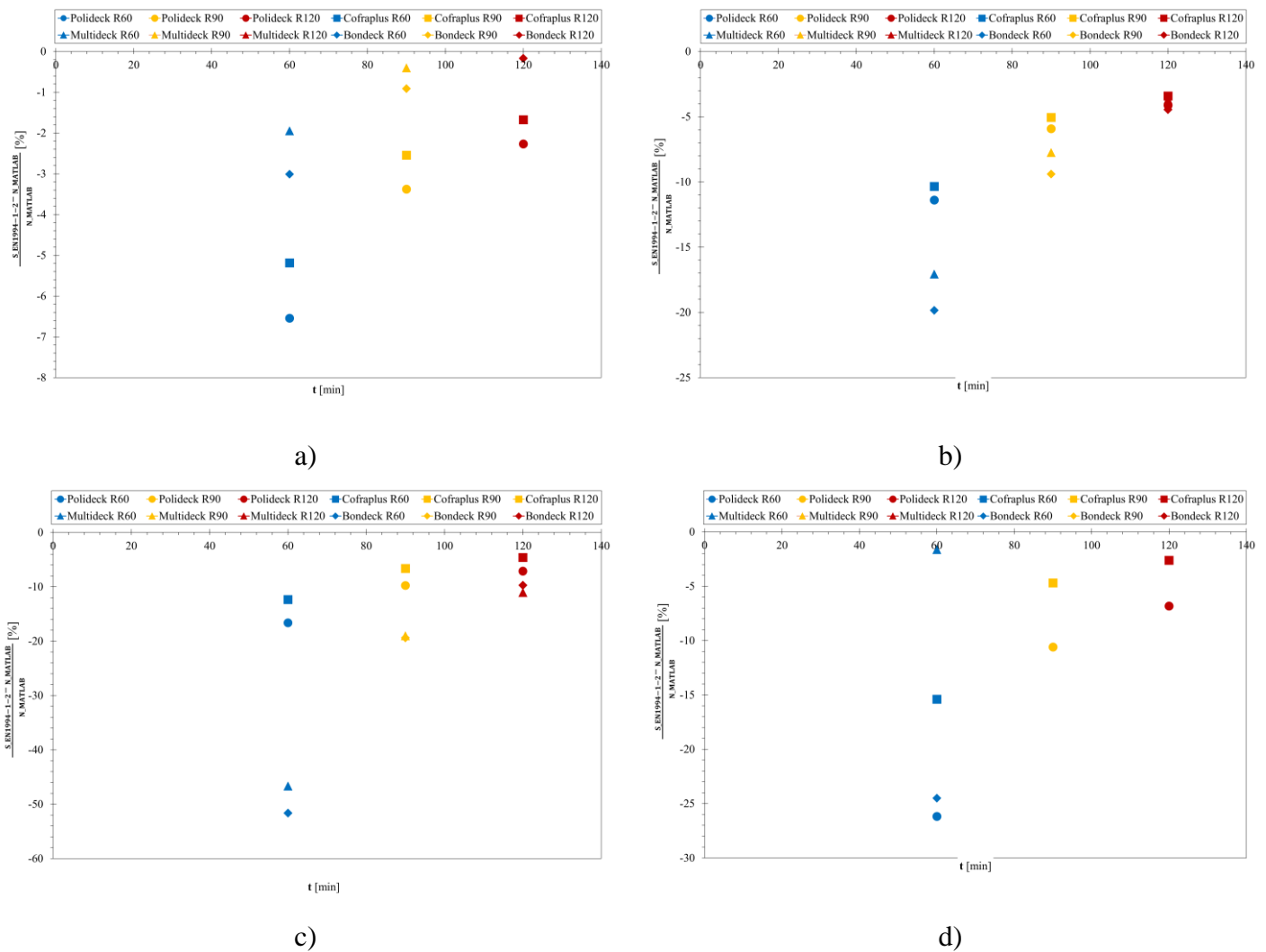


Figure 6.1: Measurement of relative errors for EN 1994-1-2 and the Numerical Results concerning resistance times 45,60,90, and 120. For the components a) Lower flange, b) Web, c) Upper flange and d) Rebar

It is also possible to verify that the simplified model, proposed by the current version of the Eurocode, predicted much lower temperatures than the numerical results, mainly for the case of steel deck components and for the lowest fire ratings. The fire resistance obtained with

the simple calculation method, proposed in the Eurocode 4, seems to be unsafe because it gives a critical time value quite higher than those obtained with the numerical simulation.

6.2. Comparison between New Proposal I and Numerical results

Figure 7.2 compares the results obtained numerically (MATLAB) and through the analytical method of New Proposal I for the fire resistance (R). The results were selected for the concrete cover $h_1 = 70$ [mm].

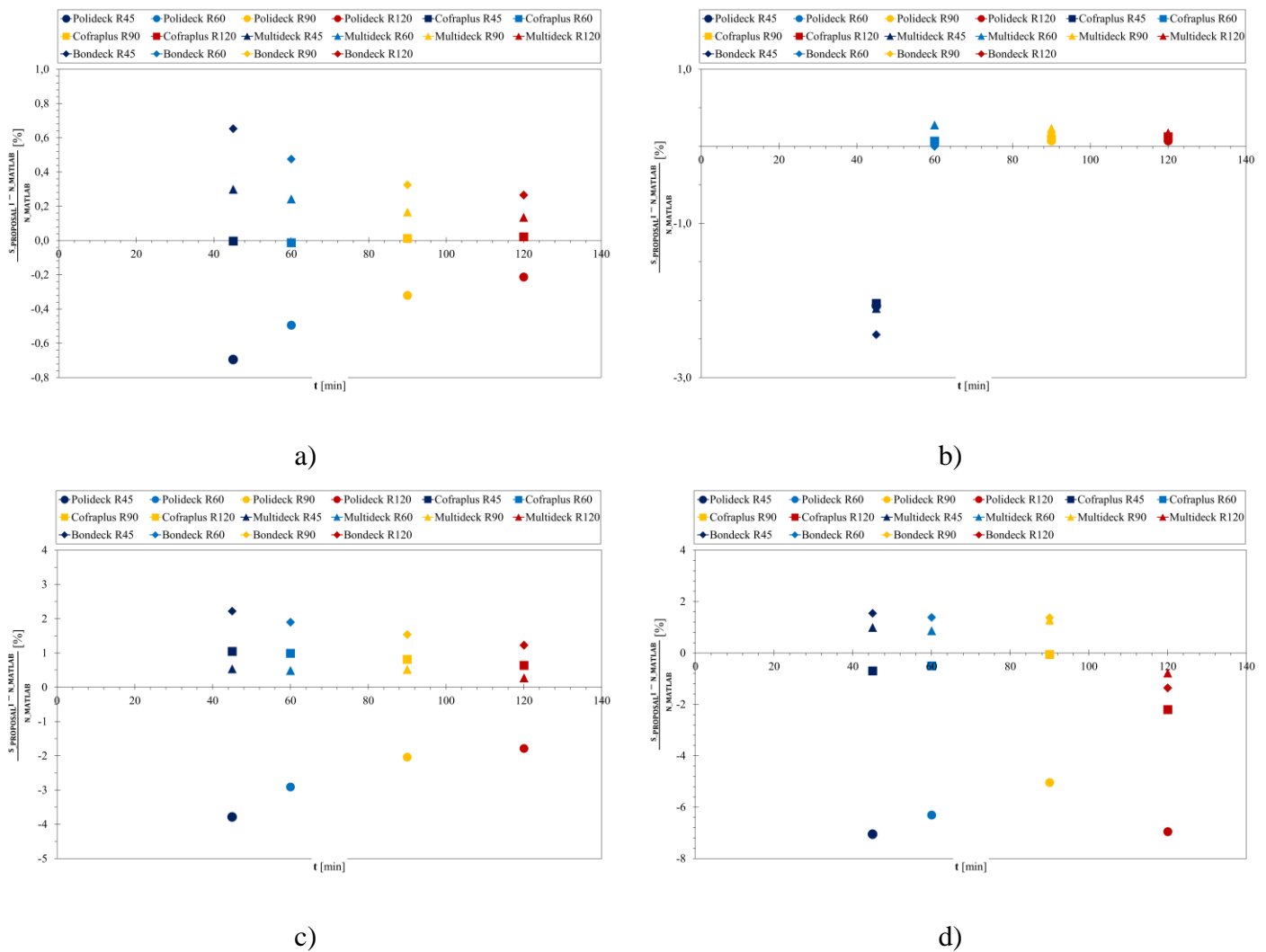


Figure 6.2: Measurement of relative errors for Numerical Results and New Proposal I concerning resistance times 45,60,90, and 120. For the components a) Lower flange, b) Web, c) Upper flange and d) Rebar

In Proposition I, compared to the notable numerical results closer to zero, the negative results indicate slightly higher results than the numerical ones. The highest percentages of

errors were observed in rebar with 7.05% in the Polideck slab, Upper flange with 1.05% in the Cofraplus slab, 0.99% in the rebar for Multideck slab and 2.22% in the Upper Flange of Bondeck slab, all for the 45 min time rating. The results are much better compared to the comparison of the numerical results with the Eurocode 4 results shown earlier. This means that the new proposal approximates the numerical simulation results obtained.

6.3. Comparison between New Proposal II and Numerical results

The New Proposal II improves the temperature estimation according to each fire rating time. The results were selected for the concrete cover $h_1 = 70$ [mm].

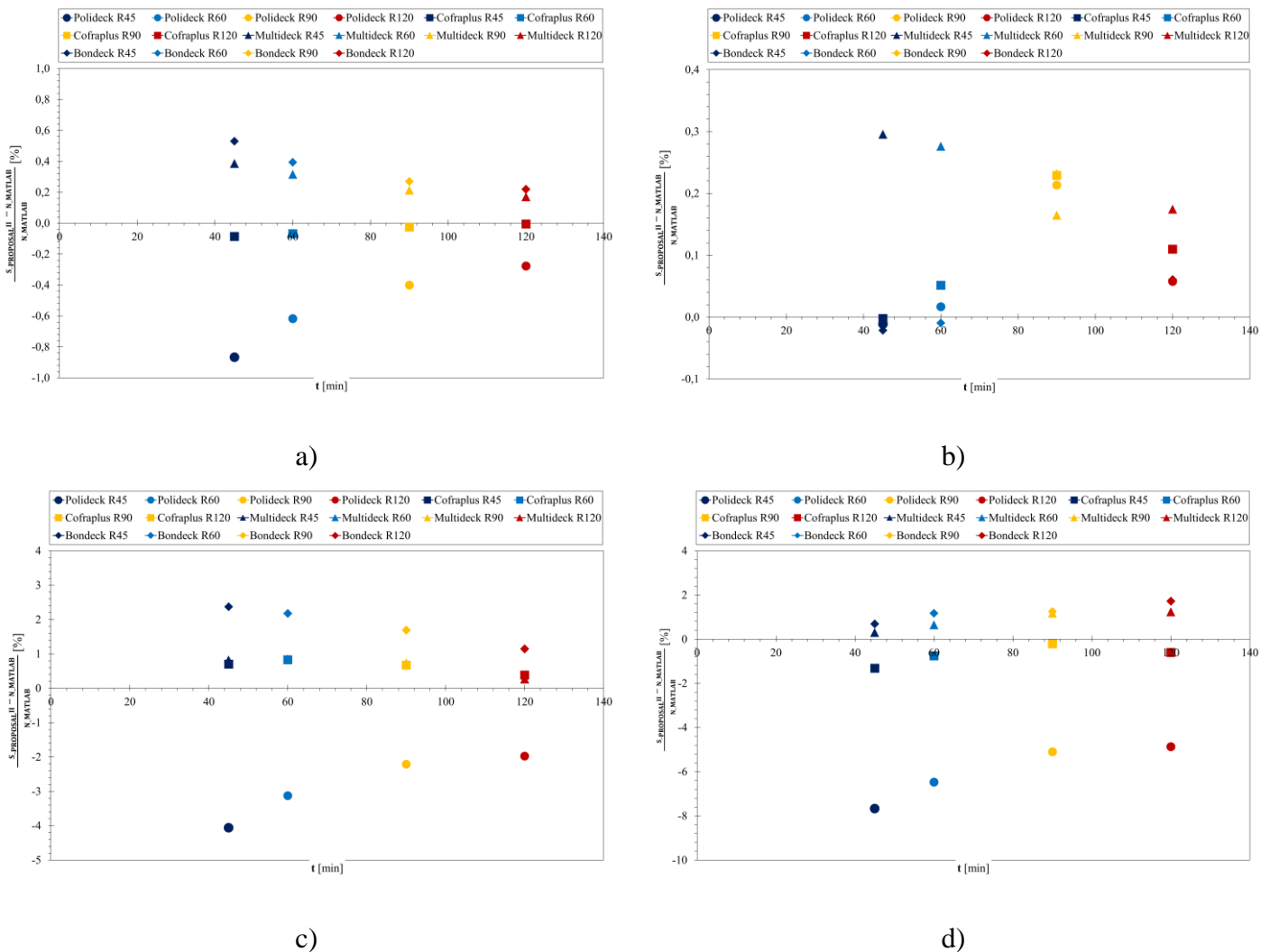


Figure 6.3: Measurement of relative errors for Numerical Results and New Proposal II concerning resistance times 45,60,90, and 120. For the components a) Lower flange, b) Web, c) Upper flange and d) Rebar

As for the relative errors of Proposal II concerning the numerical results, the largest

differences can also be observed for the 45 min time, were for the upper flange 4.06% and in the flange, 7.67% of the Polideck slab was obtained.

6.4. Comparison between New Proposal III and Numerical results

Figure 7.4 presents a comparison between the results of the New Proposal III and numerical results. The results were selected for the concrete cover $h_1 = 70$ [mm].

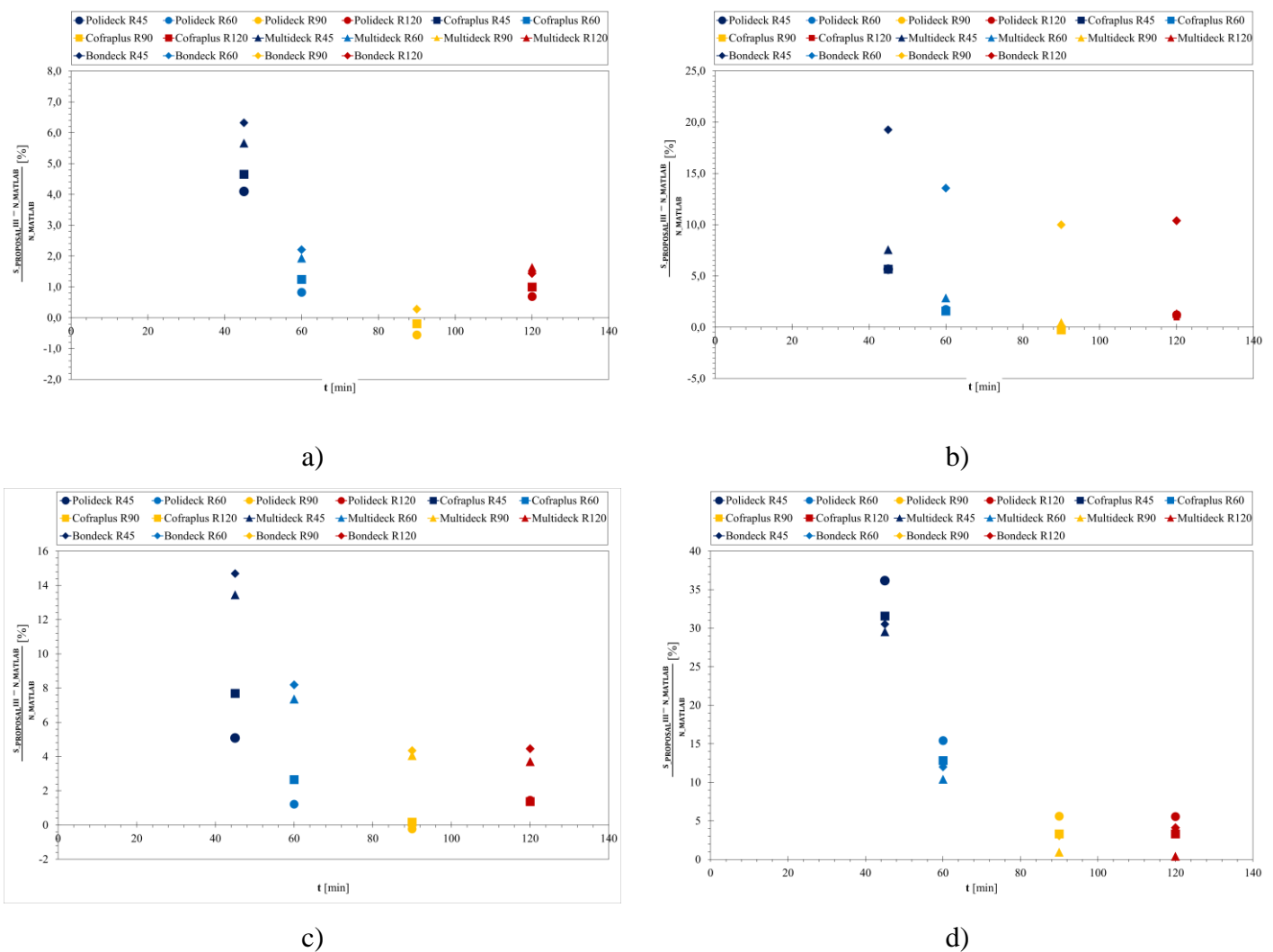


Figure 6.4: Measurement of relative errors for Numerical Results and Proposal III concerning resistance times 45,60,90, and 120. For the components a) Lower flange, b) Web, c) Upper flange and d) Rebar

For Proposal III, a higher percentage of errors was observed compared to the previous two proposals, with higher error values of about 5.09% in the Top Flange and 36.17% in the Deburring for the Polideck slab, 7.69% in the Top Flange and 31.56% in the Deburring for

the Cofraplus slab, 13.45% in the Top Flange and 29.53% in the Deburring for the Multideck slab and 14.69% in the Top Flange and 30.52% in the Deburring for the Bondeck slab and all this for 45 min. Although the errors are larger than the previous proposals, this proposal is even more simplified for the designer because it includes parameters that the other previous proposals did not include and the errors are within the limits of the standards.

6.5. Comparison between New Proposal IV and Numerical results

Figure 7.5 presents a comparison between the results of the New Proposal IV and numerical results. The results were selected for the concrete cover $h_1 = 70$ [mm].

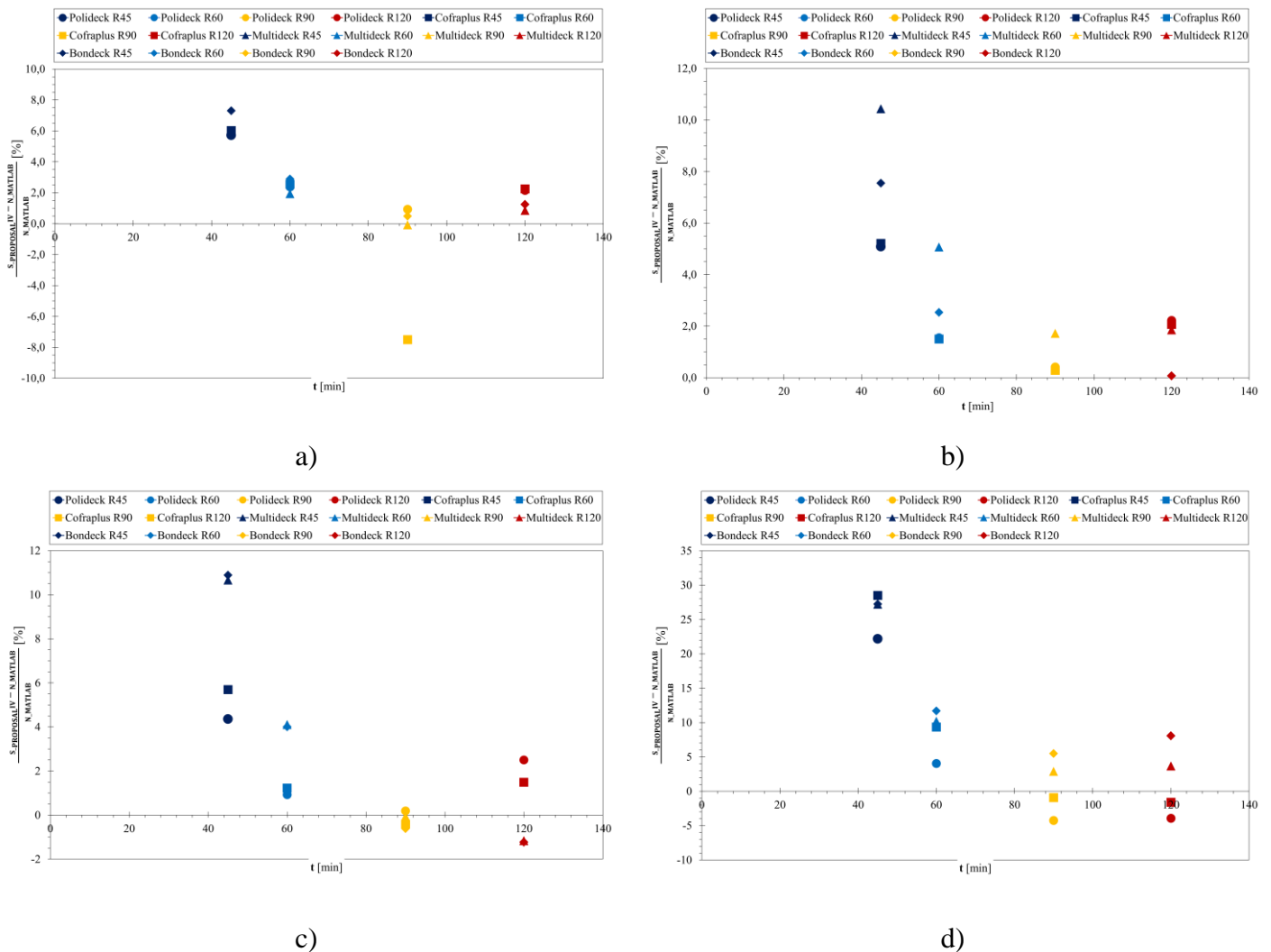


Figure 6.5: Measurement of relative errors for Numerical Results and Proposal IV concerning resistance times 45,60,90, and 120. For the components a) Lower flange, b) Web, c) Upper flange and d) Rebar

Finally, regarding proposal IV, higher percentages of errors in the rebar can be verified for the 45 min time, where the percentage of 22.20% in the Polideck slab, 28.51% in the Cofraplus slab, 27.22% in the Multideck slab and 27.25% in the Bondeck slab were obtained.

Although in computational practice there is error compensation (the positive errors compensating the negative ones), the analysis was made considering the worst case, to be sure about the accuracy of the results for the errors.

Overall, the new proposals generated satisfactory results for the fire behaviour of the composite slabs and good agreement with the numerical results describing the three-dimensional heat flow in both the components of the steel deck and the reinforcing bar.

7. CONCLUSIONS

A series of heat transfer analyses were conducted to determine the adequacy of the prescriptive codes to safeguard against standard fires. The fire methodology was applied to steel-concrete composite slabs. The fire rating of each component was quantified using the temperature limits available in ISO-834. This model allows to determine the structural fire resistance from the insulation criterion's point of view. The temperature analysis was also performed on the unexposed part of the slabs to better understand the thermal response of the composite slabs systems.

New and more realistic computational models were developed to evaluate the thermal behaviour of composite slabs under standard fire conditions. The parametric analysis results allow us to determine the temperatures for different slab geometries and compare them with those provided by the simplified calculation method of EN 1994-1-2.

The New Proposals are based on the results of a parametric study using the finite element method developed in a three-dimensional approach using MATLAB software.

Based on the data presented here, the following conclusions may be withdrawn:

- The numerical values of t_{fi} are higher when compared to the calculation in EN 1994-1-2. The fire resistance obtained with the simple calculation method proposed in Eurocode 4 does not seem safe because it gives a much higher critical time value than that obtained with the numerical simulation.
- Simulation results show that the temperatures predicted by the simplified method foreseen in the EN 1994-1-2 led, in most cases, to an unsafe design of the composite slab. The simplified model proposed by the current version of Eurocode 4 predicted much lower temperatures than the numerical results, especially for the case of steel deck components and the lowest fire ratings.
- Regarding the models for different proposals, each one presents its advantages and benefits for the determination of the insulation resistance time (I) and the determination of the temperatures in the steel components (R).

For the load bearing components affected by the temperature, four different proposals were presented, where new coefficients were proposed. When comparing the proposals among themselves, it was possible to obtain much smaller errors for both the New Proposal I and the New Proposal II, resulting in better approximations.

It is possible to observe that the last two proposals (New Proposal III and New Proposal IV) obtained larger errors, which results from the fact that these two proposals are much more complete in terms of inclusion of parameters, making possible a much more practical analysis for the designer, however it has the drawback of containing a larger prediction error.

Even if the errors of the New Proposal III and New Proposal IV are larger when compared to New Proposals I and II, they still satisfy the values according to EN 1363-1:2020 [2], and the results are within this reference range. Therefore, all proposals are following a good approximation.

7.1. Future lines of investigation

Fire protection engineers should use a conservative approach when design the passive fire protection of structural members. Specifically, an analysis procedure should be used to verify the adequacy of insulation design derived from prescriptive approaches.

Since only one set of thermal analyses for load bearing (R) and Insulation (I) criteria was examined, further research is required to generalise the results. In addition, a structural analysis is required to determine the faithful performance of the composite slab system under fire exposure.

This investigation related to the fire behaviour of composite slabs provided the following suggestions for future work to complement the results of this work:

1. Study other variations of the geometric parameters in the composite slabs, different from those used in this work;
2. Perform a numerical investigation considering different fire curves, such as natural fire curve models, since this study is only valid to standard ISO-834 fire curve;
3. Carry out parametric studies comprising a series of different steel deck profiles, air gap thicknesses and both normal weight and lightweight concrete;
4. Conduct experimental fire tests with composite slabs (trapezoidal and re-entrant steel deck profile) and compare the results with analytical and numerical methods.

REFERENCES

- [1] ISO, “ISO 834-8, Fire Resistance Tests - Elements of Building Construction, International Organization for Standardization, Geneva,” *Elem. Build. Constr. Genova ISO*, 1999.
- [2] I. I. Mitin, “EN-1363-1, Fire Resistance Tests -Part 1: General Requirements, European Committee for standardization, Brussels,” *Tseliuloza, Bum. Karton/Pulp, Pap. Board*, no. 5, pp. 18-22+95, 2020, doi: 10.4324/9781315780320-29.
- [3] “CEN - European Committee for Standardization, EN 1991-1-2: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire. Brussels,” 2002.
- [4] “CEN - European Committee for Standardization, EN 1994-1-2: Design of composite steel and concrete structures - Part 1 - 2: General rules - Structural fire design. Brussels, 2005.,” *CEN - Eur. Comm. Stand.*, vol. 1, no. 2005, 2005.
- [5] Crisinel, M., “Recent Developments in Steel/Concrete Composite Slabs,” *Struct. Eng. Int.*, vol. 6, no. 1, pp. 41–41, 1996, doi: 10.2749/101686696780495987.
- [6] G. M. Cooke, G. M. E., LKawson, R. M., Newman, “Fire resistance of composite deck slabs,” *Struct. Eng.*, vol. 66, 1988.
- [7] J. Jiang, A. Pintar, J. M. Weigand, J. A. Main, and F. Sadek, “Improved calculation method for insulation-based fire resistance of composite slabs,” *Fire Saf. J.*, vol. 105, no., pp. 144–153, 2018.
- [8] S. Lamont, A. S. Usmani, and M. Gillie, “Behaviour of a small composite steel frame structure in a ‘long-cool’ and a ‘short-hot’ fire,” *Fire Saf. J.*, vol. 39, no. 5, pp. 327–357, Jul. 2004, doi: 10.1016/j.firesaf.2004.01.002.
- [9] “British Steel, ‘The behaviour of multi-storey steel frame buildings in fire.’ British Steel, Rotherham.” 1999.
- [10] 1998. C. Both, The fire resistance of composite steel-concrete slabs, Thesis, Delft University Press, Delft, “The fire resistance of composite steel-concrete slabs.” 1998.
- [11] American Society for Testing and Materials, “ASTM E119 - Standard test methods for fire test of building construction and materials.,” *ASTM - Am. Soc. Test. Mater.*, vol. 552, no. 1, p. 36, 1992, [Online]. Available: www.aslm.org
- [12] Publication 32. ECCS, “ECCS, “Calculation of the fire resistance of composite concrete slabs with profiled steel sheet exposed to the standard fire,” *Comm. T3-Fire Saf. steel Struct. Tech. note*, p. 48, 1983.
- [13] P. Piloto, L. Prates, C. Balsa, and R. Rigobello, “Fire Resistance of Composite Slabs

- with Steel Deck: From Experiments to Numerical Simulation,” *Mecânica Exp.*, vol. 31, pp. 85–94, 2019.
- [14] D. C. O. Mohamed, A. H. Abdel-Halim, M. R. Hakmi, “Fire resistance of composite floor slabs using a model fire test facility,” *Eng. Struct.*, vol. 21, no. 2, pp. 176–182, 1999, doi: [https://doi.org/10.1016/S0141-0296\(97\)00153-3](https://doi.org/10.1016/S0141-0296(97)00153-3).
- [15] C. G. Bailey, T. Lennon, and D. B. Moore, “The behaviour of full-scale steel-framed buildings subjected to compartment fires,” *Struct. Eng.*, vol. 77, no. 8, pp. 15–21, 1999.
- [16] F. Bolina, B. Tutikian, and J. P. C. Rodrigues, “Thermal analysis of steel decking concrete slabs in case of fire,” *Fire Saf. J.*, vol. 121, p. 103295, May 2021, doi: [10.1016/j.firesaf.2021.103295](https://doi.org/10.1016/j.firesaf.2021.103295).
- [17] “European Convention for Constructional Steelwork,” 1984.
- [18] R. Hamerlinck and J. W. B. Stark, “Scholars ’ Mine A Numerical Model for Fire-exposed Composite Steel / concrete Slabs,” 1990.
- [19] R. Hamerlinck, *The Behaviour of Fire-Exposed Composite Steel/Concrete Slabs*. 1991. doi: [10.6100/IR348360](https://doi.org/10.6100/IR348360).
- [20] C. Both, “Fire-exposed continuous span composite steel-concrete slabs,” *Heron*, vol. 41, no. 3, pp. 187–199, 1996.
- [21] C. Both, J. H. H. Fellingner, and L. Twilt, “Shallow floor construction with deep composite deck: From fire tests to simple calculation rules,” *Heron*, vol. 42, no. 3, pp. 145–158, 1997.
- [22] D. Lamont, S., Usmani, A., & Drysdale, “Heat transfer analysis of the composite slab in the Cardington frame fire tests,” *Fire Saf. J.*, vol. 36, pp. 815–83, 2001.
- [23] J. Jiang, J. A. Main, F. Sadek, and J. M. Weigand, “Numerical Modeling and Analysis of Heat Transfer in Composite Slabs with Profiled Steel Decking,” *Natl. Inst. Stand. Technol.*, no. April, pp. 1–56, 2017, [Online]. Available: <https://doi.org/10.6028/NIST.TN.1958>
- [24] P. A. G. Piloto, L. M. S. Prates, C. Balsa, and R. Rigobello, “Numerical simulation of the fire resistance of composite slabs with steel deck,” *Int. J. Eng. Technol.*, vol. 7, no. 2, pp. 83–86, 2018, doi: [10.14419/ijet.v7i2.23.11889](https://doi.org/10.14419/ijet.v7i2.23.11889).
- [25] P. A. G. Piloto, C. Balsa, F. Ribeiro, L. Santos, R. Rigobello, and É. Kimura, “Three-Dimensional Numerical Modelling of Fire Exposed Composite Slabs With Steel Deck,” *MATTER Int. J. Sci. Technol.*, vol. 5, no. 2, pp. 48–67, 2019, doi: [10.20319/mijst.2019.52.4867](https://doi.org/10.20319/mijst.2019.52.4867).

- [26] P. A. G. Piloto, C. Balsa, L. M. C. Santos, and É. F. A. Kimura, “Effect of the load level on the resistance of composite slabs with steel decking under fire conditions,” *J. Fire Sci.*, vol. 38, no. 2, pp. 212–231, 2020, doi: 10.1177/0734904119892210.
- [27] P. Piloto, C. Balsa, F. Ribeiro, R. Rigobello, L. Santos, and E. Kimura, “Validation models on the fire resistance of composite slab with steel deck,” *Congr. Numer. Methods Eng. – C. 2019*, no. ISBN: 978-989-54496-0-6, pp. 625–642, 2019.
- [28] C. M. B. M. V. Piloto, Paulo A. G.; Balsa, “Computational Modeling of the Thermal Effects on Composite Slabs Under Fire Conditions,” *Commun. Comput. Inf. Sci.*, pp. 497–511, 2021, doi: 10.1007/978-3-030-90241-4.38.
- [29] “EN 13501-2 Fire classification of construction products and building elements,” 2010.
- [30] J. Jiang, J. A. Main, J. M. Weigand, and F. H. Sadek, “Thermal performance of composite slabs with profiled steel decking exposed to fire effects,” *Fire Saf. J.*, vol. 95, no. May 2017, pp. 25–41, 2018, doi: 10.1016/j.firesaf.2017.10.003.
- [31] A. Cengel, Y. & Ghajar, “Heat and Mass Transfer, Fundamentals & Application, Fifth Edition in SI Units 496. isbn: 9780471457282,” *Fifth Ed. New York McGraw-Hill Educ.*, 2015.
- [32] “CEN - European Committee for Standardization, EN 1993-1-2: Design of steel structures - Part 1-2: General rules - Structural fire design. Brussels,” 2005.
- [33] “CEN - European Committee for Standardization, EN 1992-1-2: Design of concrete structures - Part 1-2: General rules - Structural fire design. Brussels,” 2004.
- [34] P. Vila Real, *Incêndio em estruturas metálicas: cálculo estrutural*, 1^a ed. Alfragide, 2003.
- [35] E. Fonseca and P. V. Real, *Análise não-linear do comportamento termo-mecânico de componentes em aço sujeitas ao fogo*. 1999.
- [36] P. Piloto, C. Balsa, L. Prates, and R. Rigobello, “The air gap effect on the fire resistance of composite slab with steel deck,” *Numer. Methods Eng. – C. 2019*, pp. 610–624, 2019.
- [37] The MathWorks, “MathWorks. Partial Differential Equation Toolbox User’s Guide;Heat Transfer Problem with Temperature-Dependent Properties;” Inc.: Natick, MA, USA, 2016., 2016.
- [38] M. W. Shampine, L.F.; Reichelt, “The MATLAB ODE Suite.,” *SIAM J. Sci. Comput.*, vol. 18, pp. 1–22, 1997.
- [39] C. Balsa, M. Silveira, V. Mange, and P. A. G. Piloto, “Modelling the Thermal Effects on Structural Components of Composite Slabs Under Fire Conditions,” *Computation*,

vol. 10, no. 6, pp. 1–21, 2022, doi: 10.3390/computation10060094.

- [40] T. Chai and R. R. Draxler, “Root mean square error (RMSE) or mean absolute error (MAE) – Arguments against avoiding RMSE in the literature,” *Geosci. Model Dev.*, vol. 7, no. 3, pp. 1247–1250, Jun. 2014, doi: 10.5194/gmd-7-1247-2014.

APPENDIX

ANNEX A – Data Sheet for trapezoidal geometry.

ANNEX B – Data Sheet for re-entrant geometry.

ANNEX C – Comparison proposed rules versus model predictions.

ANNEX D – Comparison EN-1994-1-2 rule versus proposed rules.

Appendix A

Annex A - Data Sheet for trapezoidal geometry.

Data Sheet for the simulations performed for the thermal simulations performed in the parametric study for trapezoidal geometry.

| DATA SHEET | | | |
|---|---|--|--|
| Model 1: Slab 1 – Polydeck 59 S – $h_1 = 50$ mm | | | |
| Model 1 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 1: Thermal Analysis with MATLAB - (2/2) | | | SIM. 1 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 43.18 t_{fi} , Ave: 46.36 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

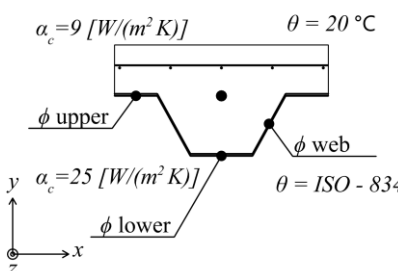
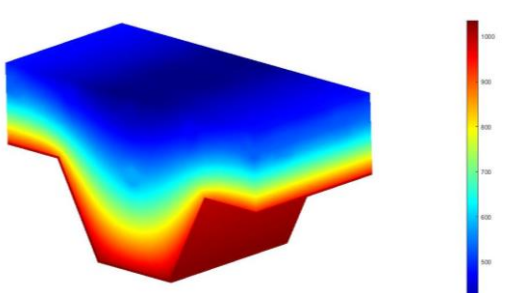
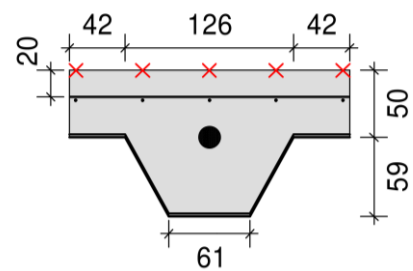
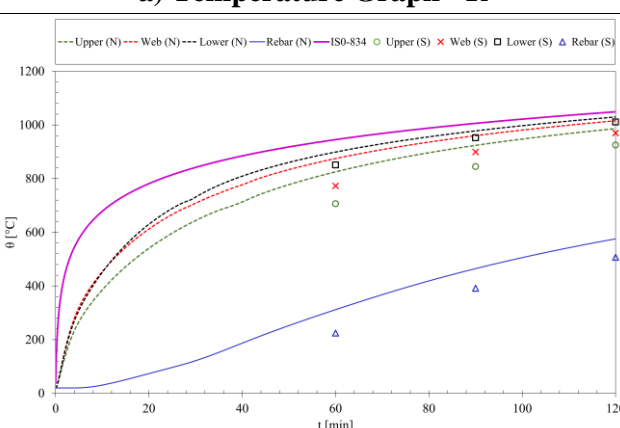
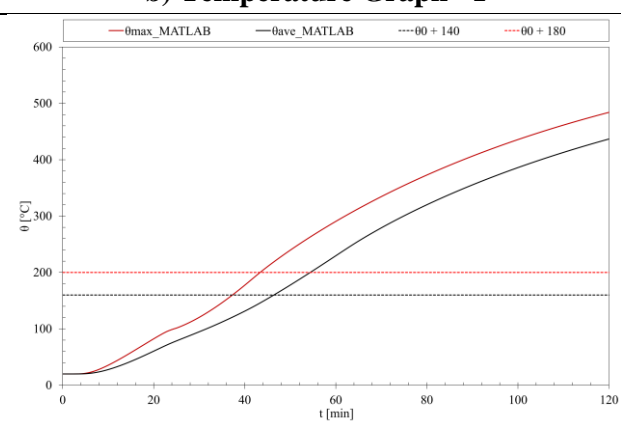
| DATA SHEET | | | |
|---|---|---|---|
| Model 1: Slab 1 – Polydeck 59 S – $h_1 = 50$ mm | | | |
| Model 1 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) /$h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1\varnothing16 Grade: S500 | Description: \varnothing5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 1: Thermal Analysis with MATLAB - (2/2) | | | SIM. 2 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}: 43.73$ $t_{fi, \text{Ave}}: 46.45$ |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 1: Slab 1 – Polydeck 59 S – $h_1 = 50$ mm | | | |
| Model 1 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 1: Thermal Analysis with MATLAB - (2/2) | | | SIM. 3 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 43.71 $t_{fi, \text{Ave}}$: 46.56 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 1: Slab 1 – Polydeck 59 S – $h_1 = 50$ mm | | | |
| Model 1 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 1: Thermal Analysis with MATLAB - (2/2) | | | SIM. 4 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
|  | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 43.03 t_{fi} , Ave: 46.71 |
|  | |  | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
|  | |  | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 2: Slab 1 – Polydeck 59 S – $h_1 = 70$ mm | | | |
| Model 2 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 2: Thermal Analysis with MATLAB - (2/2) | | | SIM. 5 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 73.10 t_{fi} , Ave: 71.35 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 2: Slab 1 – Polydeck 59 S – $h_1 = 70$ mm | | | |
| Model 2 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

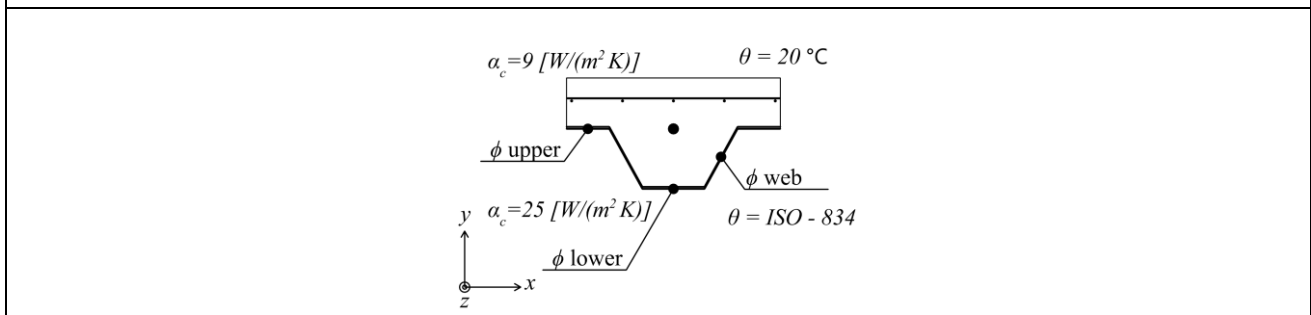
| Model 2: Thermal Analysis with MATLAB - (2/2) | | | SIM. 6 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 72.78 t_{fi} , Ave: 71.35 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 2: Slab 1 – Polydeck 59 S – $h_1 = 70$ mm | | | |
| Model 2 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) /$h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 2: Thermal Analysis with MATLAB - (2/2) **SIM. 7**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

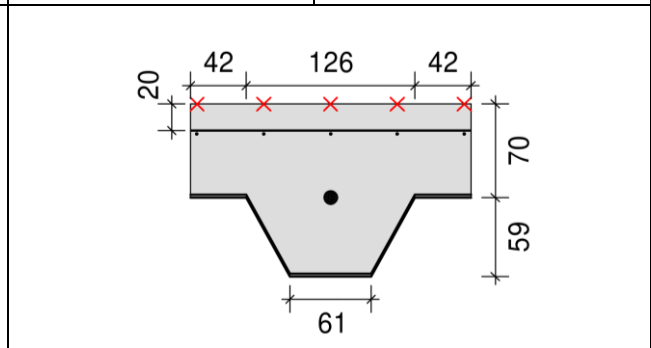
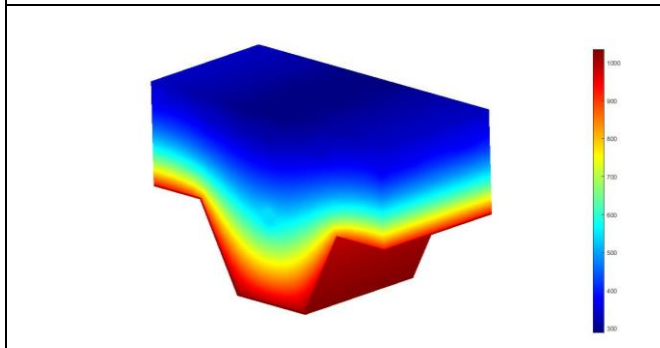
Boundary Conditions



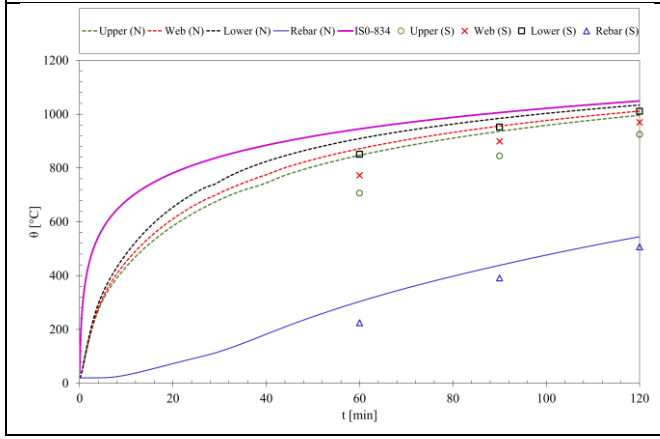
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

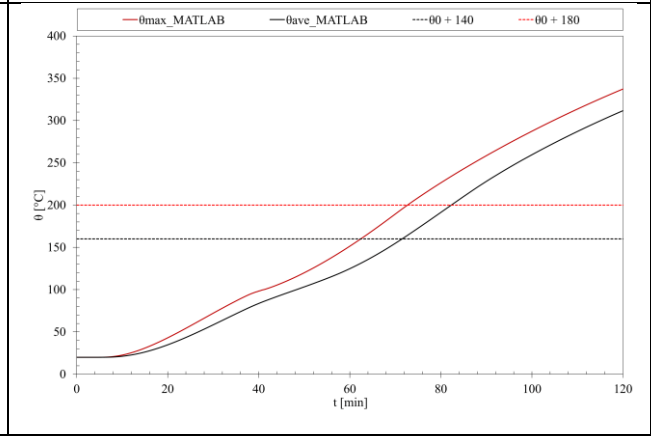
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: 72.90 $t_{fi, \text{Ave}}$: 71.65 |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 2: Slab 1 – Polydeck 59 S – $h_1 = 70$ mm | | | |
| Model 2 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 2: Thermal Analysis with MATLAB - (2/2) | | | SIM. 8 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 72.75 t_{fi} , Ave: 71.26 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 3: Slab 1 – Polydeck 59 S – $h_1 = 90$ mm | | | |
| Model 3 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 3: Thermal Analysis with MATLAB - (2/2) | | | SIM. 9 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 109.53 t_{fi} , Ave: 101.06 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|---|
| Model 3: Slab 1 – Polydeck 59 S – $h_1 = 90$ mm | | | |
| Model 3 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1 \varnothing 16 Grade: S500 | Description: \varnothing 5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

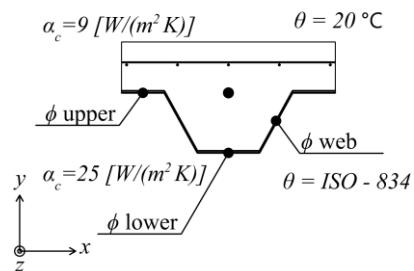
| Model 3: Thermal Analysis with MATLAB - (2/2) | | | SIM. 10 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 109.03 t_{fi} , Ave: 101.01 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 3: Slab 1 – Polydeck 59 S – $h_1 = 90$ mm | | | |
| Model 3 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 3: Thermal Analysis with MATLAB - (2/2) **SIM. 11**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

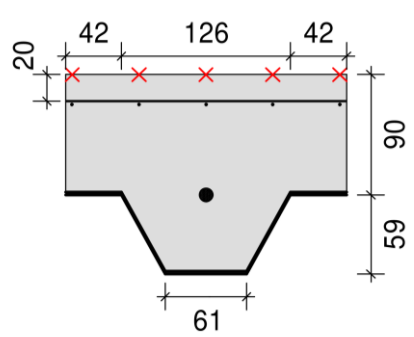
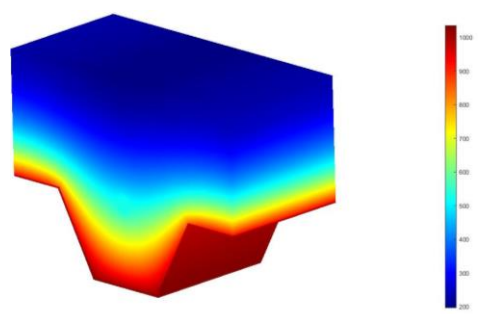
Boundary Conditions



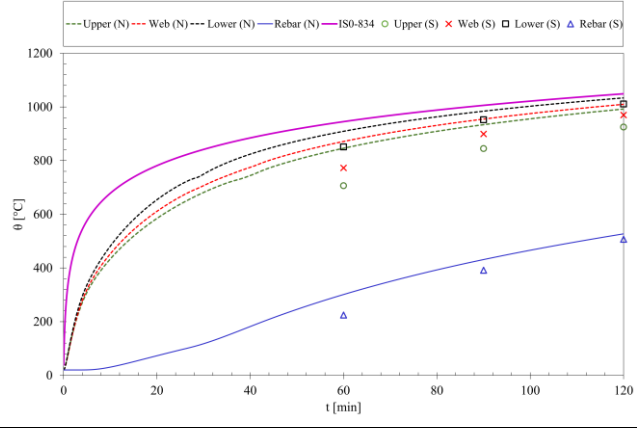
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

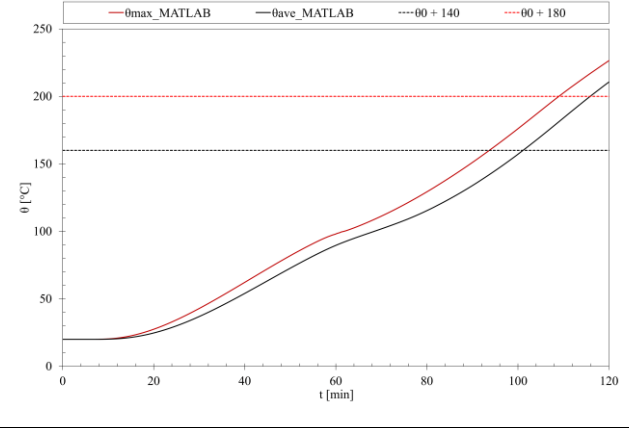
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 109.01 t_{fi} , Ave: 101.25 |



a) Temperature Graph - R



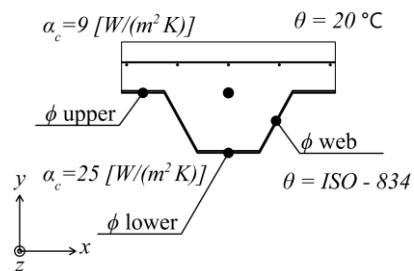
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 4: Slab 1 – Polydeck 59 S – $h_1 = 90$ mm | | | |
| Model 4 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

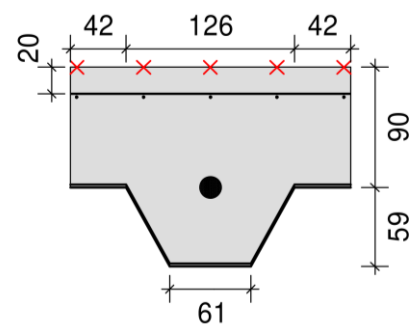
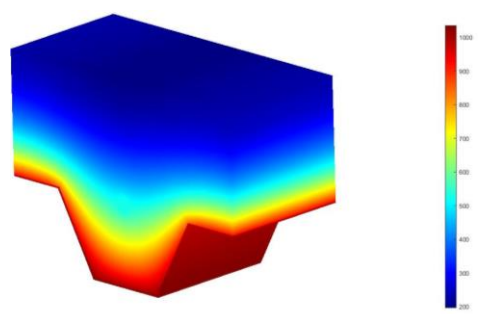
Boundary Conditions



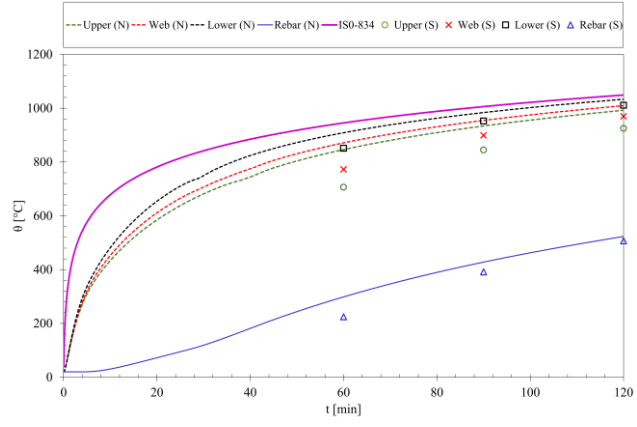
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

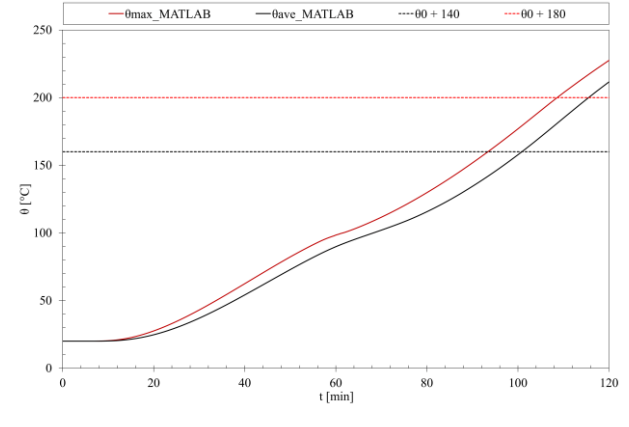
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 108.75 t_{fi} , Ave: 100.85 |



a) Temperature Graph - R



b) Temperature Graph - I



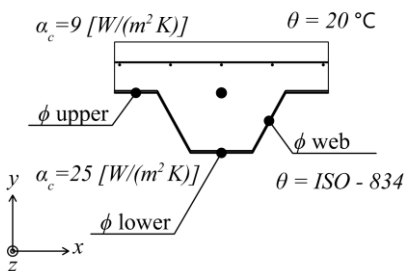
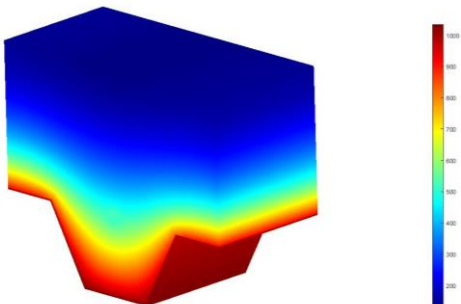
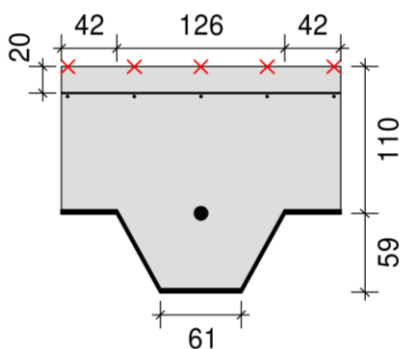
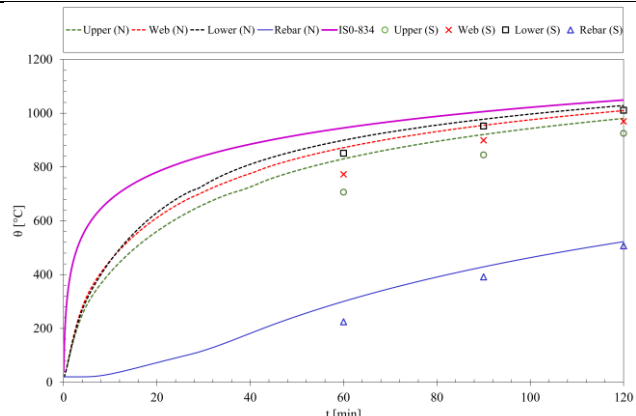
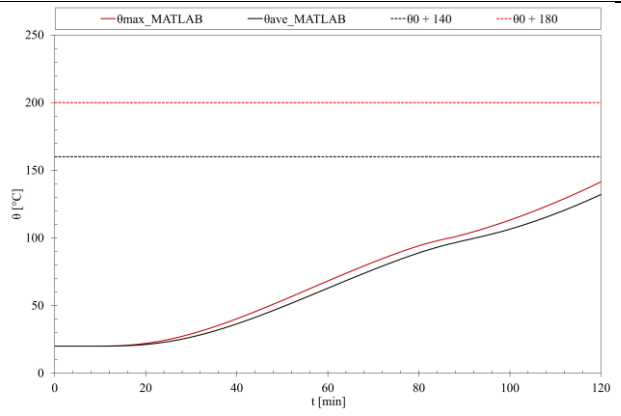
| DATA SHEET | | | |
|---|---|--|--|
| Model 4: Slab 1 – Polydeck 59 S – $h_1 = 110$ mm | | | |
| Model 4 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 4: Thermal Analysis with MATLAB - (2/2) | | | SIM. 13 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 4: Slab 1 – Polydeck 59 S – $h_1 = 110$ mm | | | |
| Model 4 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 4: Thermal Analysis with MATLAB - (2/2) | | | SIM. 14 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

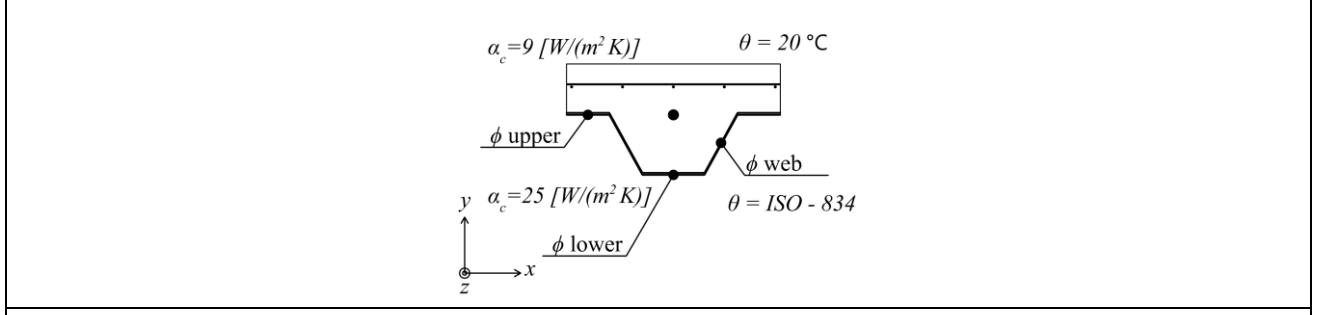
| DATA SHEET | | | |
|---|---|--|--|
| Model 4: Slab 1 – Polydeck 59 S – $h_1 = 110$ mm | | | |
| Model 4 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 4: Thermal Analysis with MATLAB - (2/2) | | | SIM. 15 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
|  | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
|  | |  | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
|  | |  | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 4: Slab 1 – Polydeck 59 S – $h_1 = 110$ mm | | | |
| Model 4 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

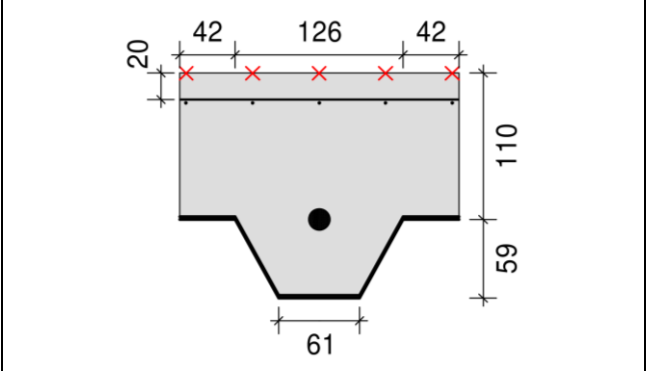
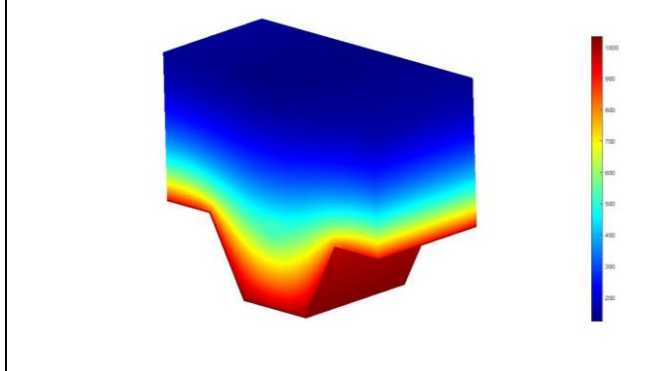
Boundary Conditions



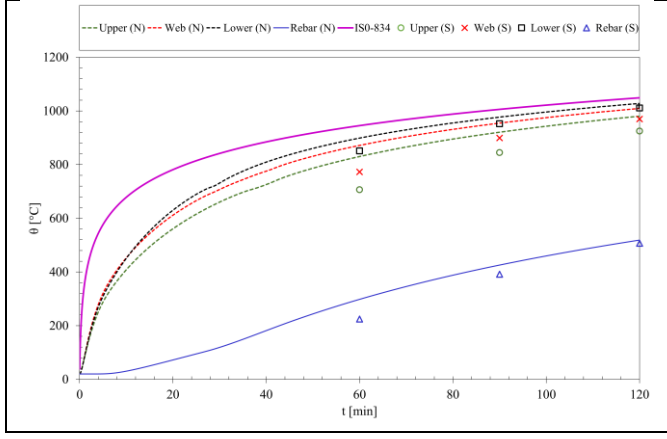
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

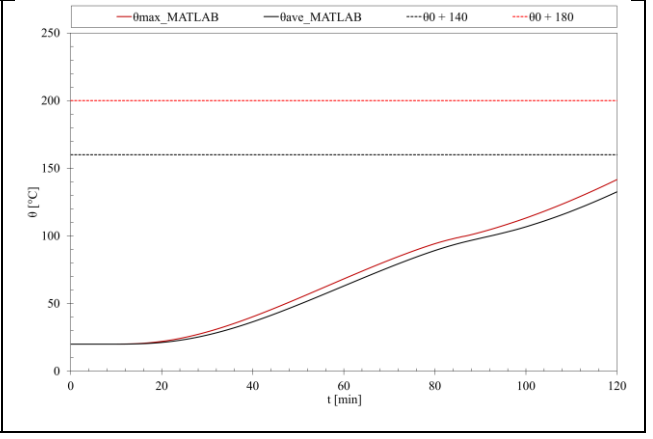
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



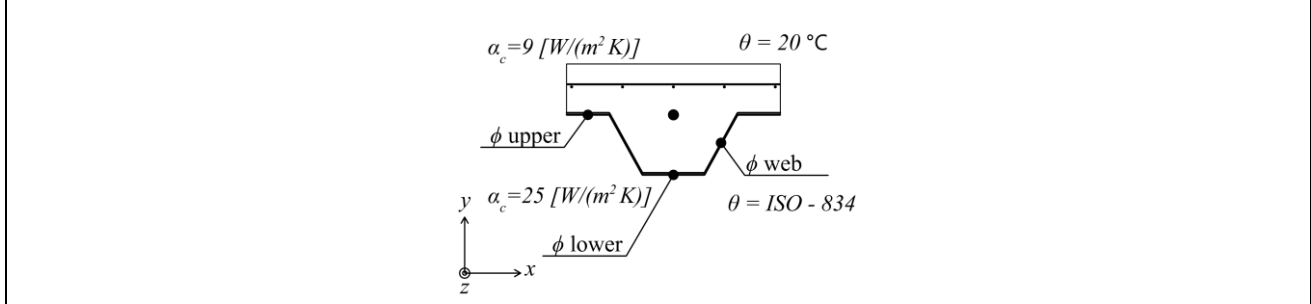
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 5: Slab 1 – Polydeck 59 S – $h_1 = 125$ mm | | | |
| Model 5 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 834 Unexposed Surface: 20°C |

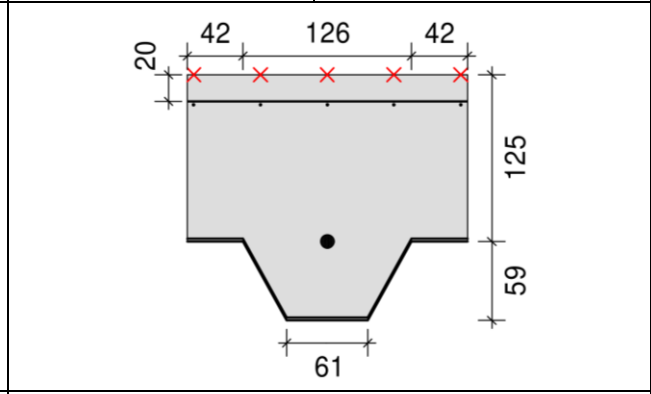
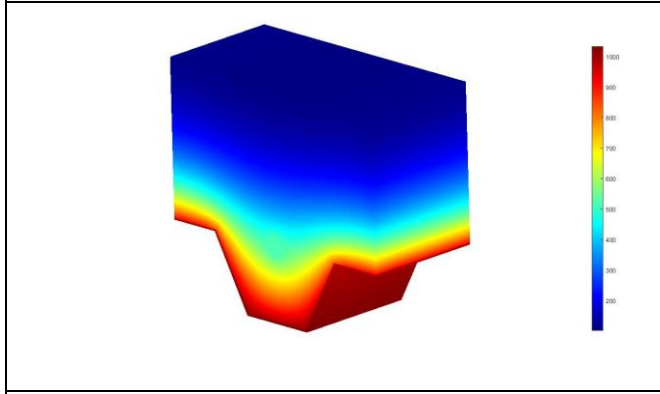
Boundary Conditions



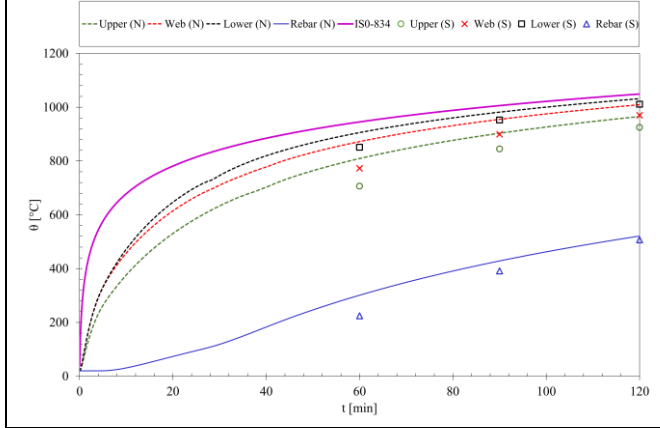
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

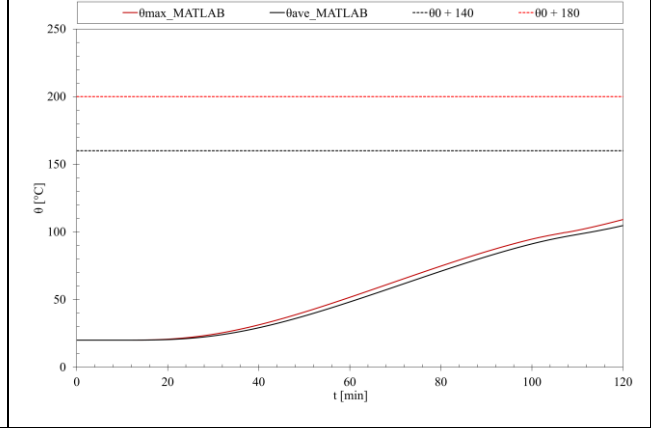
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



b) Temperature Graph - I



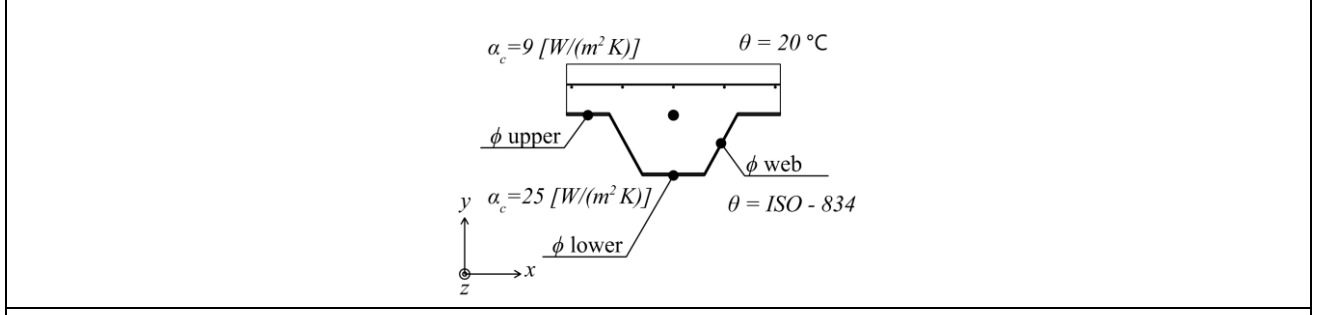
| DATA SHEET | | | |
|---|---|--|--|
| Model 5: Slab 1 – Polydeck 59 S – $h_1 = 125$ mm | | | |
| Model 5 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 5: Thermal Analysis with MATLAB - (2/2) | | | SIM. 18 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 5: Slab 1 – Polydeck 59 S – $h_1 = 125$ mm | | | |
| Model 5 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

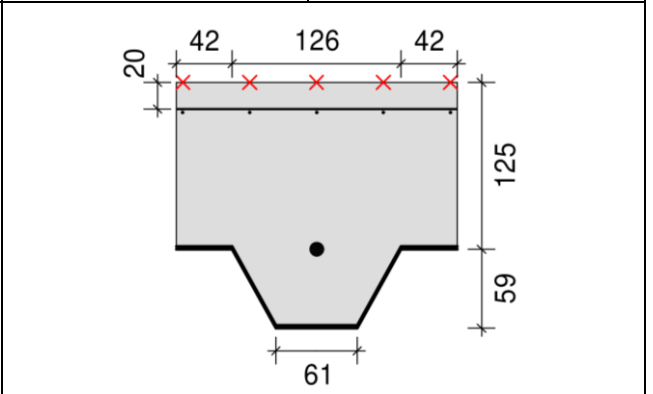
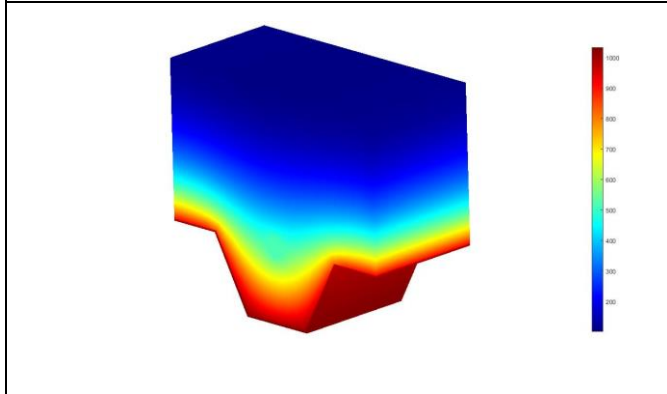
Boundary Conditions



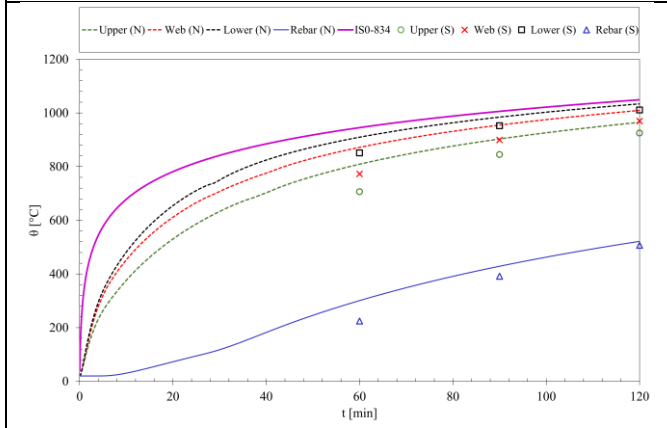
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

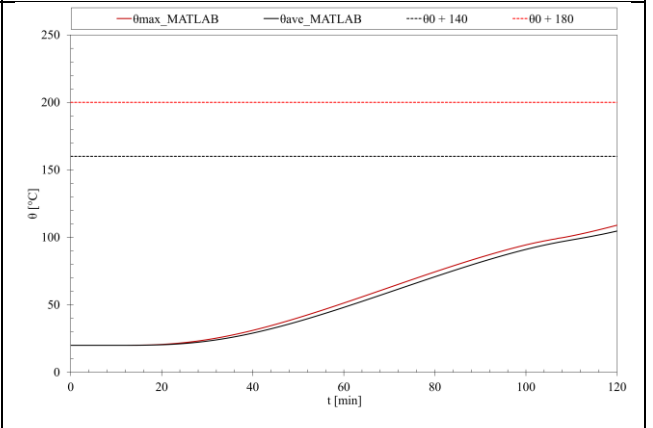
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 5: Slab 1 – Polydeck 59 S – $h_1 = 125$ mm | | | |
| Model 5 - Basic Data (1/2) | | | |
| Experimental type | Title: Polydeck 59S (BRA) / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 5: Thermal Analysis with MATLAB - (2/2) | | | SIM. 20 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 6: Slab 2 – Cofraplus 60 – $h_1 = 50$ mm | | | |
| Model 6 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 6: Thermal Analysis with MATLAB - (2/2) | | | SIM. 21 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 43.03 t_{fi} , Ave: 41.48 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 6: Slab 2 – Cofraplus 60 – $h_1 = 50$ mm | | | |
| Model 6 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 6: Thermal Analysis with MATLAB - (2/2) | | | SIM. 22 |
|--|---|--|--|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: 41.63 t_{fi}, Ave: 43.06 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

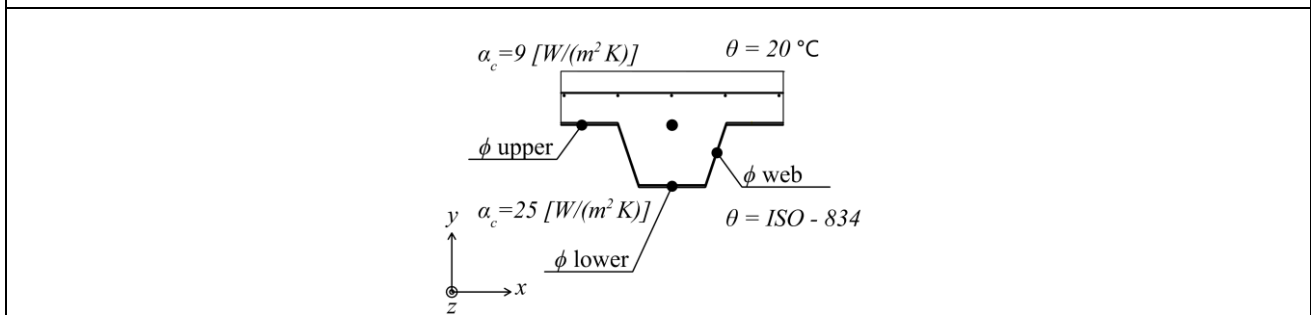
| DATA SHEET | | | |
|---|---|--|--|
| Model 6: Slab 2 – Cofraplus 60 – $h_1 = 50$ mm | | | |
| Model 6 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 6: Thermal Analysis with MATLAB - (2/2) | | | SIM. 23 |
|--|---|---|--|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.75 Web: 0.64 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: 42.18 t_{fi}, Ave: 43.46 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 6: Slab 2 – Cofraplus 60 – $h_1 = 50$ mm | | | |
| Model 6 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

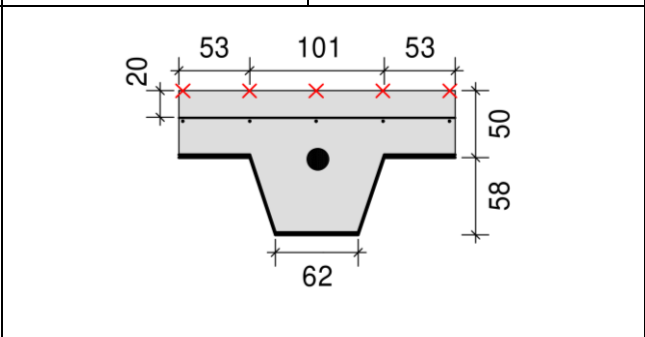
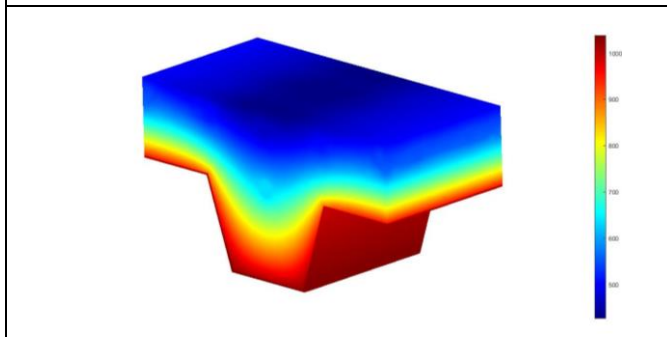
Boundary Conditions



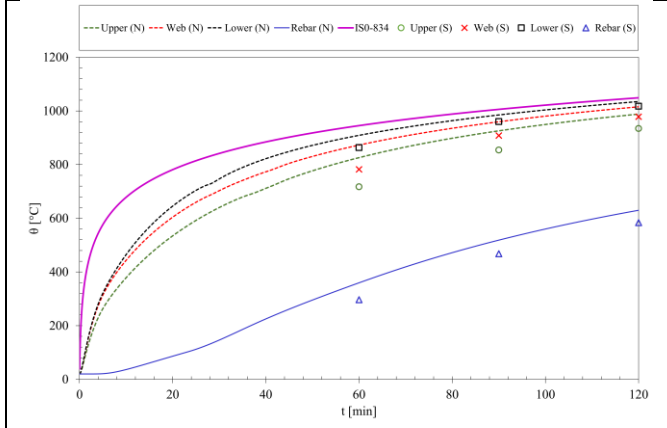
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

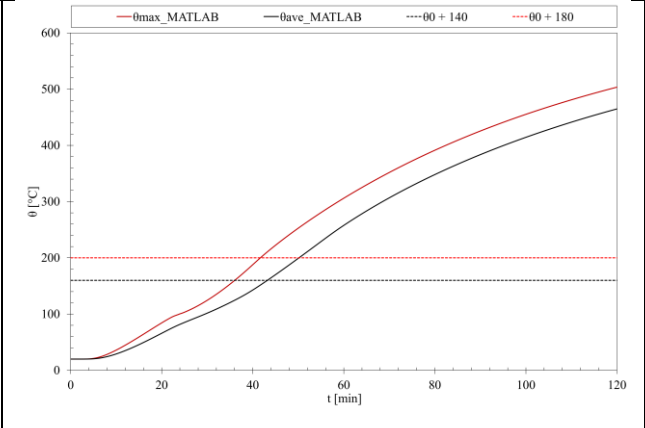
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 41.95 t_{fi} , Ave: 43.48 |



a) Temperature Graph - R



b) Temperature Graph - I



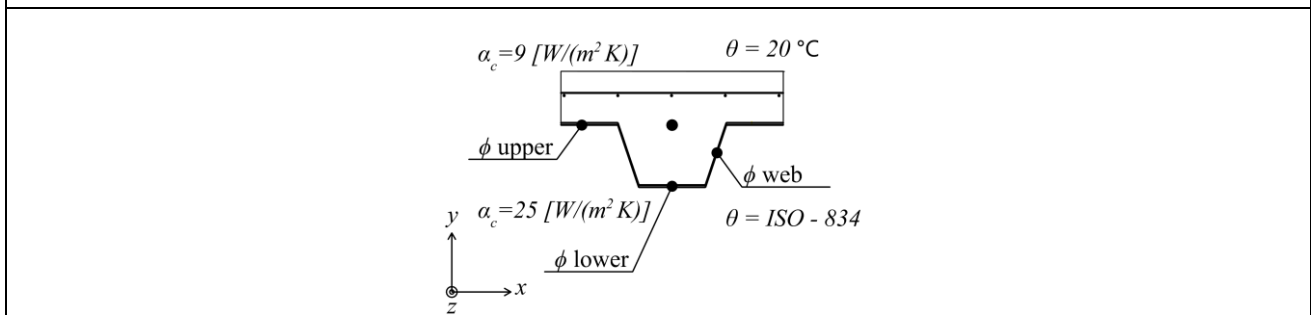
| DATA SHEET | | | |
|---|---|--|--|
| Model 7: Slab 2 – Cofraplus 60 – $h_1 = 70$ mm | | | |
| Model 7 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 7: Thermal Analysis with MATLAB - (2/2) | | | SIM. 25 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 69.18 t_{fi} , Ave: 66.68 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 7: Slab 2 – Cofraplus 60 – $h_1 = 70$ mm | | | |
| Model 7 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

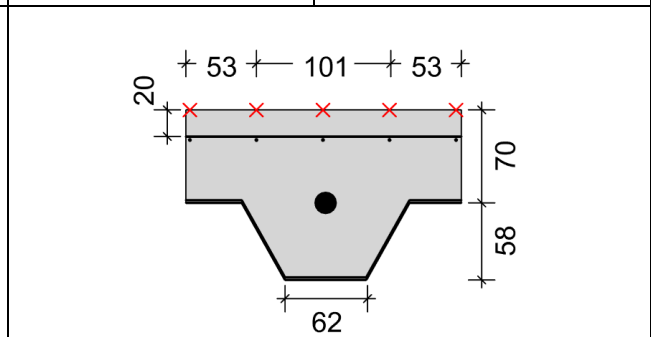
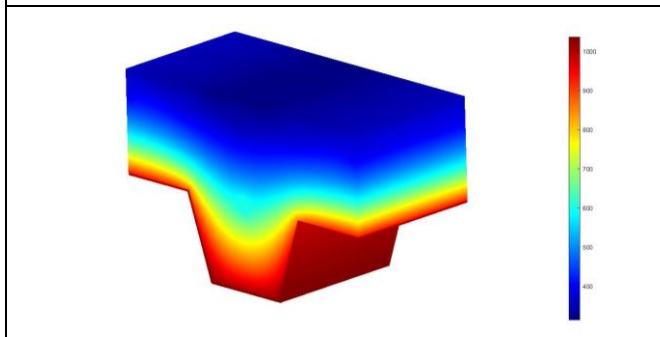
Boundary Conditions



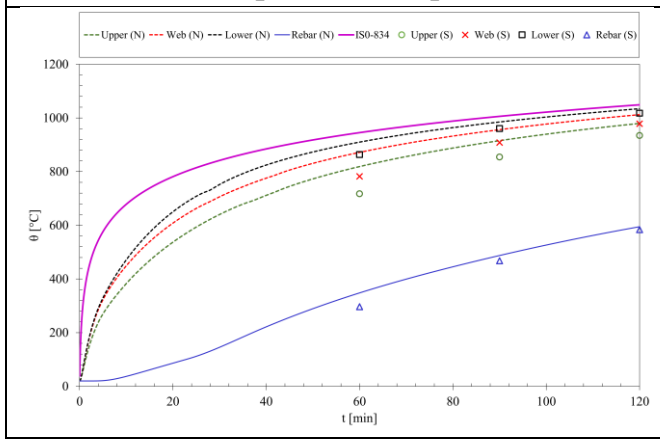
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

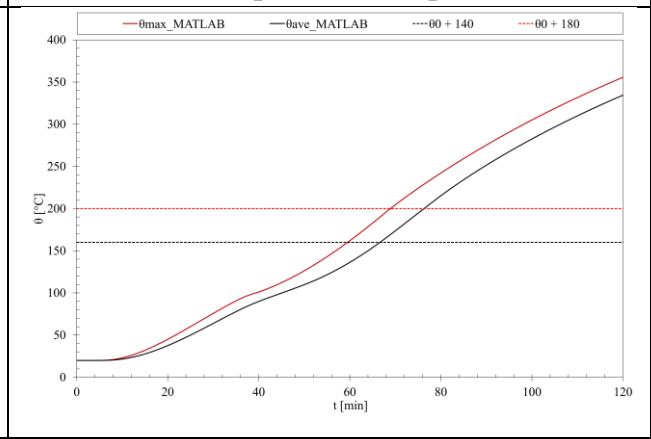
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}: 69.15$ $t_{fi, \text{Ave}}: 66.73$ |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 7: Slab 2 – Cofraplus 60 – $h_1 = 70$ mm | | | |
| Model 7 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 7: Thermal Analysis with MATLAB - (2/2) | | | SIM. 27 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 69.20 t_{fi} , Ave: 67.03 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 7: Slab 2 – Cofraplus 60 – $h_1 = 70$ mm | | | |
| Model 7 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 7: Thermal Analysis with MATLAB - (2/2) | | | SIM. 28 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] $t_{fi, \text{Max}}: 69.21$ $t_{fi, \text{Ave}}: 66.68$ | |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 8: Slab 2 – Cofraplus 60 – $h_1 = 90$ mm | | | |
| Model 8 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 8: Thermal Analysis with MATLAB - (2/2) | | | SIM. 29 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 103.10 $t_{fi, \text{Ave}}$: 95.20 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

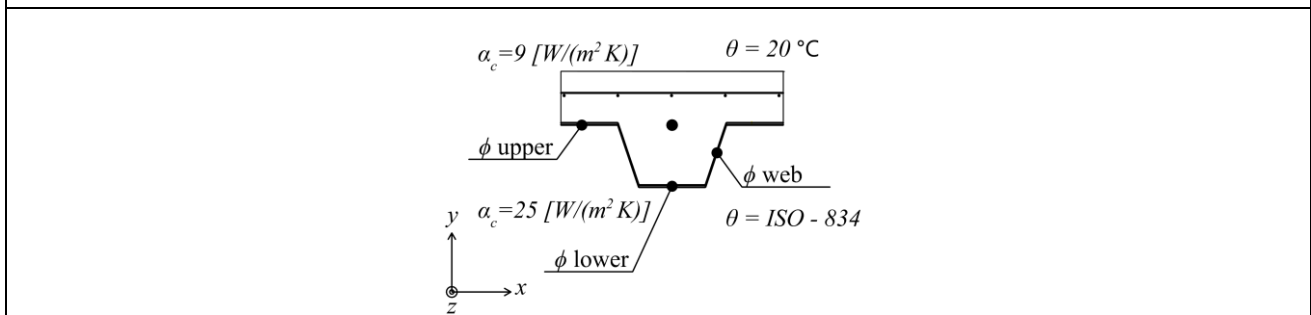
| DATA SHEET | | | |
|---|---|--|--|
| Model 8: Slab 2 – Cofraplus 60 – $h_1 = 90$ mm | | | |
| Model 8 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 8: Thermal Analysis with MATLAB - (2/2) | | | SIM. 30 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 103.10 t_{fi} , Ave: 95.08 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 8: Slab 2 – Cofraplus 60 – $h_1 = 90$ mm | | | |
| Model 8 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

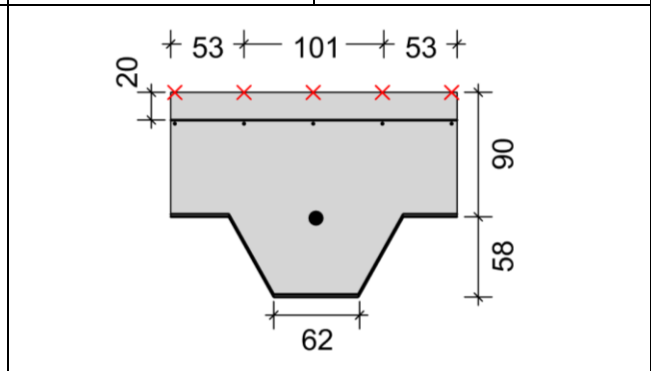
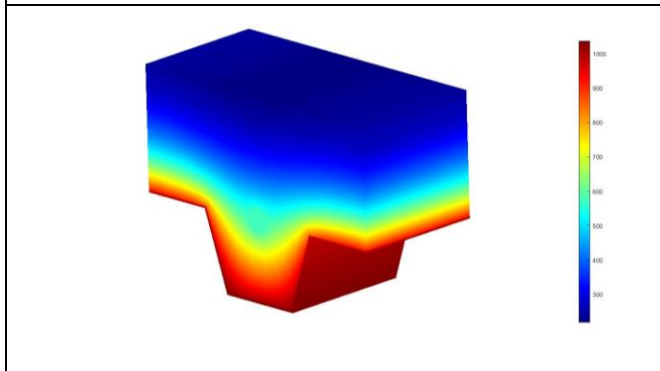
Boundary Conditions



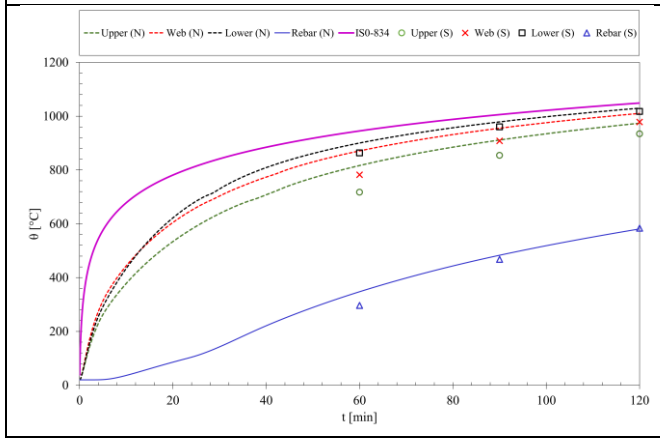
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

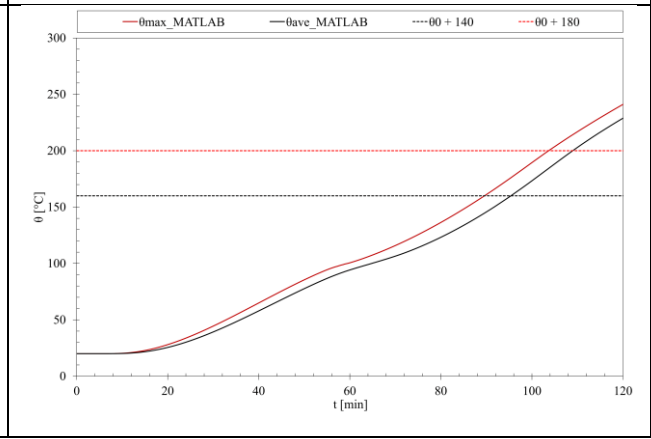
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 95.33 t_{fi} , Ave: 103.60 |



a) Temperature Graph - R



b) Temperature Graph - I

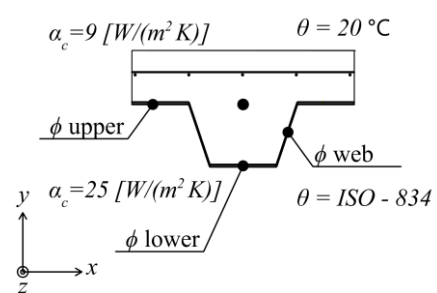


| DATA SHEET | | | |
|---|---|--|--|
| Model 8: Slab 2 – Cofraplus 60 – $h_1 = 90$ mm | | | |
| Model 8 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 8: Thermal Analysis with MATLAB - (2/2) **SIM. 32**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

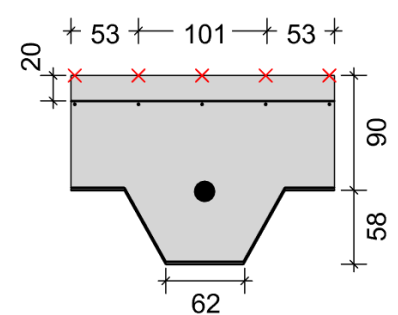
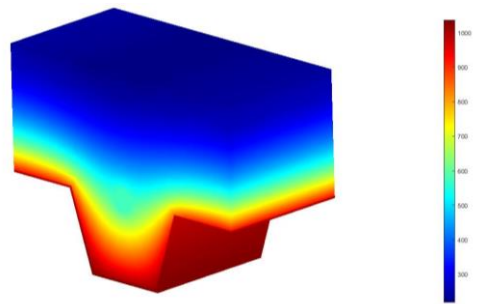
Boundary Conditions



Additional Information

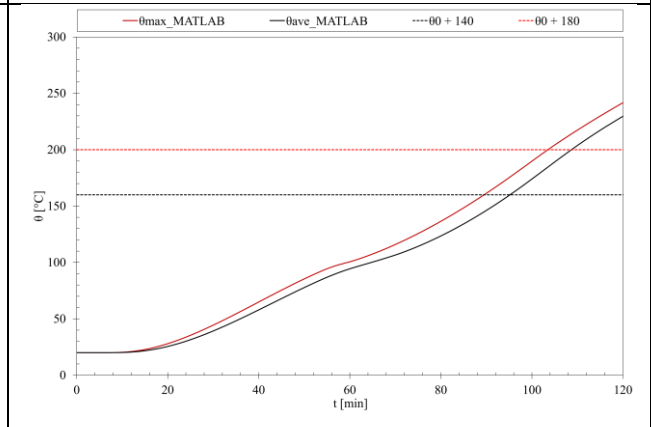
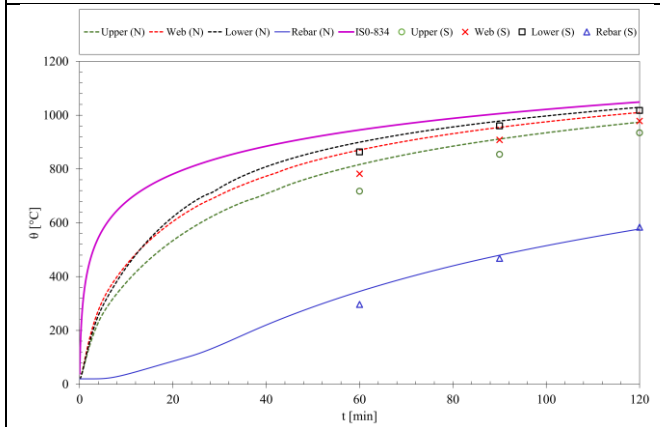
N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: 103.36 $t_{fi, \text{Ave}}$: 94.98 |



a) Temperature Graph - R

b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 9: Slab 2 – Cofraplus 60 – $h_1 = 110$ mm | | | |
| Model 9 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 9: Thermal Analysis with MATLAB - (2/2) | | | SIM. 33 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 9: Slab 2 – Cofraplus 60 – $h_1 = 110$ mm | | | |
| Model 9 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 9: Thermal Analysis with MATLAB - (2/2) | | | SIM. 34 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

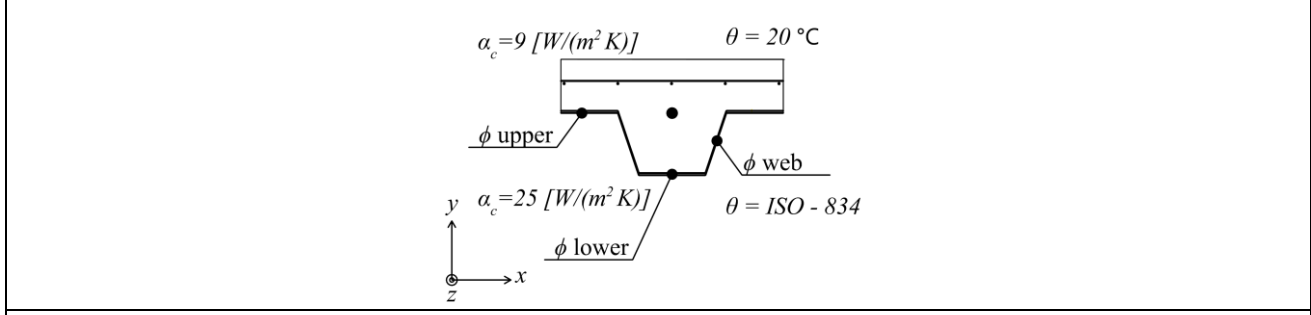
| DATA SHEET | | | |
|---|---|--|--|
| Model 9: Slab 2 – Cofraplus 60 – $h_1 = 110$ mm | | | |
| Model 9 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 9: Thermal Analysis with MATLAB - (2/2) | | | SIM. 35 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 9: Slab 2 – Cofraplus 60 – $h_1 = 110$ mm | | | |
| Model 9 - Basic Data (1/2) | | | |
| Experimental type | Title Cofraplus 60 / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

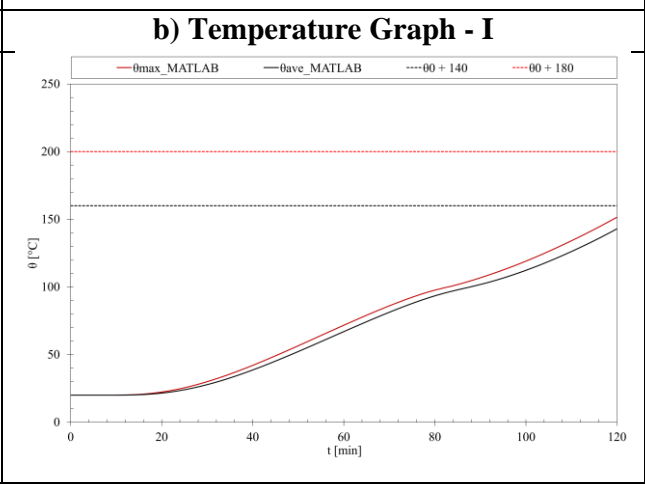
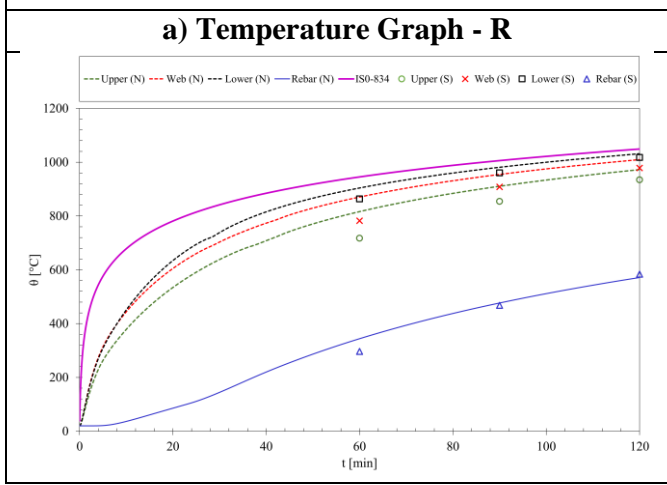
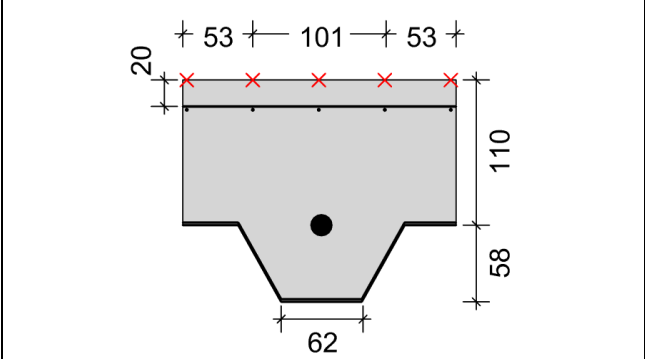
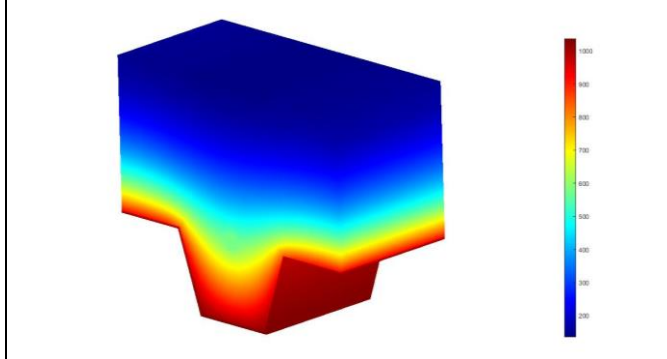
Boundary Conditions



Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

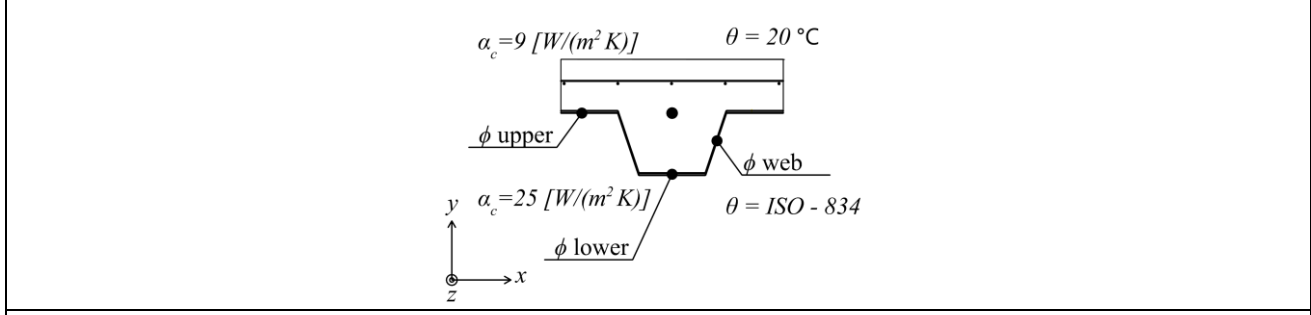
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



| DATA SHEET | | | |
|---|---|--|--|
| Model 10: Slab 2 – Cofraplus 60 – $h_1 = 125$ mm | | | |
| Model 10 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 = 125 mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

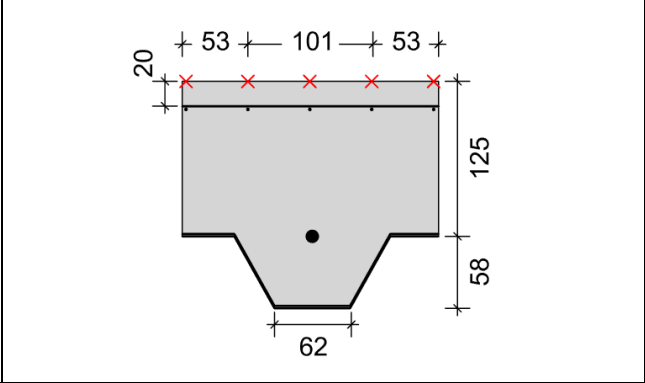
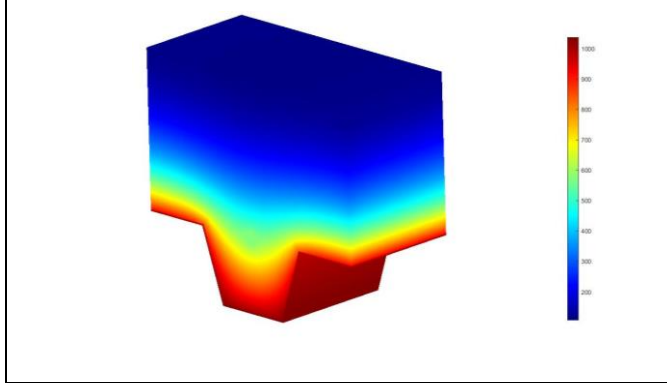
Boundary Conditions



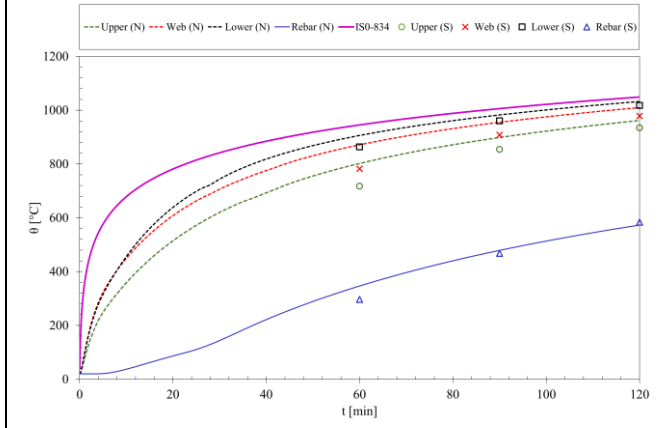
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

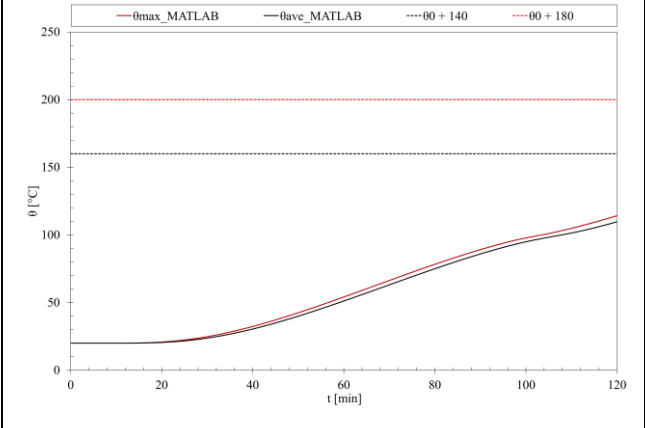
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



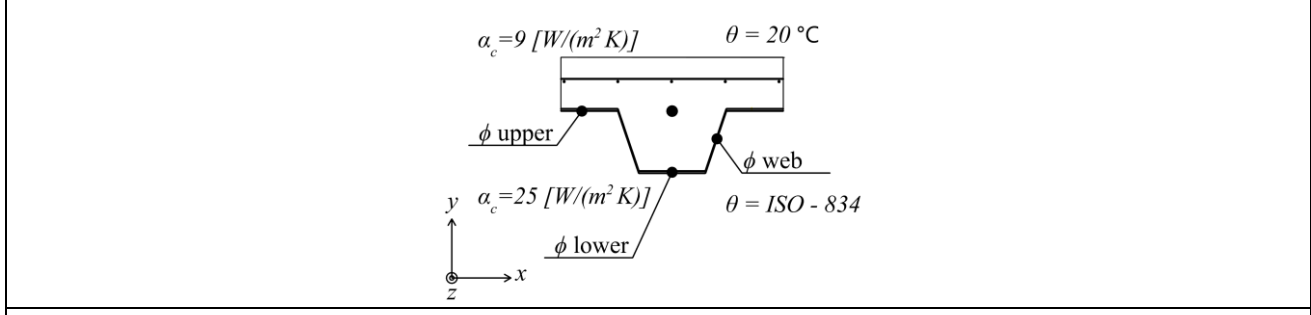
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 10: Slab 2 – Cofraplus 60 – $h_1 = 125$ mm | | | |
| Model 10 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

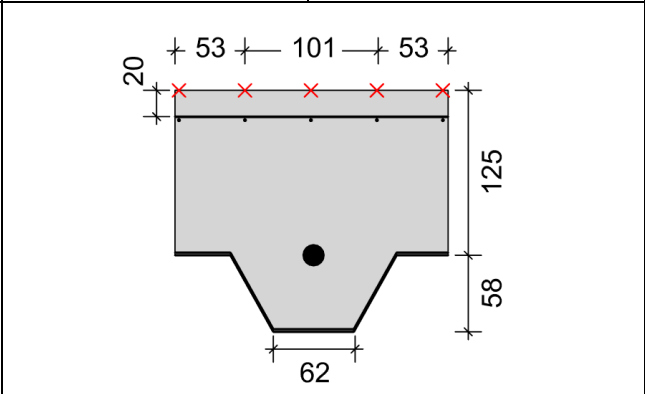
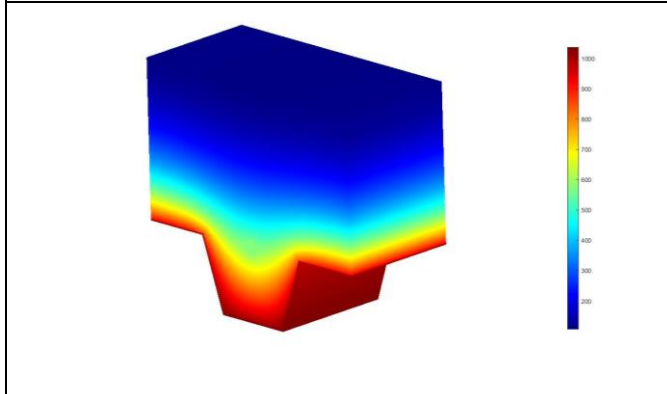
Boundary Conditions



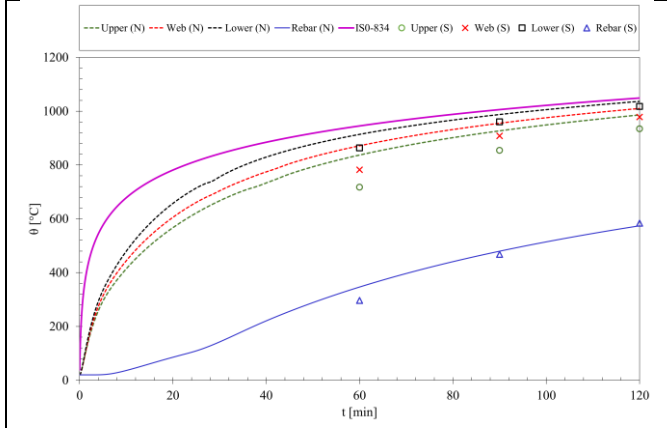
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

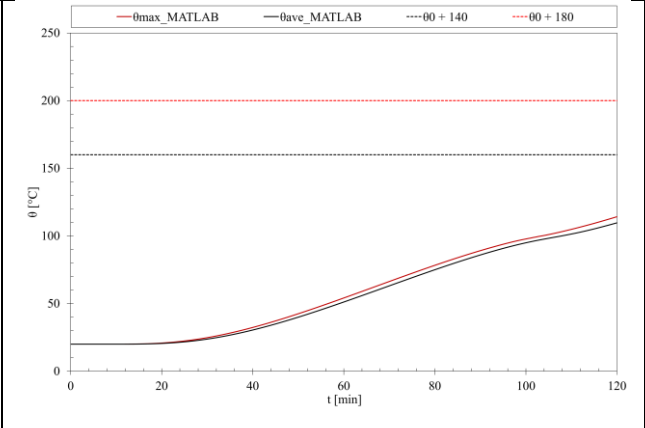
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |



a) Temperature Graph - R



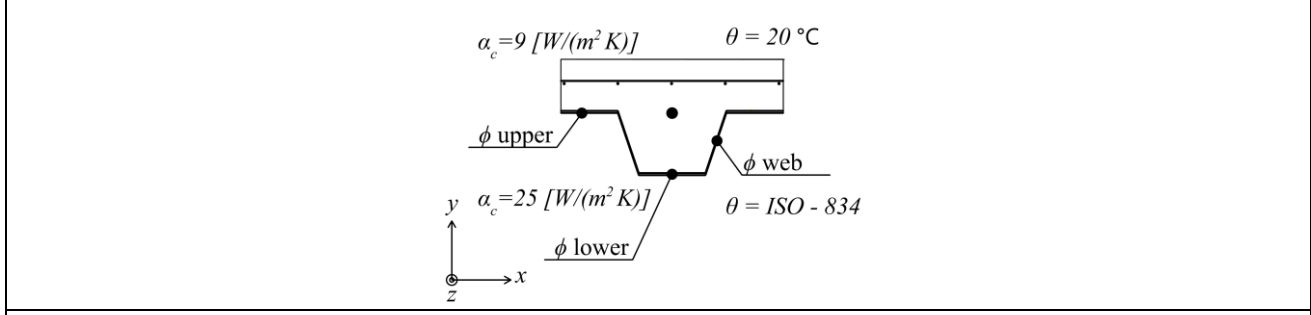
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 10: Slab 2 – Cofraplus 60 – $h_1 = 125$ mm | | | |
| Model 10 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

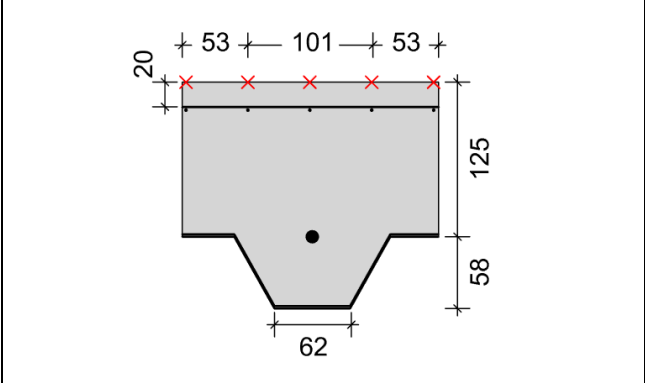
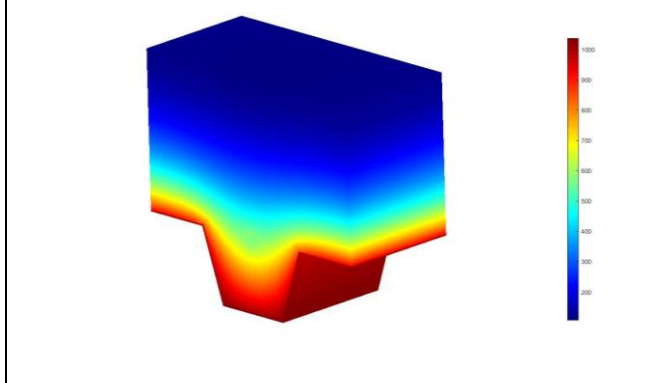
Boundary Conditions



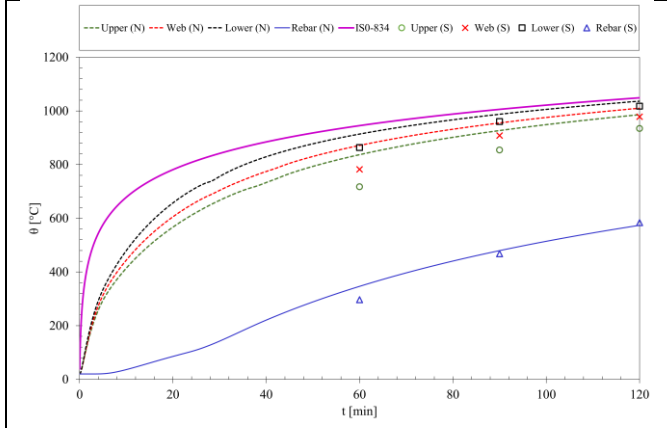
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

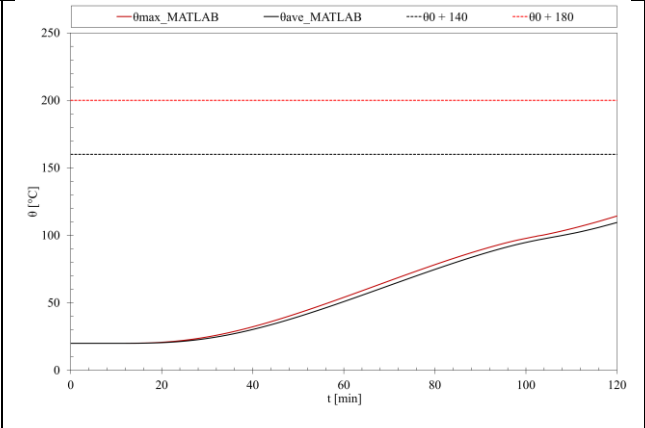
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 10: Slab 2 – Cofraplus 60 – $h_1 = 125$ mm | | | |
| Model 10 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Trapezoidal Thickness: 1.25 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 10: Thermal Analysis with MATLAB - (2/2) | | | SIM. 40 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.73 Web: 0.56 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

Appendix B

Annex B - Data Sheet for re-entrant geometry.

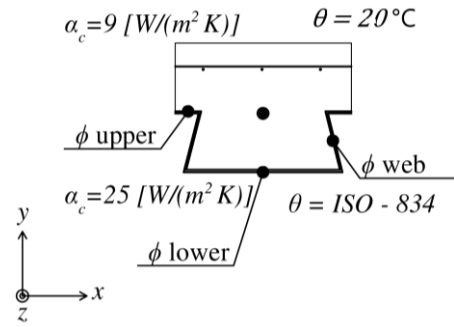
Data Sheet for the simulations performed for the thermal simulations performed in the parametric study for re-entrant geometry.

| DATA SHEET | | | |
|--|---|--|--|
| Model 11: Slab 3 – Multideck – $h_1 = 60$ mm | | | |
| Model 11 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 11: Thermal Analysis with MATLAB - (2/2) **SIM. 41**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

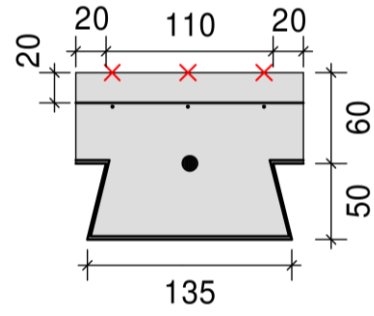
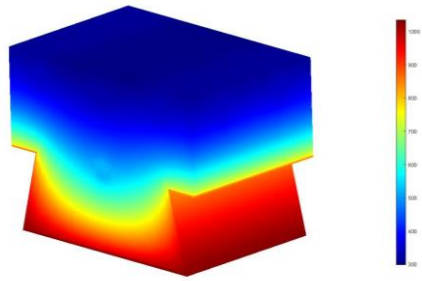
Boundary Conditions



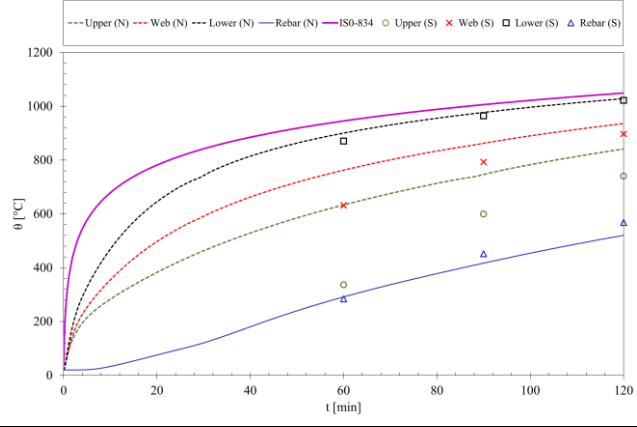
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

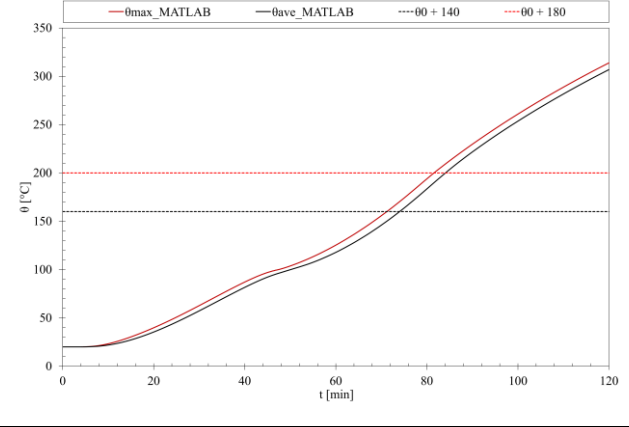
| Steel Deck Components | Isolation Criterion (I) | |
|--|------------------------------|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] | t_{fi}, Max: 81.75 t_{fi}, Ave: 74.06 |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|--|---|--|--|
| Model 11: Slab 3 – Multideck – $h_1 = 60$ mm | | | |
| Model 11 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 11: Thermal Analysis with MATLAB - (2/2) | | | SIM. 42 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 81.43 $t_{fi, \text{Ave}}$: 73.50 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

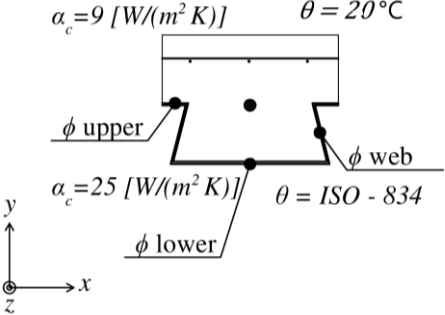
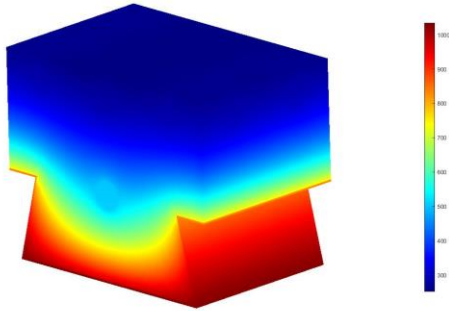
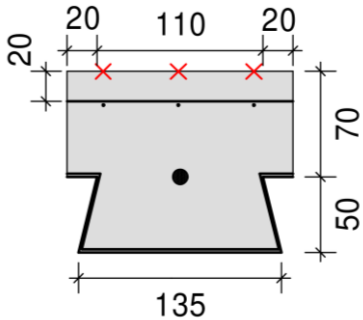
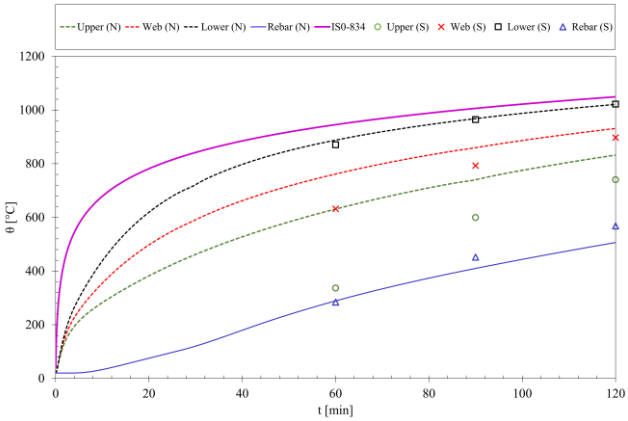
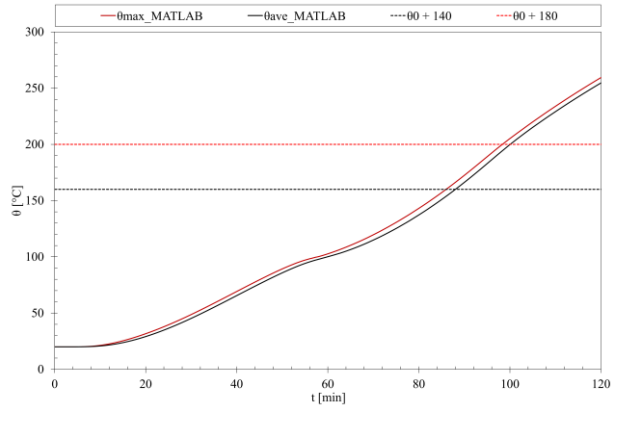
| DATA SHEET | | | |
|--|---|--|--|
| Model 11: Slab 3 – Multideck – $h_1 = 60$ mm | | | |
| Model 11 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 11: Thermal Analysis with MATLAB - (2/2) | | | SIM. 43 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 81.35 $t_{fi, \text{Ave}}$: 73.73 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|--|---|--|--|
| Model 11: Slab 3 – Multideck – $h_1 = 60$ mm | | | |
| Model 11 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 11: Thermal Analysis with MATLAB - (2/2) | | | SIM. 44 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 80.73 t_{fi} , Ave: 73.40 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

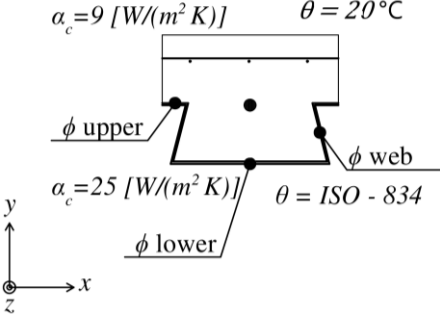
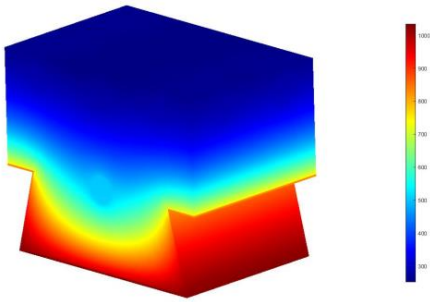
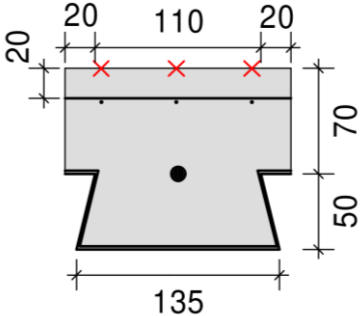
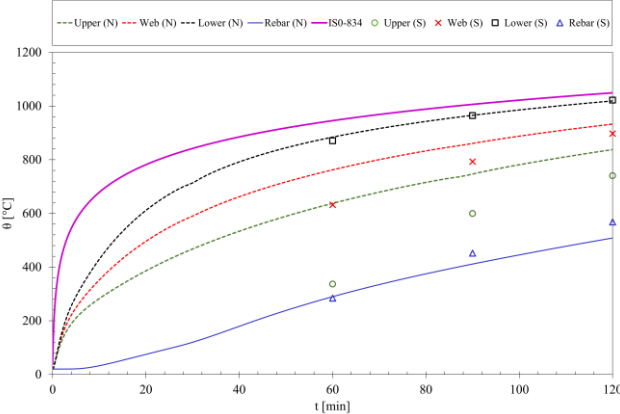
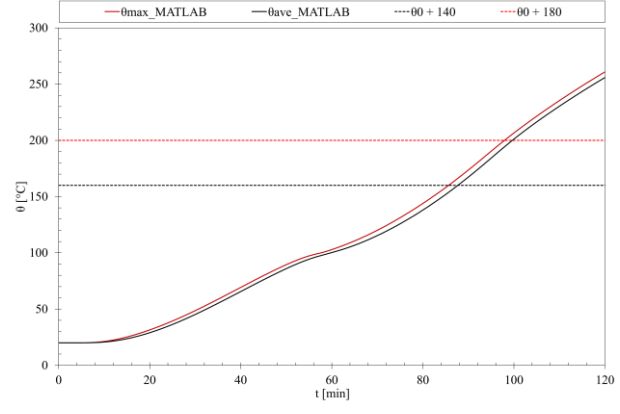
| DATA SHEET | | | |
|--|---|--|---|
| Model 12: Slab 3 – Multideck – $h_1 = 70$ mm | | | |
| Model 12 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1 \varnothing 10 Grade: S500 | Description: \varnothing 5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 12: Thermal Analysis with MATLAB - (2/2) | | | SIM. 45 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
|  | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 98.23 t_{fi} , Ave: 88.05 |
|  | |  | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
|  | |  | |

| DATA SHEET | | | |
|--|---|--|--|
| Model 12: Slab 3 – Multideck – $h_1 = 70$ mm | | | |
| Model 12 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 12: Thermal Analysis with MATLAB - (2/2) | | | SIM. 46 |
|--|---|--|--|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: 97.90 t_{fi}, Ave: 87.30 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

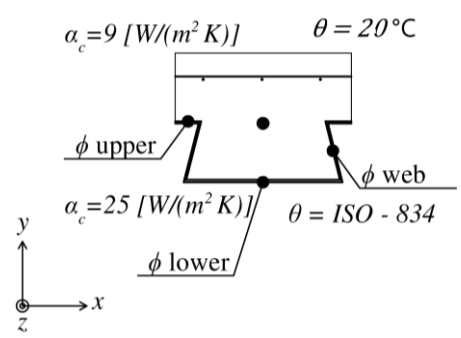
| DATA SHEET | | | |
|--|---|--|--|
| Model 12: Slab 3 – Multideck – $h_1 = 70$ mm | | | |
| Model 12 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 12: Thermal Analysis with MATLAB - (2/2) | | | SIM. 47 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
|  | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 98.15 $t_{fi, \text{Ave}}$: 87.78 |
|  | |  | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
|  | |  | |

| DATA SHEET | | | |
|--|---|--|--|
| Model 12: Slab 3 – Multideck – $h_1 = 70$ mm | | | |
| Model 12 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 mm Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

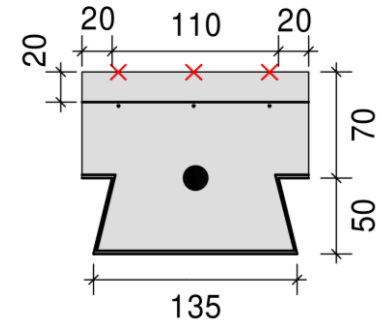
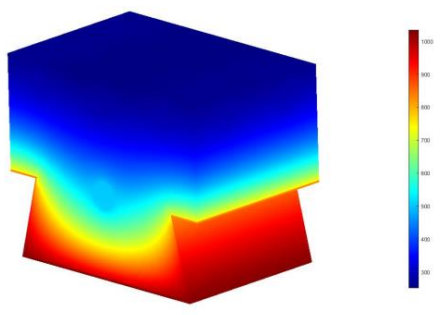
Boundary Conditions



Additional Information

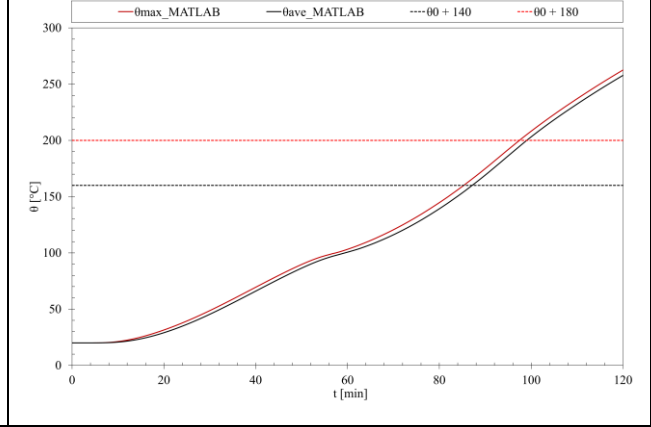
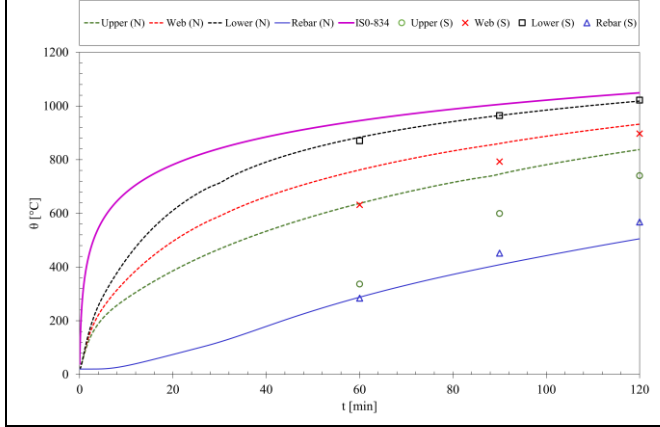
N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: 97.50 $t_{fi, \text{Ave}}$: 86.88 |



a) Temperature Graph - R

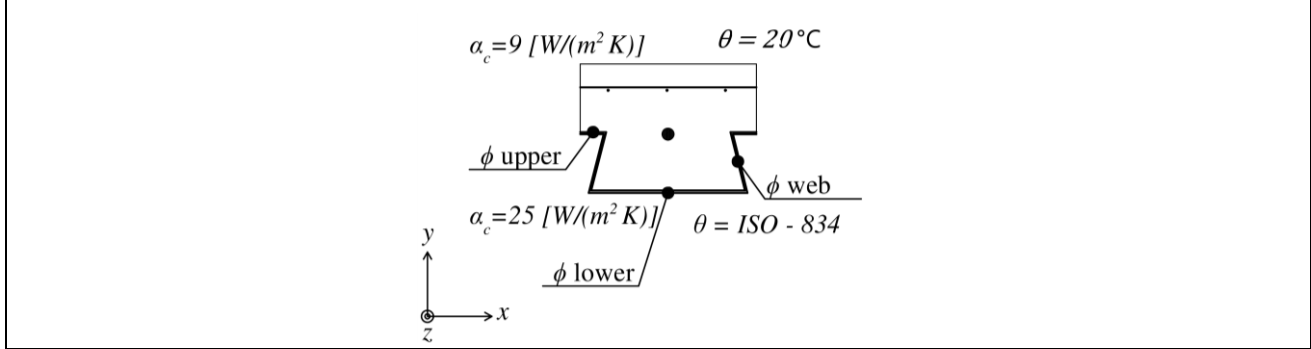
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 13: Slab 3 – Multideck – $h_1 = 90$ mm | | | |
| Model 13 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

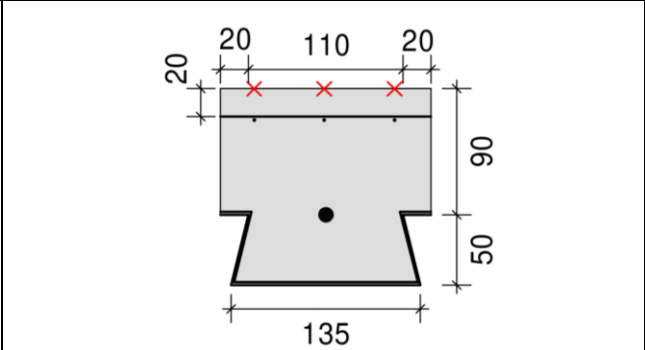
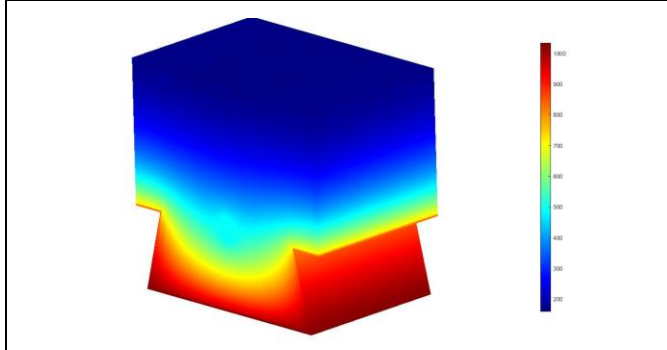
Boundary Conditions



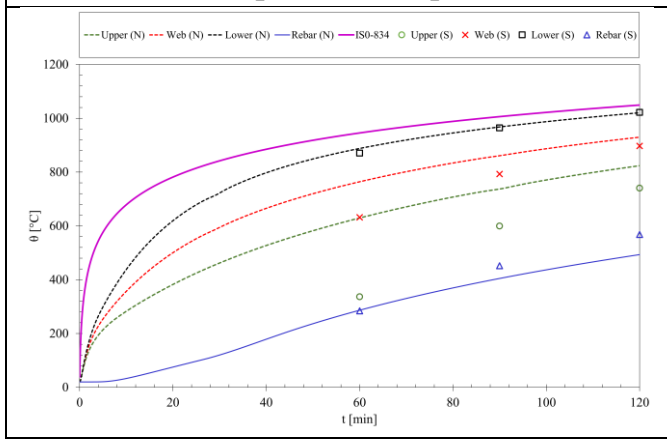
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

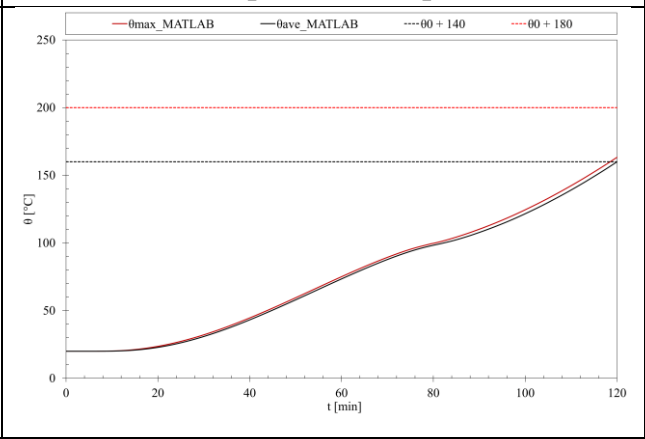
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 119.38 t_{fi} , Ave: - |



a) Temperature Graph - R



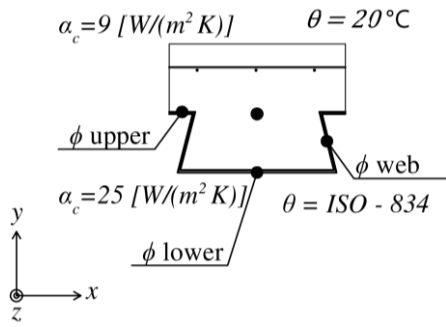
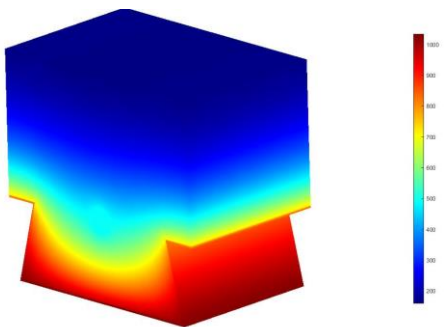
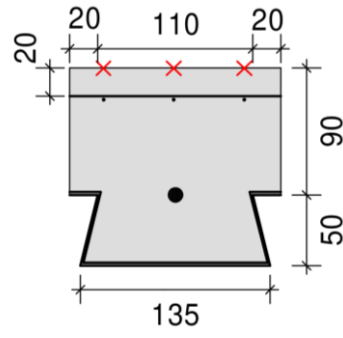
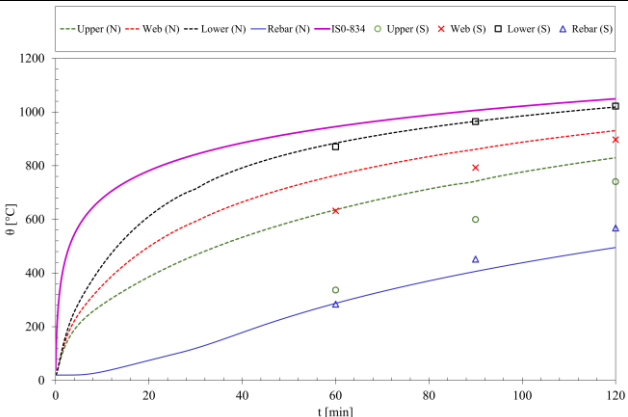
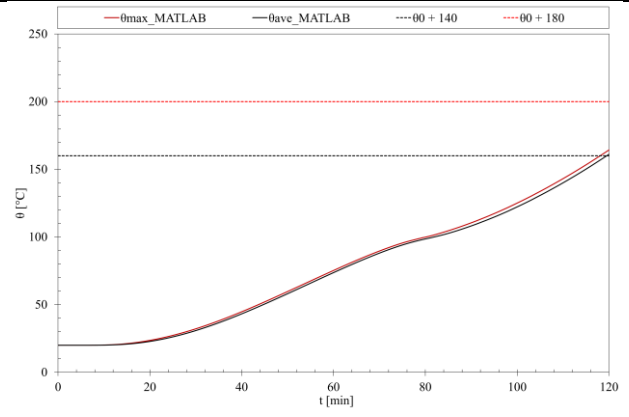
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 13: Slab 3 – Multideck – $h_1 = 90$ mm | | | |
| Model 13 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 13: Thermal Analysis with MATLAB - (2/2) | | | SIM. 50 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: 119.65 t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

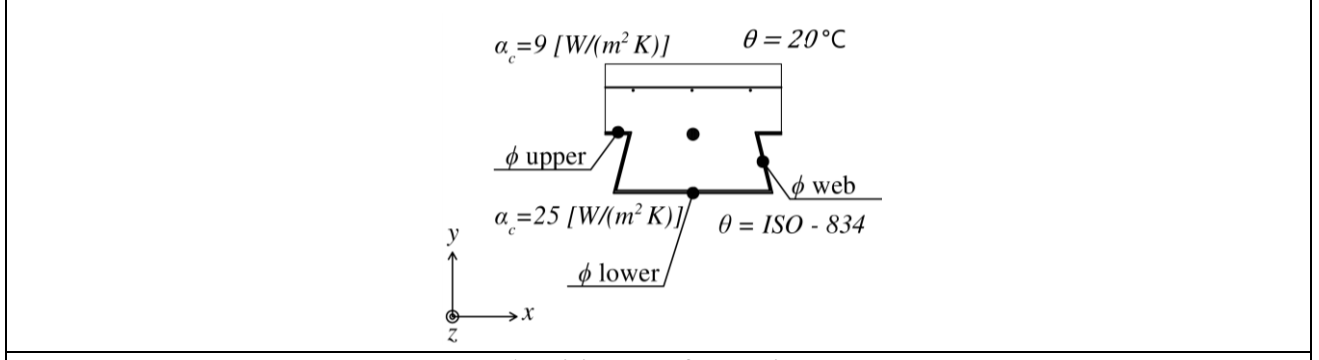
| DATA SHEET | | | |
|---|---|--|--|
| Model 13: Slab 3 – Multideck – $h_1 = 90$ mm | | | |
| Model 13 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 13: Thermal Analysis with MATLAB - (2/2) | | | SIM. 51 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
|  | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: 119.41 t_{fi}, Ave: - |
|  | |  | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
|  | |  | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 13: Slab 3 – Multideck – $h_1 = 90$ mm | | | |
| Model 13 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

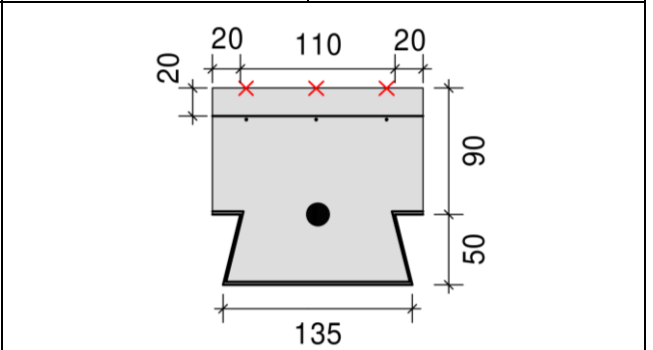
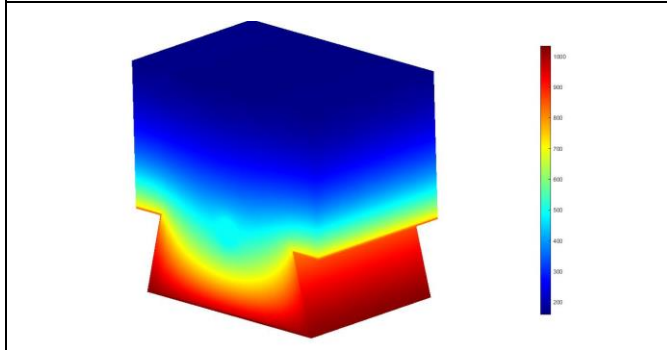
Boundary Conditions



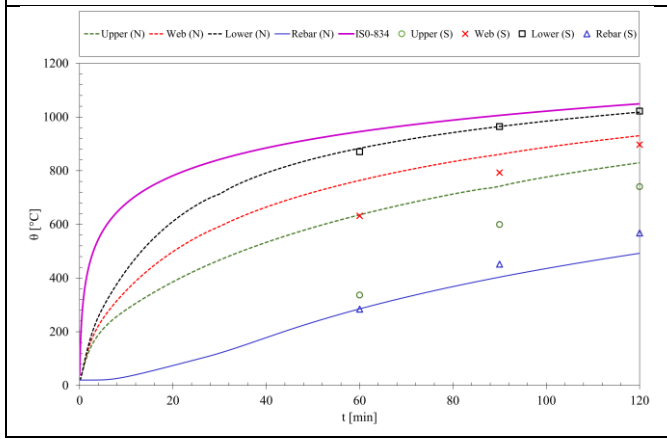
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

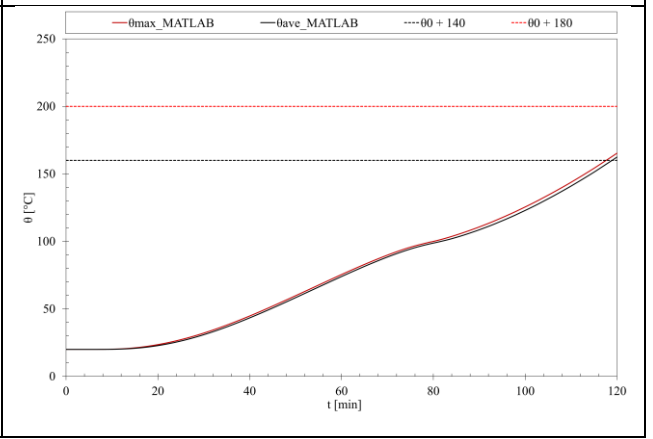
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 118.93 t_{fi} , Ave: - |



a) Temperature Graph - R



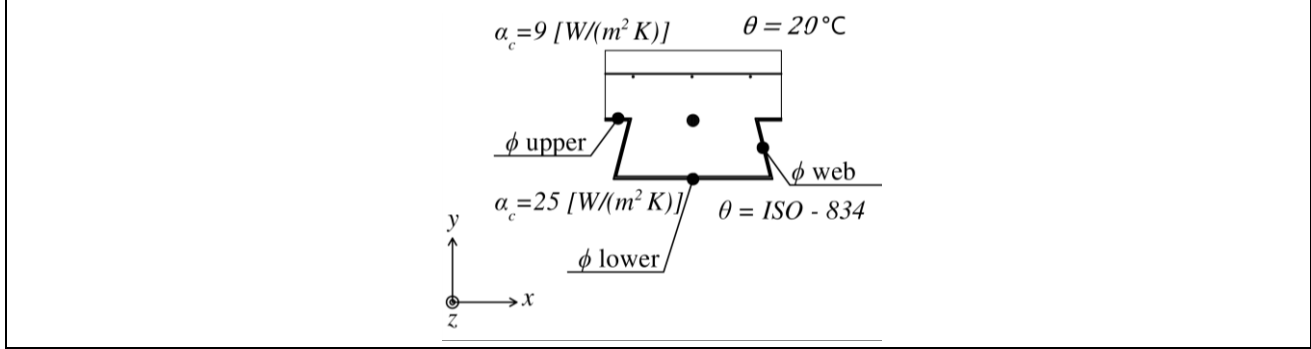
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 14: Slab 3 – Multideck – $h_1 = 110$ mm | | | |
| Model 14 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

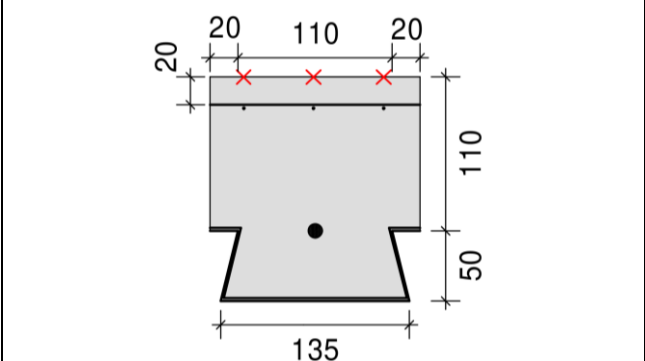
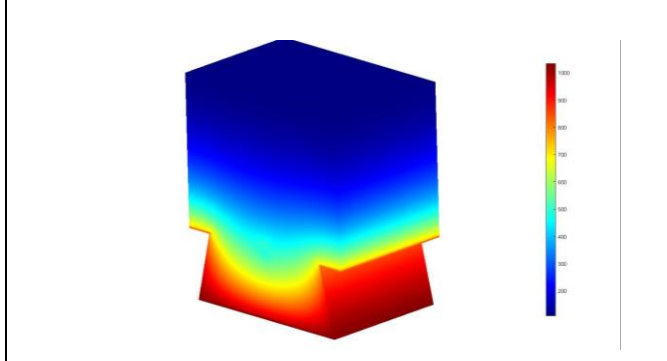
Boundary Conditions



Additional Information

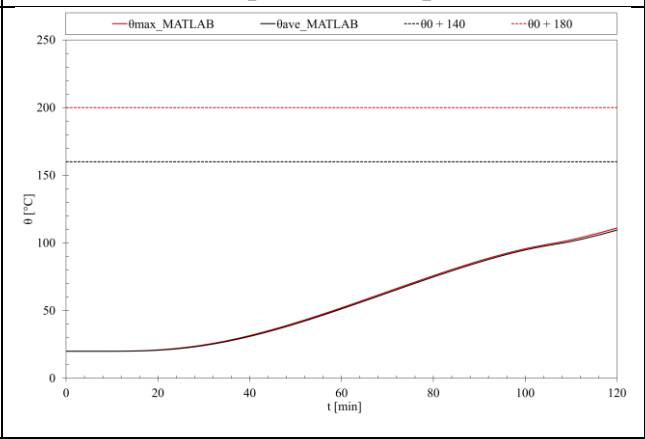
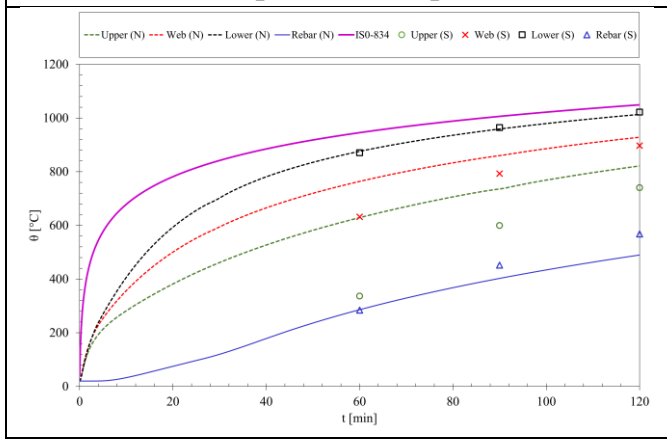
N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R

b) Temperature Graph - I



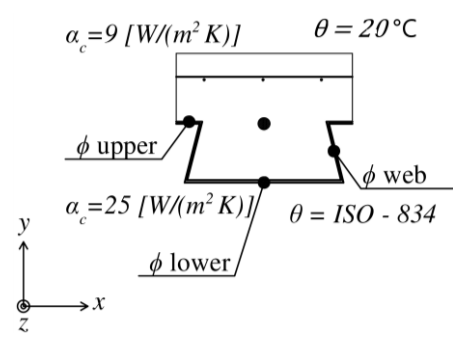
| DATA SHEET | | | |
|---|---|--|--|
| Model 14: Slab 3 – Multideck – $h_1 = 110$ mm | | | |
| Model 14 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 14: Thermal Analysis with MATLAB - (2/2) | | | SIM. 54 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - | |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 14: Slab 3 – Multideck – $h_1 = 110$ mm | | | |
| Model 14 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

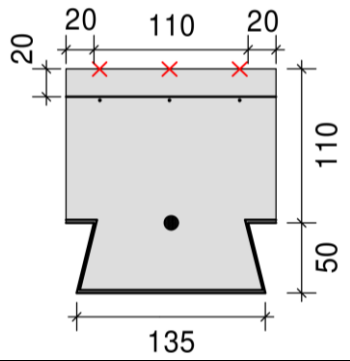
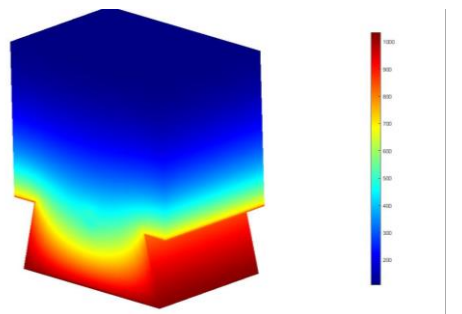
Boundary Conditions



Additional Information

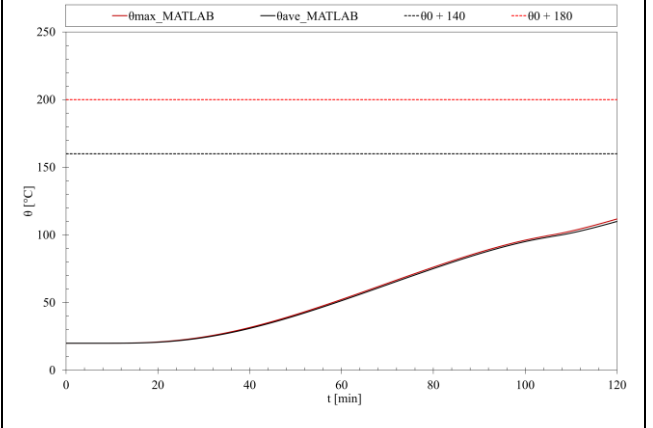
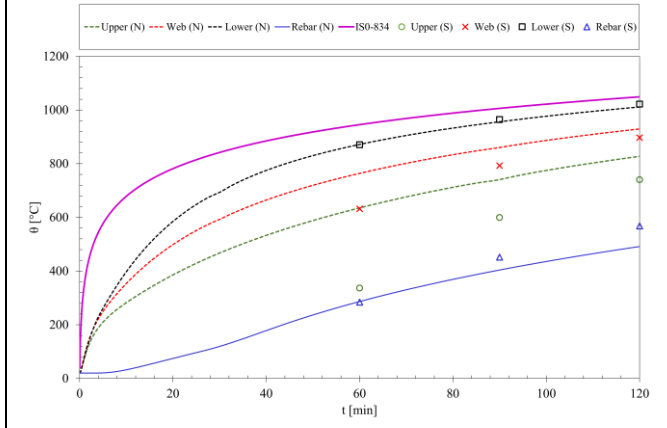
N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |



a) Temperature Graph - R

b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 14: Slab 3 – Multideck – $h_1 = 110$ mm | | | |
| Model 14 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 14: Thermal Analysis with MATLAB - (2/2) | | | SIM. 56 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

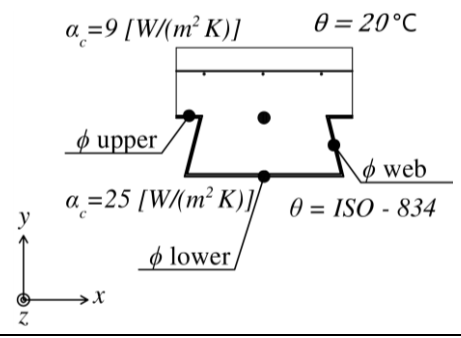
| DATA SHEET | | | |
|---|---|--|--|
| Model 15: Slab 3 – Multideck – $h_1 = 125$ mm | | | |
| Model 15 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 15: Thermal Analysis with MATLAB - (2/2) | | | SIM. 57 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 15: Slab 3 – Multideck – $h_1 = 125$ mm | | | |
| Model 15 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

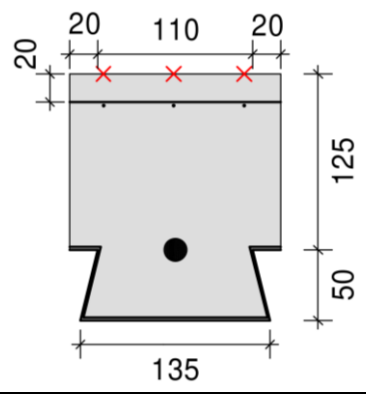
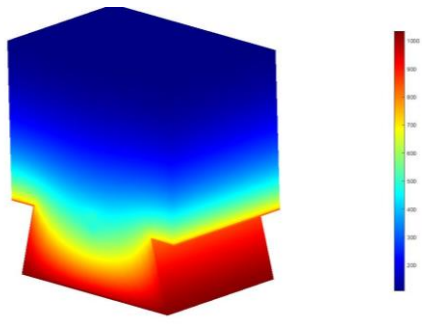
Boundary Conditions



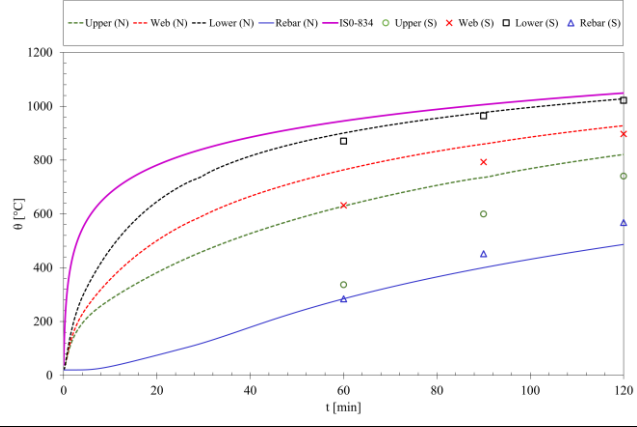
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

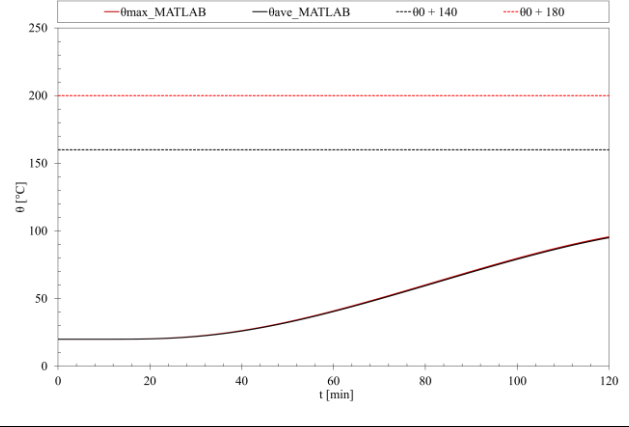
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |



a) Temperature Graph - R



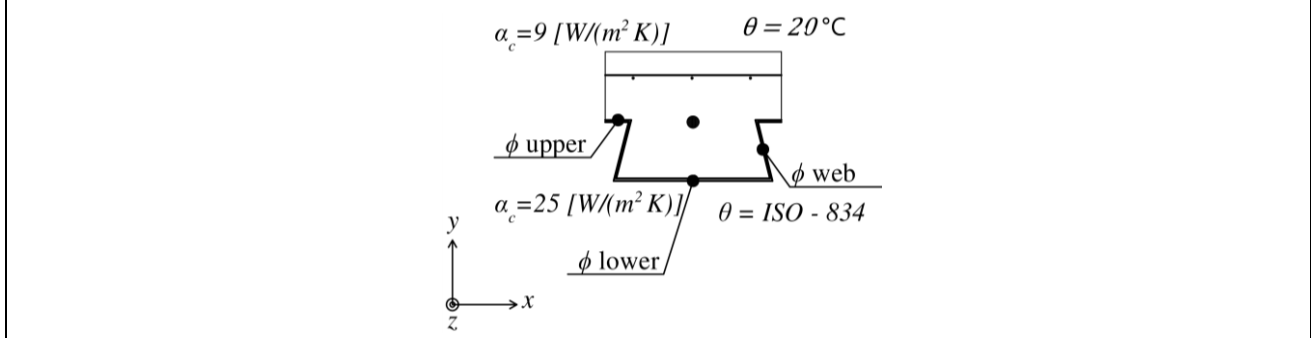
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 15: Slab 3 – Multideck – $h_1 = 125$ mm | | | |
| Model 15 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

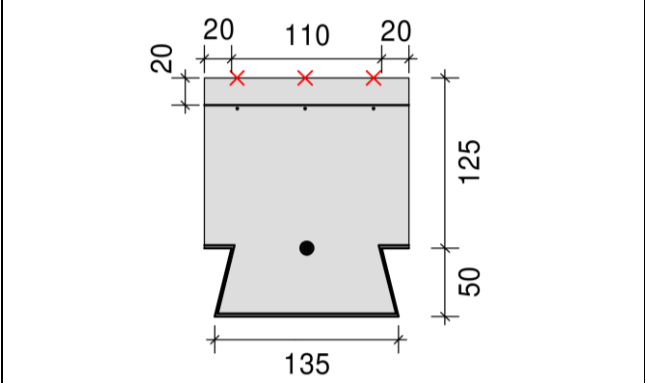
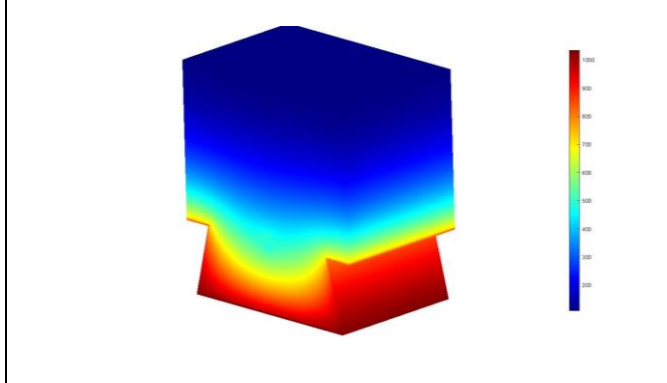
Boundary Conditions



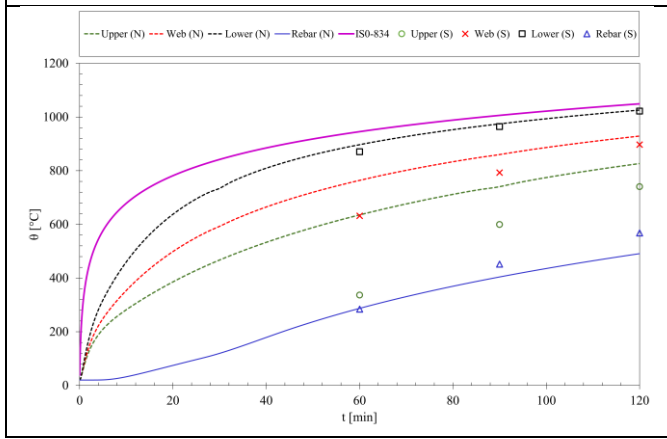
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

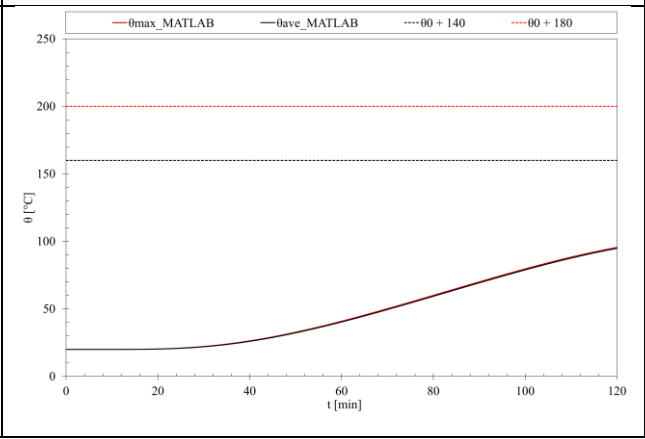
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |



a) Temperature Graph - R



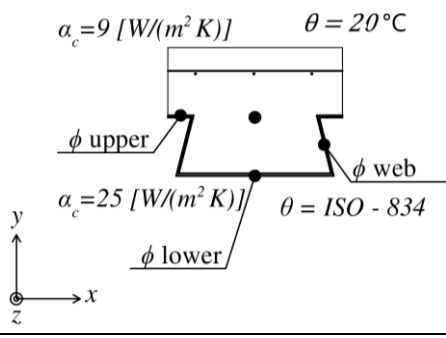
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 15: Slab 3 – Multideck – $h_1 = 125$ mm | | | |
| Model 15 - Basic Data (1/2) | | | |
| Experimental type | Title: Multideck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.20 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.14 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

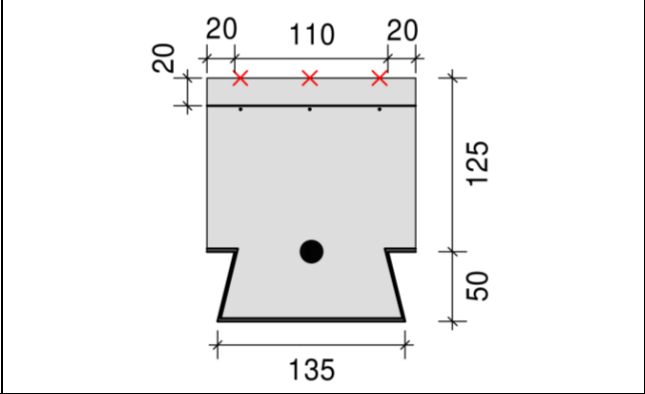
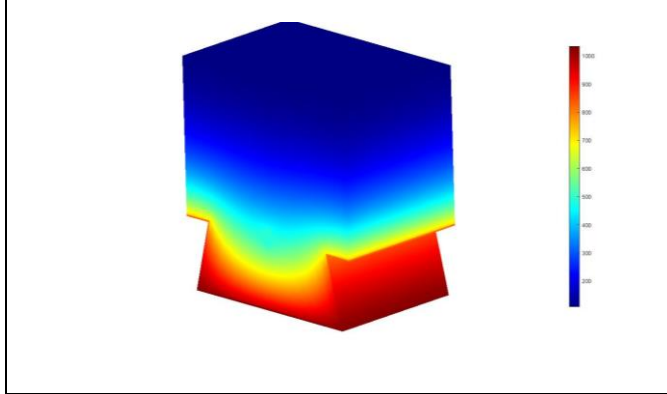
Boundary Conditions



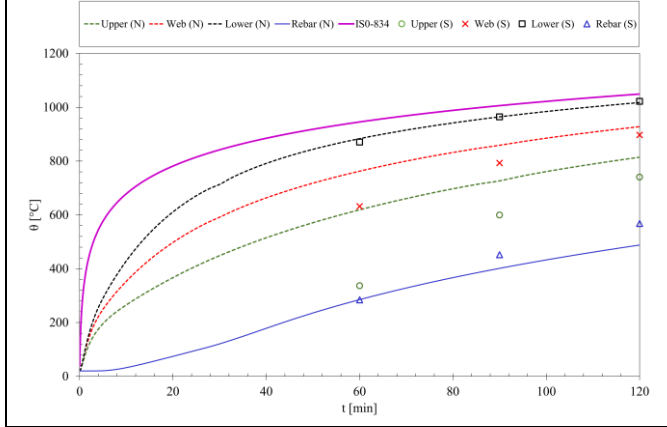
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

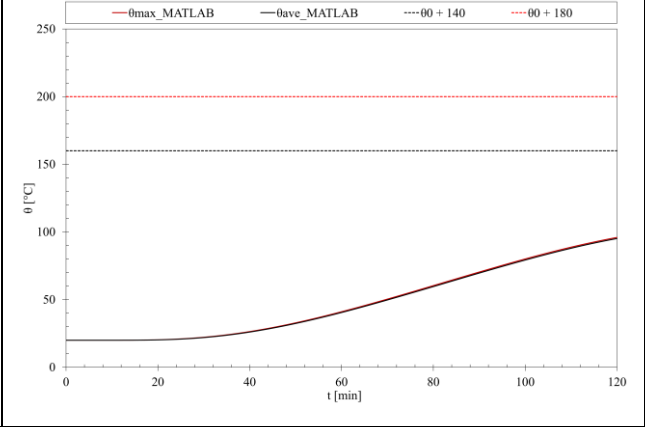
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



b) Temperature Graph - I

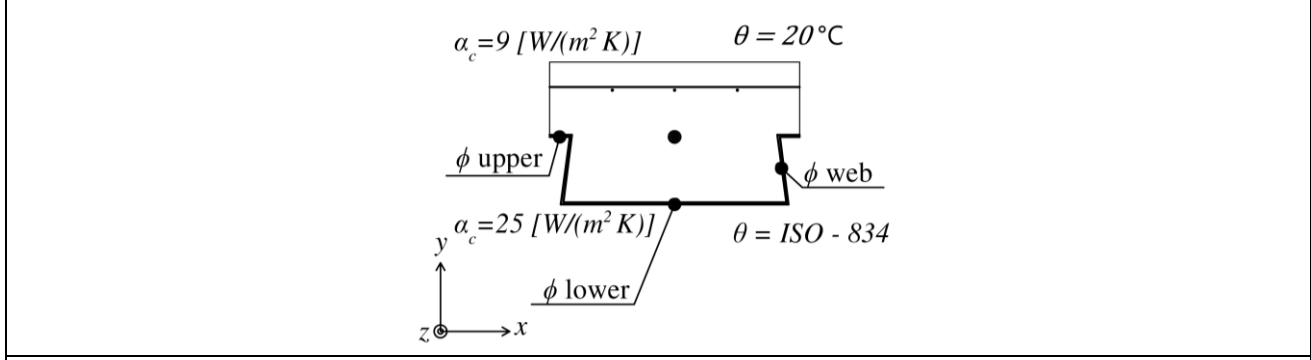


| DATA SHEET | | | |
|---|---|--|--|
| Model 16: Slab 4 – Bondeck – $h_1 = 60$ mm | | | |
| Model 16 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 50$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 16: Thermal Analysis with MATLAB - (2/2) **SIM. 61**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

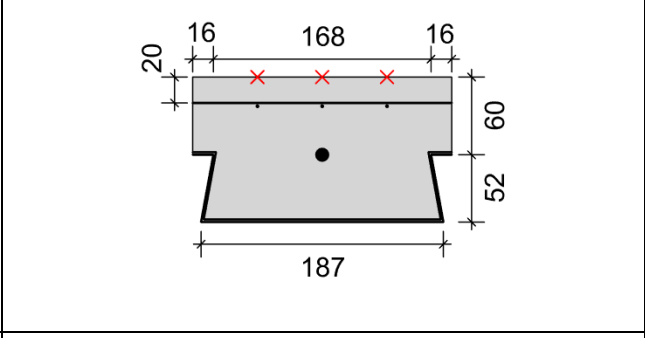
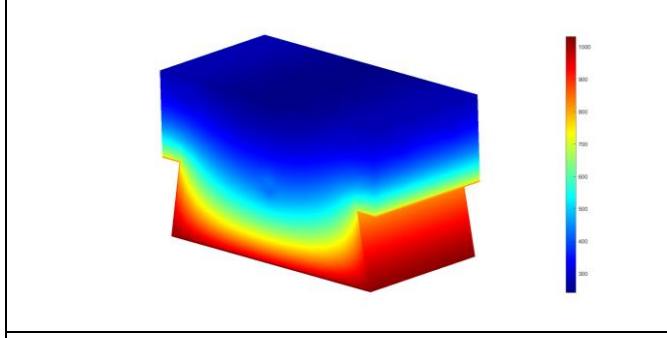
Boundary Conditions



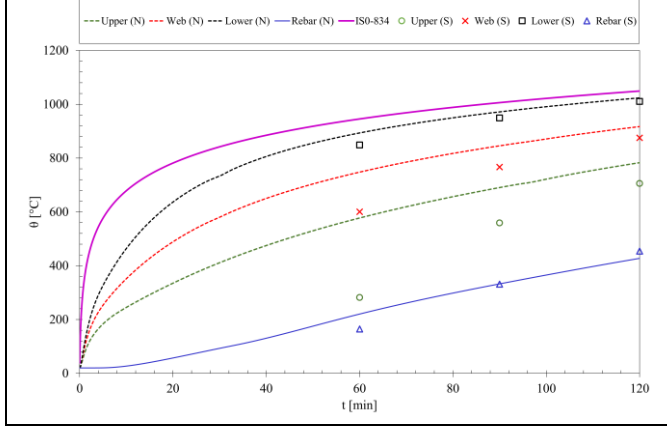
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

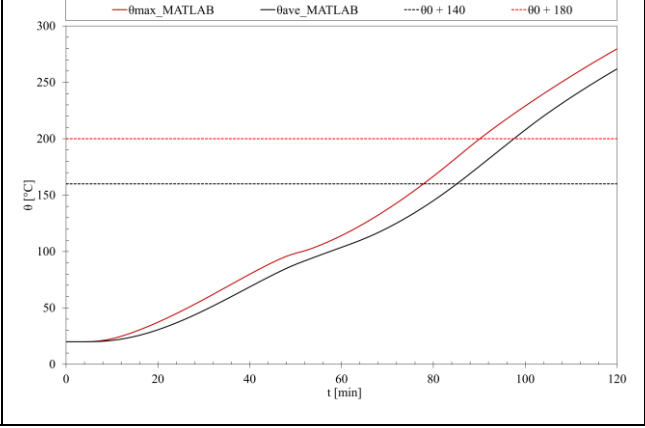
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: 90.25 $t_{fi, \text{Ave}}$: 85.22 |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 16: Slab 4 – Bondeck – $h_1 = 60$ mm | | | |
| Model 6 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 16: Thermal Analysis with MATLAB - (2/2) | | | SIM. 62 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: 90.33 $t_{fi, \text{Ave}}$: 84.63 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 16: Slab 4 – Bondeck – $h_1 = 60$ mm | | | |
| Model 16 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

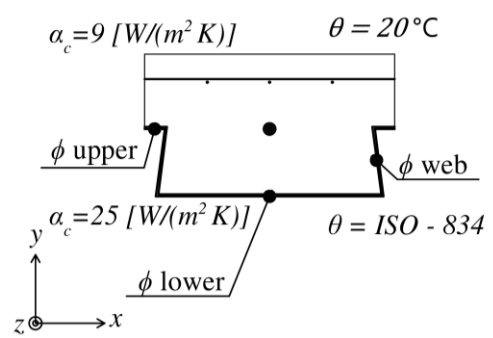
| Model 16: Thermal Analysis with MATLAB - (2/2) | | | SIM. 63 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: 90.03 t_{fi} , Ave: 84.78 |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 16: Slab 4 – Bondeck – $h_1 = 60$ mm | | | |
| Model 16 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 60$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 16: Thermal Analysis with MATLAB - (2/2) **SIM. 64**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

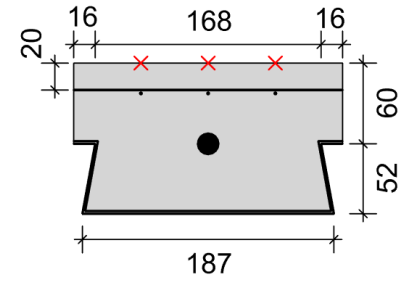
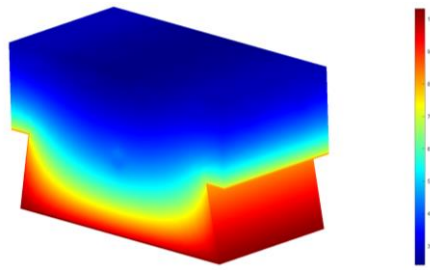
Boundary Conditions



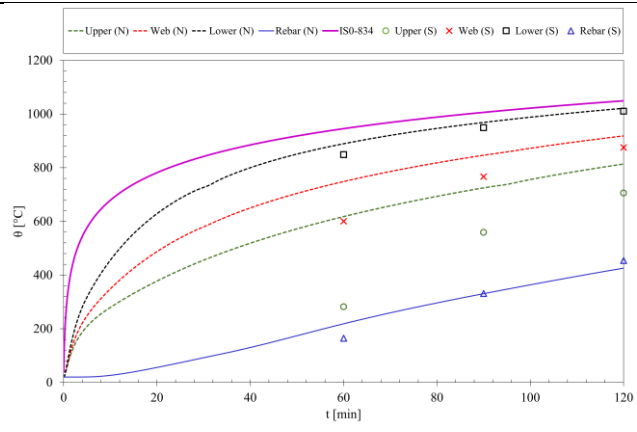
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

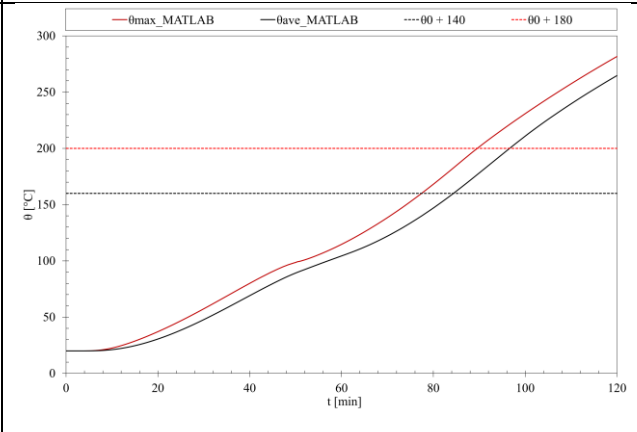
| Steel Deck Components | Isolation Criterion (I) |
|--|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: 89.67 $t_{fi, \text{Ave}}$: 84.45 |



a) Temperature Graph - R



b) Temperature Graph - I



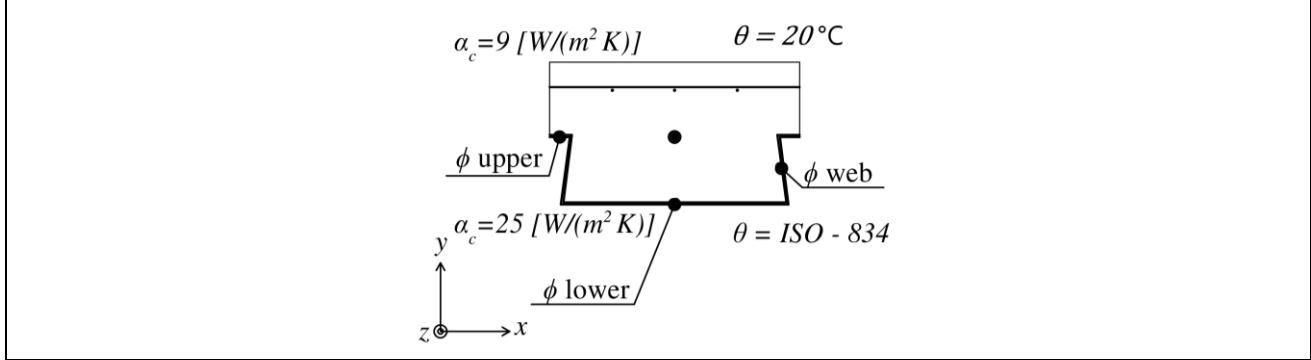
| DATA SHEET | | | |
|---|---|--|--|
| Model 17: Slab 4 – Bondeck – $h_1 = 70$ mm | | | |
| Model 17 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 17: Thermal Analysis with MATLAB - (2/2) | | | SIM. 65 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}: 109.60$ $t_{fi, \text{Ave}}: 100.63$ |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 17: Slab 4 – Bondeck – $h_1 = 70$ mm | | | |
| Model 2 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

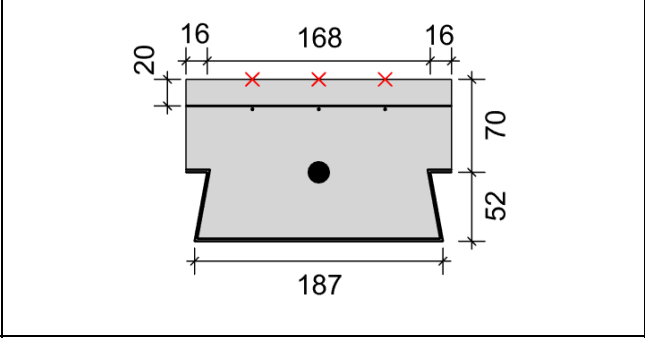
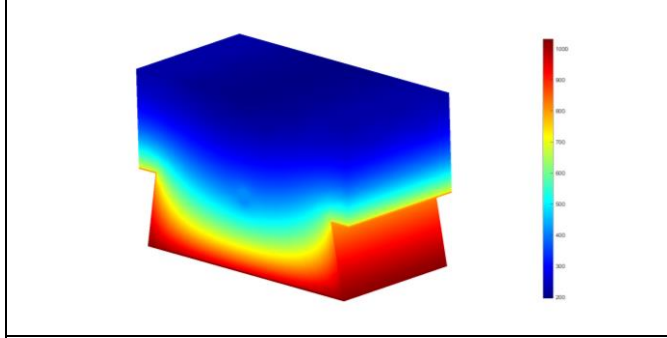
Boundary Conditions



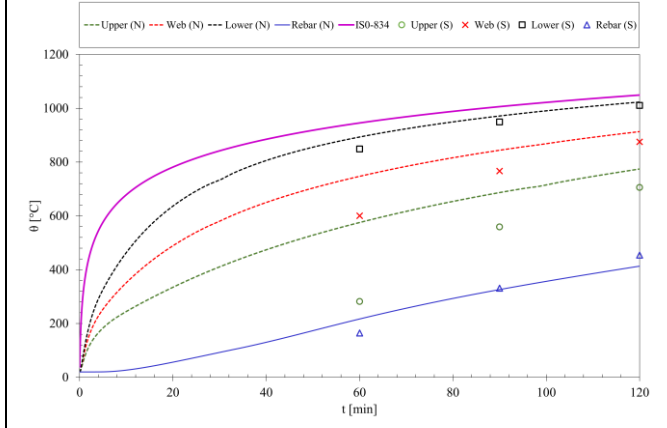
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

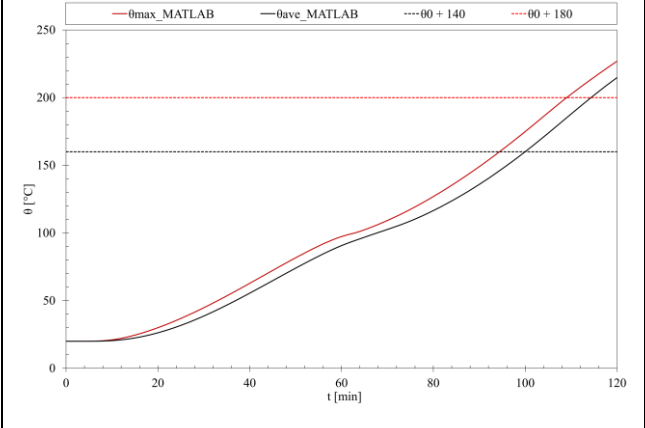
| Steel Deck Components | Isolation Criterion (I) | |
|--|------------------------------|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] | $t_{fi, \text{Max}}$: 109.02 $t_{fi, \text{Ave}}$: 100.20 |



a) Temperature Graph - R



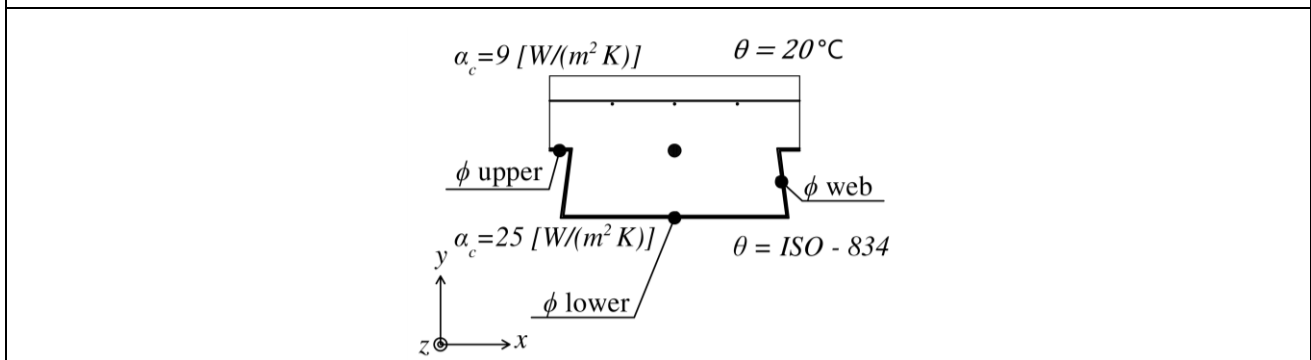
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 17: Slab 4 – Bondeck – $h_1 = 70$ mm | | | |
| Model 17 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

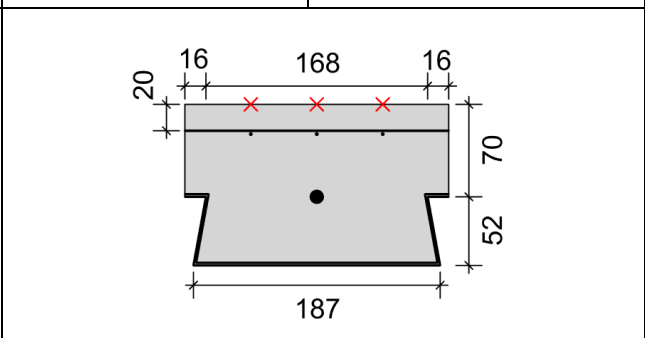
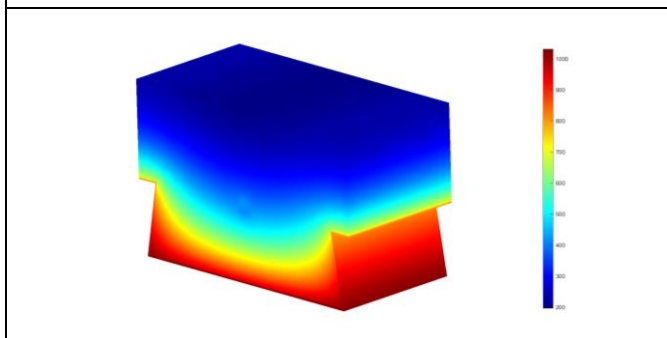
Boundary Conditions



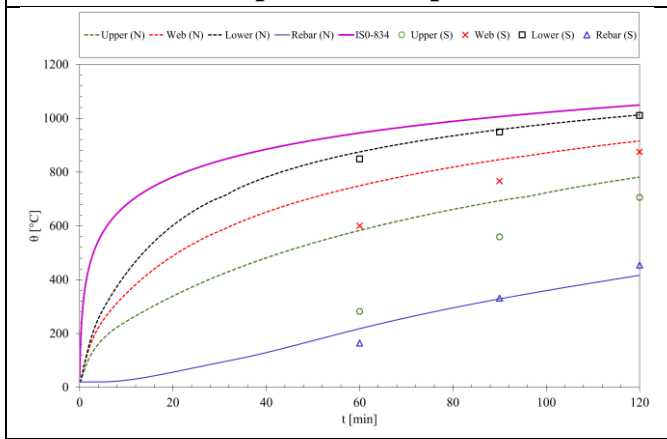
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

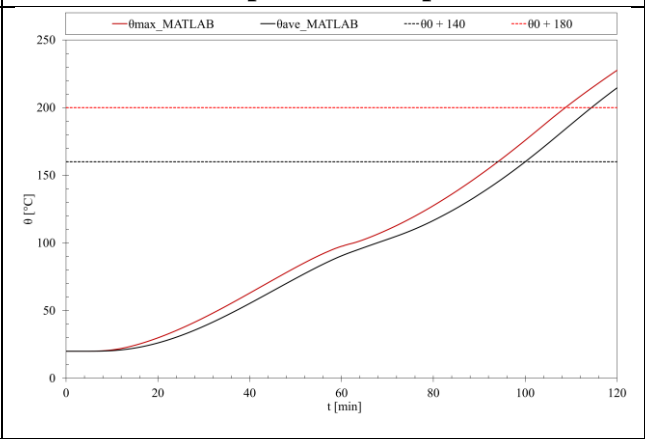
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}: 108.76$ $t_{fi, \text{Ave}}: 100.02$ |



a) Temperature Graph - R



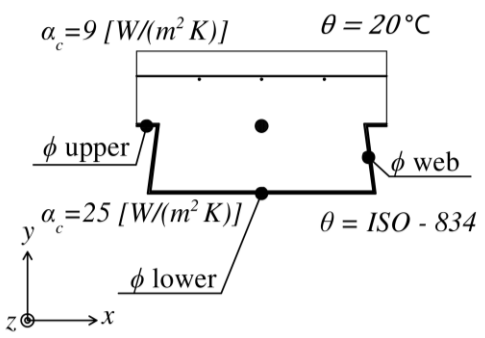
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 17: Slab 4 – Bondeck – $h_1 = 70$ mm | | | |
| Model 17 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 70$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

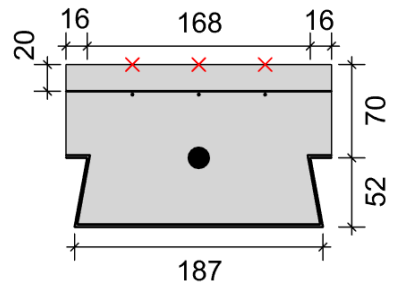
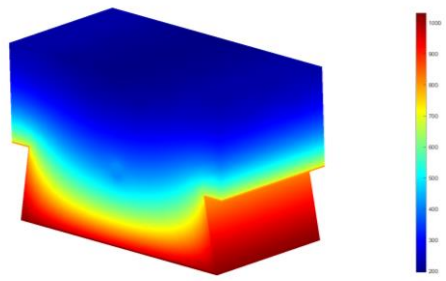
Boundary Conditions



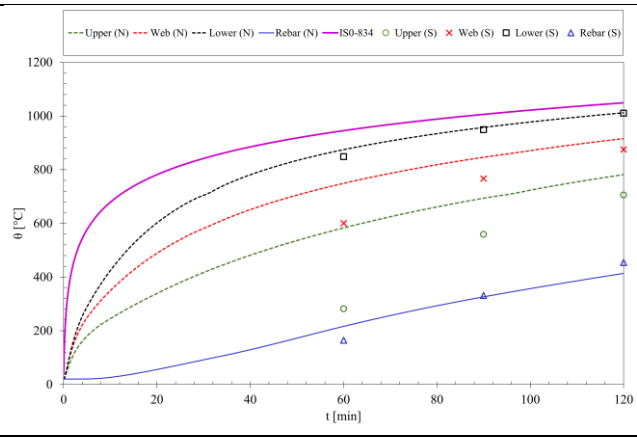
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

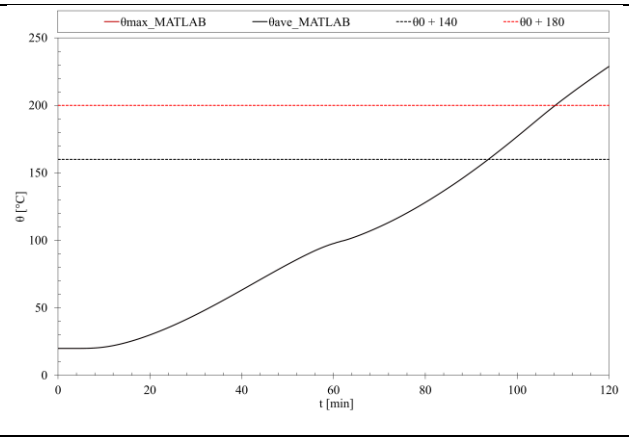
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: 108.33 t_{fi} , Ave: 93.88 |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 18: Slab 4 – Bondeck – $h_1 = 90$ mm | | | |
| Model 18 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 18: Thermal Analysis with MATLAB - (2/2) | | | SIM. 69 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

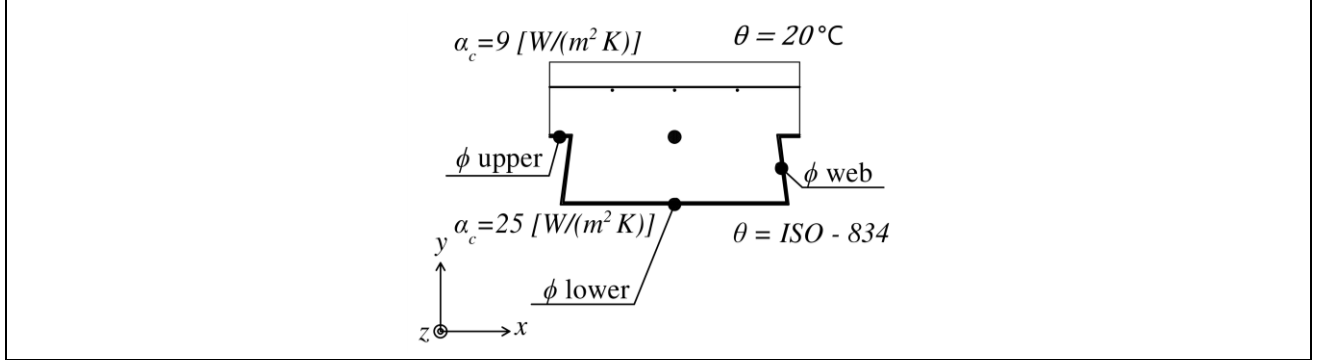
| DATA SHEET | | | |
|---|---|--|--|
| Model 18: Slab 4 – Bondeck – $h_1 = 90$ mm | | | |
| Model 18 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 18: Thermal Analysis with MATLAB - (2/2) | | | SIM. 70 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 18: Slab 4 – Bondeck – $h_1 = 90$ mm | | | |
| Model 18 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

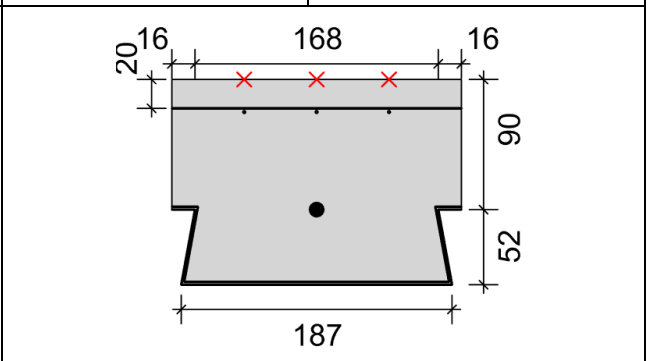
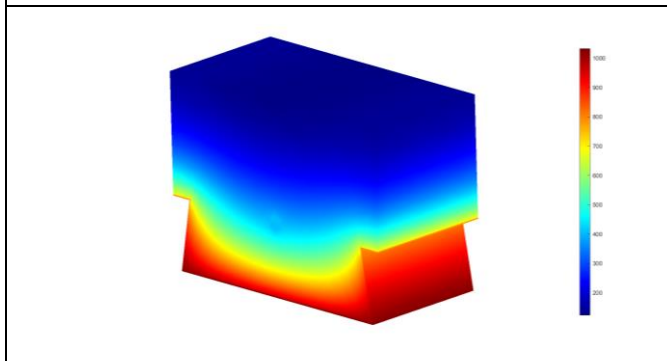
Boundary Conditions



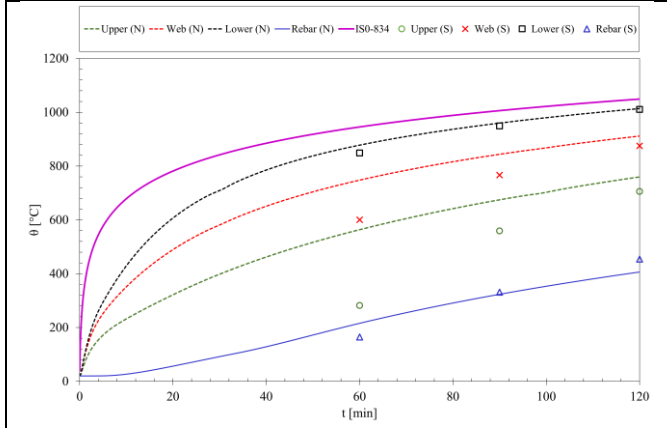
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

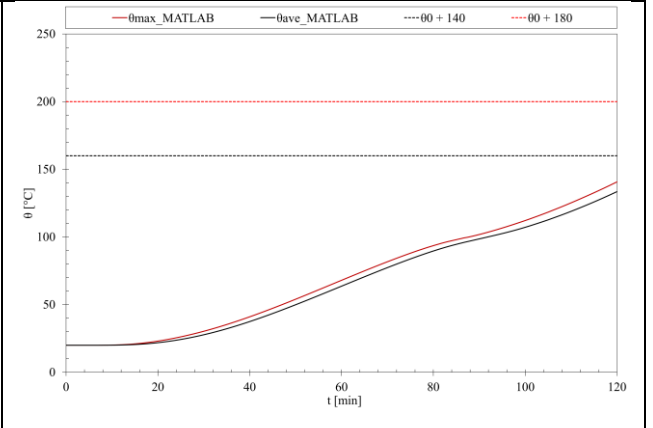
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |



a) Temperature Graph - R



b) Temperature Graph - I

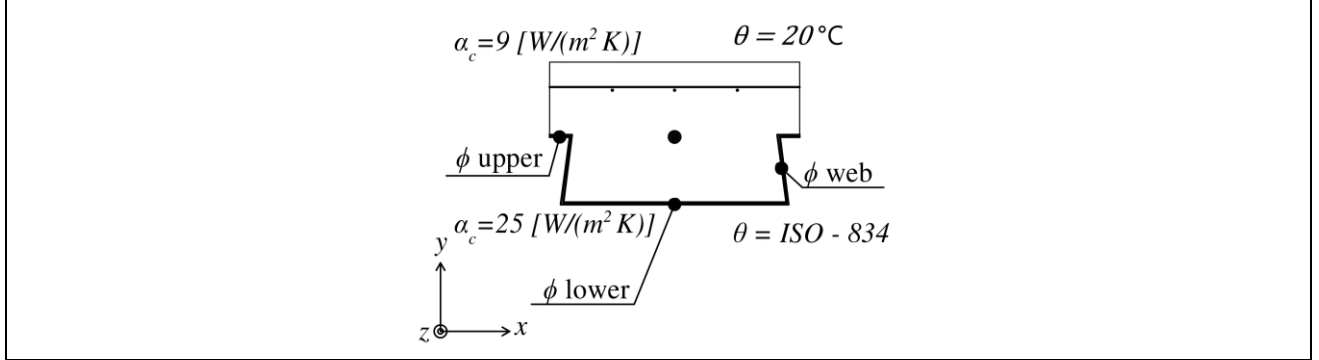


| DATA SHEET | | | |
|---|---|--|--|
| Model 18: Slab 4 – Bondeck – $h_1 = 90$ mm | | | |
| Model 18 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 90$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

Model 18: Thermal Analysis with MATLAB - (2/2) **SIM. 72**

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

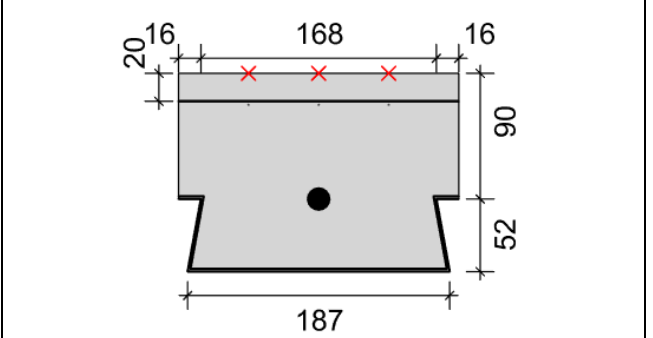
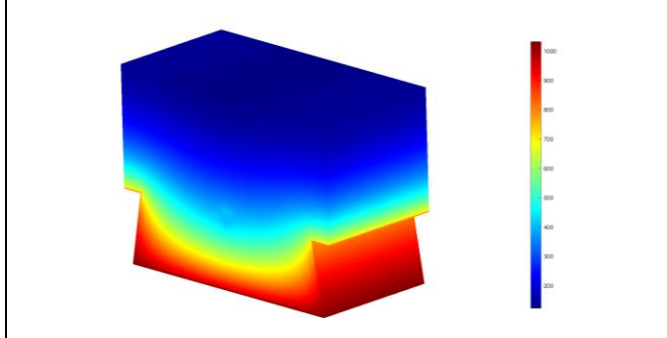
Boundary Conditions



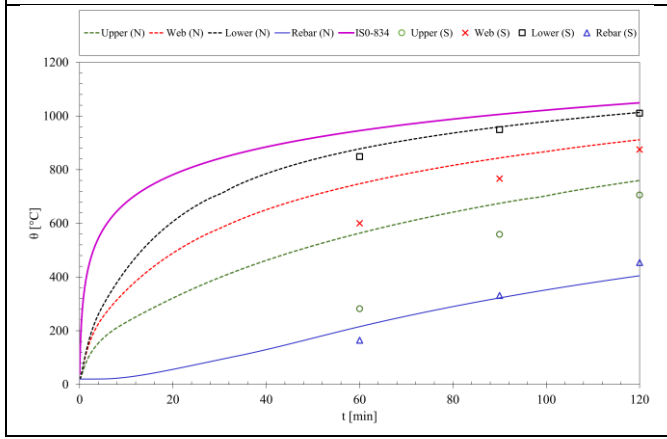
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

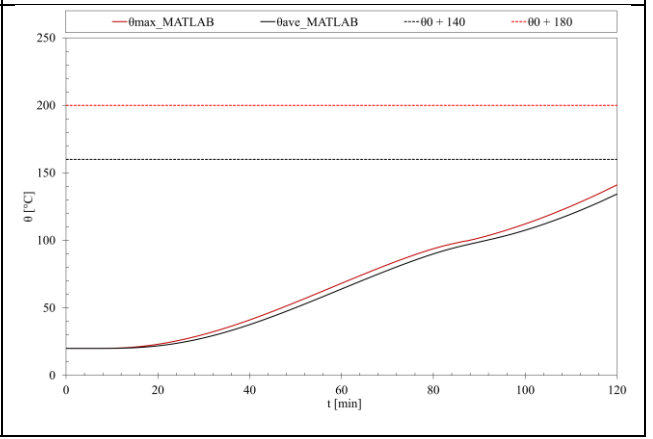
| Steel Deck Components | Isolation Criterion (I) | |
|--|------------------------------|--|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |



a) Temperature Graph - R



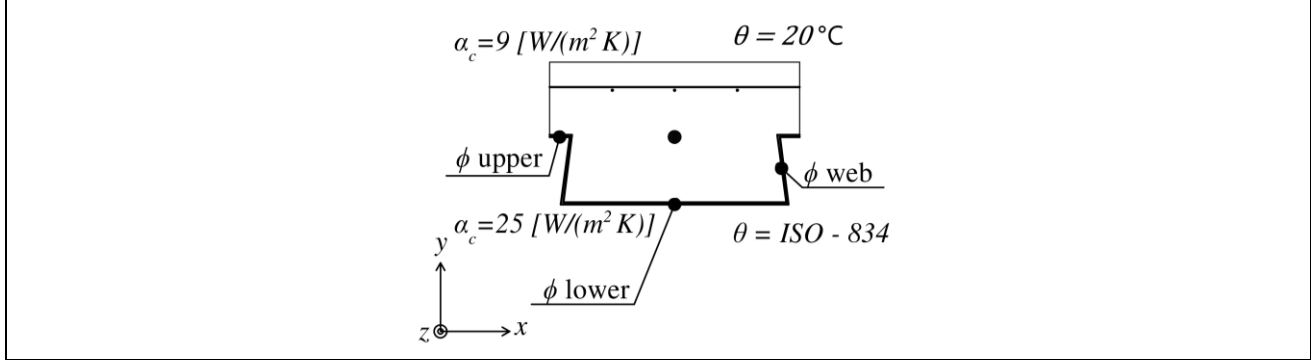
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 19: Slab 2 – Cofraplus 60 – $h_1 = 110$ mm | | | |
| Model 19 - Basic Data (1/2) | | | |
| Experimental type | Title: Cofraplus 60 / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

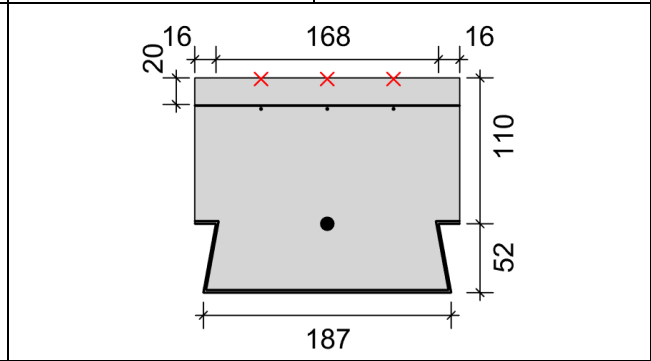
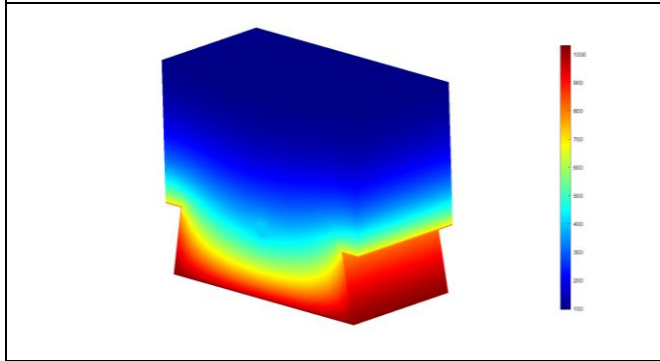
Boundary Conditions



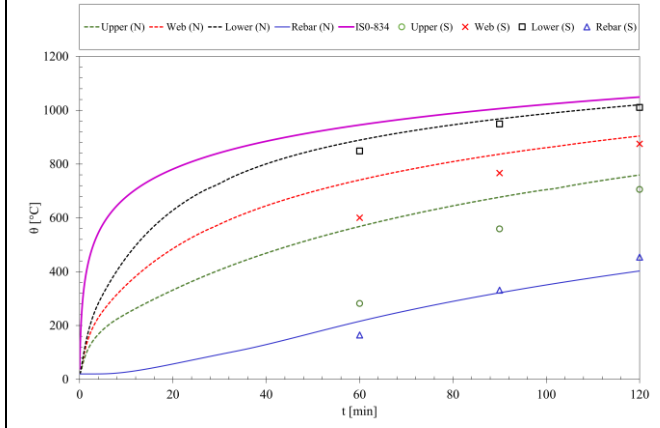
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

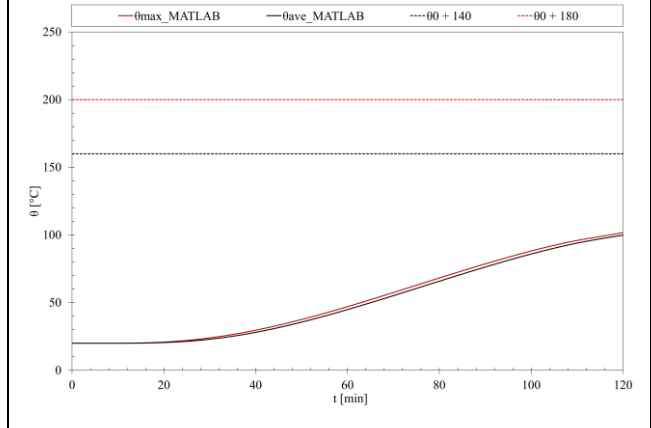
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 19: Slab 4 – Bondeck – $h_1 = 110$ mm | | | |
| Model 19 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 19: Thermal Analysis with MATLAB - (2/2) | | | SIM. 74 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 19: Slab 4 – Bondeck – $h_1 = 110$ mm | | | |
| Model 19 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 19: Thermal Analysis with MATLAB - (2/2) | | | SIM. 75 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi}, Max: - t_{fi}, Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 19: Slab 4 – Bondeck – $h_1 = 110$ mm | | | |
| Model 1 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 110$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 19: Thermal Analysis with MATLAB - (2/2) | | | SIM. 76 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W}/\text{m}^2\text{K}$ Unexposed Surface: $9 \text{ W}/\text{m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | t_{fi} , Max: - t_{fi} , Ave: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

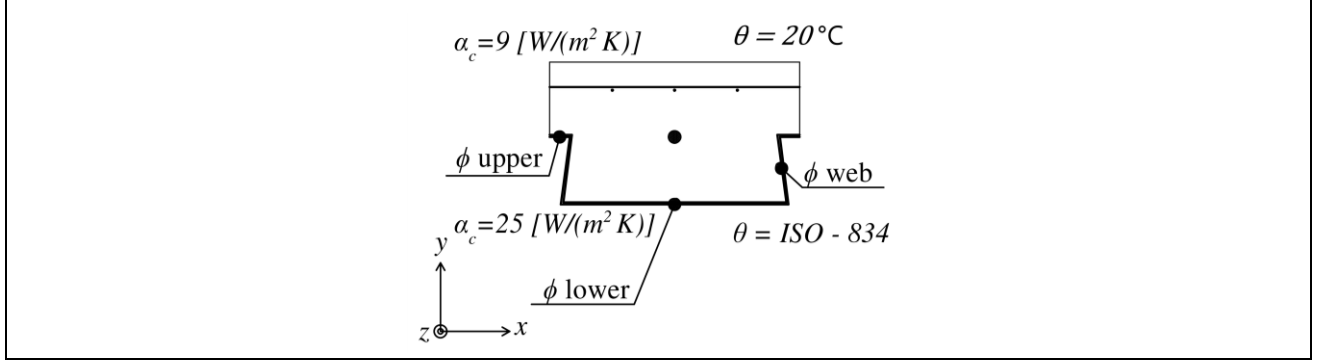
| DATA SHEET | | | |
|---|---|--|--|
| Model 20: Slab 4 – Bondeck – $h_1 = 125$ mm | | | |
| Model 20 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| Model 20: Thermal Analysis with MATLAB - (2/2) | | | SIM. 77 |
|--|---|--|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}: -$ $t_{fi, \text{Ave}}: -$ |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

| DATA SHEET | | | |
|---|---|--|--|
| Model 20: Slab 2 – Bondeck – $h_1 = 125$ mm | | | |
| Model 20 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 0.75 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|--|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

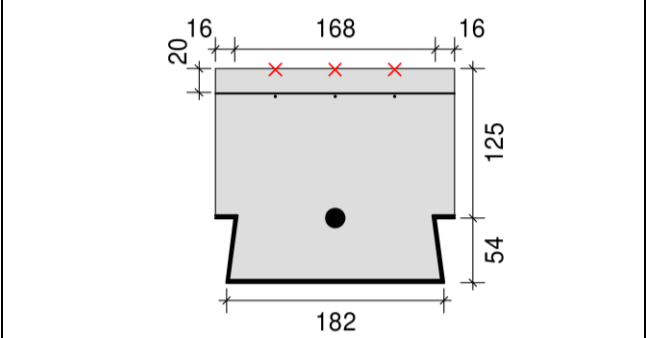
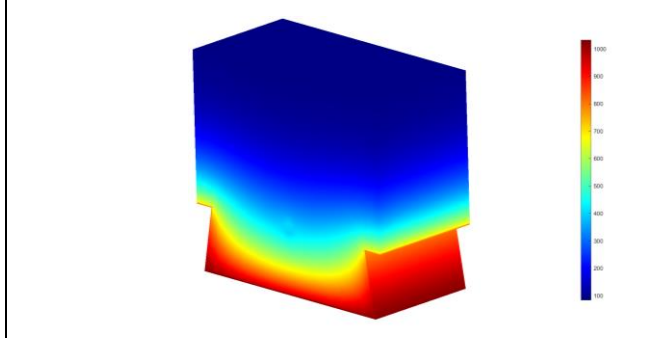
Boundary Conditions



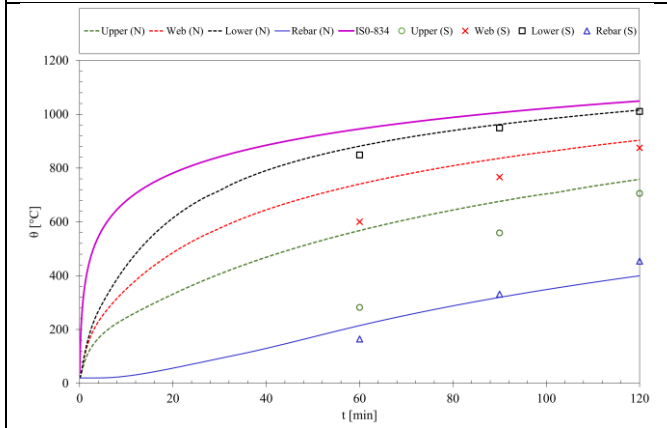
Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

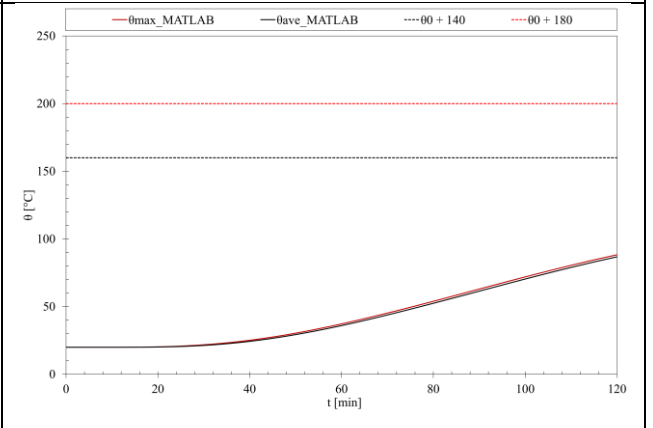
| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



a) Temperature Graph - R



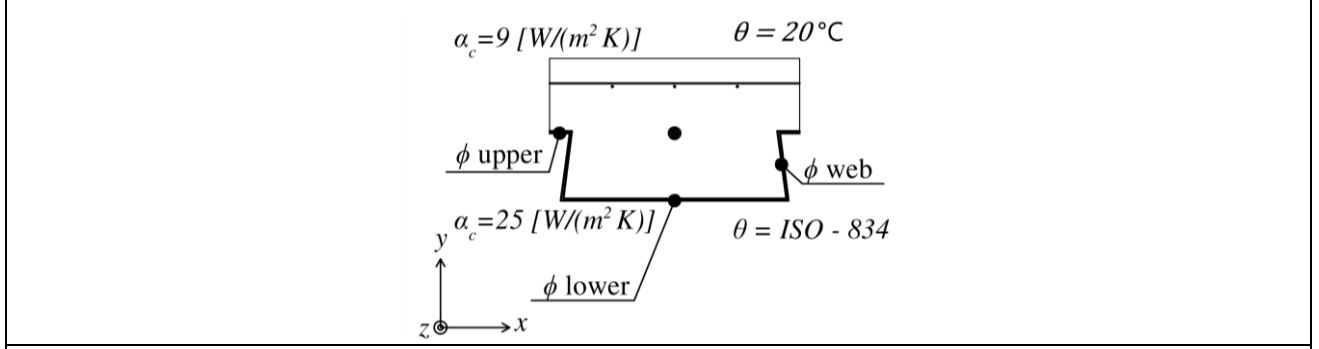
b) Temperature Graph - I



| DATA SHEET | | | |
|---|---|--|--|
| Model 20: Slab 2 – Bondeck – $h_1 = 125$ mm | | | |
| Model 20 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø10 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
|--|---|--|---|
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |

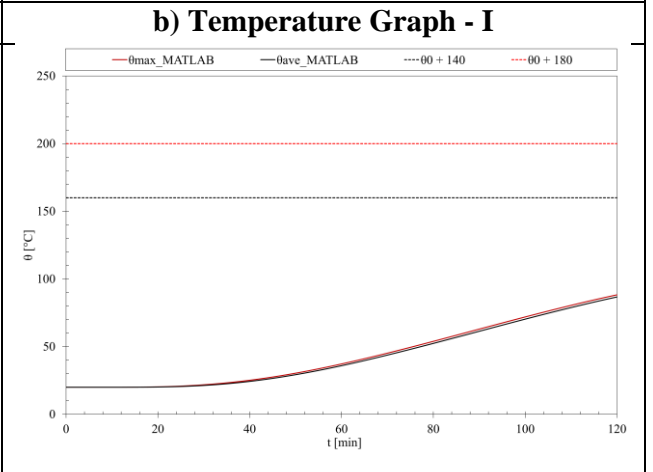
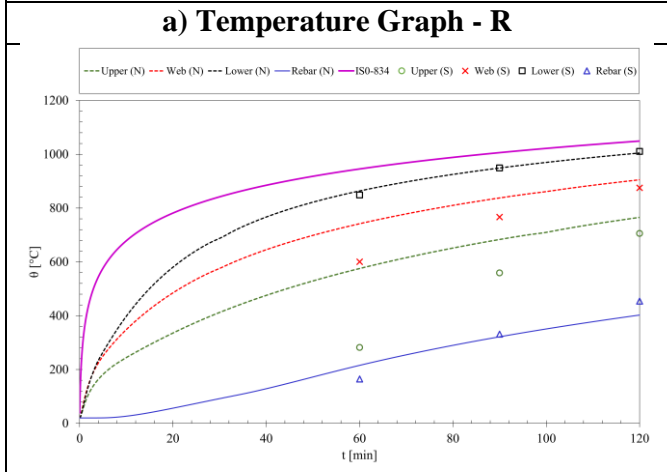
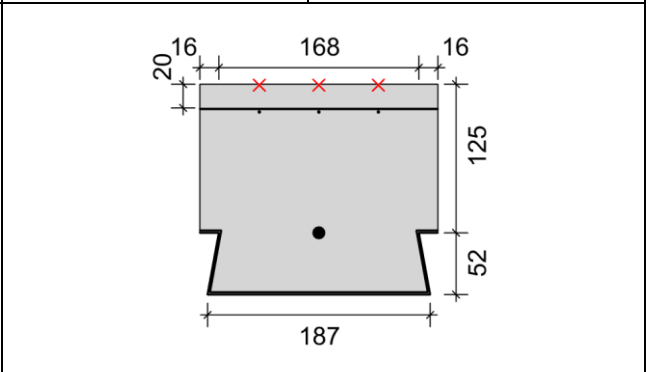
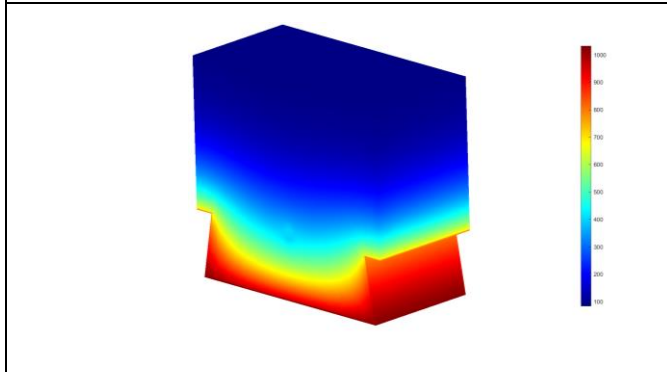
Boundary Conditions



Additional Information

N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components.

| Steel Deck Components | Isolation Criterion (I) |
|--|---|
| Finite Element - Temperature Distribution at 7200 s | Fire resistance [min] t_{fi} , Max: - t_{fi} , Ave: - |



| DATA SHEET | | | |
|---|---|--|--|
| Model 20: Slab 2 – Bondeck – $h_1 = 125$ mm | | | |
| Model 20 - Basic Data (1/2) | | | |
| Experimental type | Title: Bondeck / $h_1 = 125$ mm | | |
| Parametric study | Author: Lima, L. da R. S. | Year: 2022 | |
| Detailing | | | |
| Steel Deck | Concrete | Steel Bars | |
| Geometry: Re-entrant Thickness: 1.00 Grade: S350 | Density: Normal Weight Class: 25/30 Moisture: 3.0% | Reinforcement Bars [mm] | Steel Mesh [mm] |
| | | Description: 1Ø16 Grade: S500 | Description: Ø5//50 Grade: S500 |
| Cross – Section | | | |
| | | | |
| Three-dimensional Finite Element Model | | | |
| | | | |

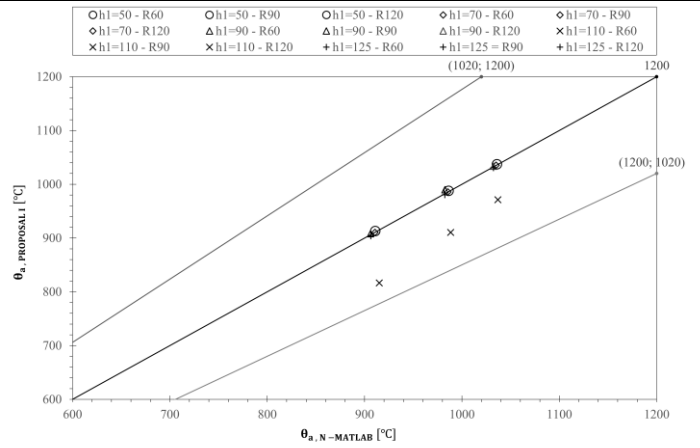
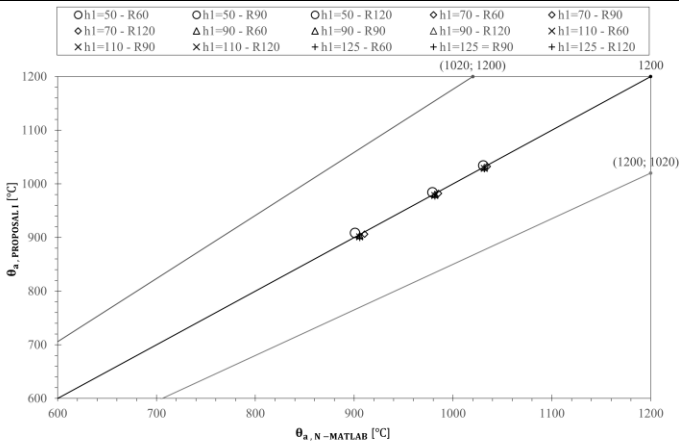
| Model 20: Thermal Analysis with MATLAB - (2/2) | | | SIM. 80 |
|--|---|---|---|
| MATLAB Element | Convection Coef. (α_c) | View Factor (Φ) | Temperature Curve |
| Steel Deck: Tetrahedral Concrete: Tetrahedral Steel Bars: Tetrahedral | Exposed Surface: $25 \text{ W/m}^2\text{K}$ Unexposed Surface: $9 \text{ W/m}^2\text{K}$ | Upper Flange: 0.12 Web: 0.09 Lower Flange: 1.00 | Exposed Surface: ISO-834 Unexposed Surface: 20°C |
| Boundary Conditions | | | |
| | | | |
| Additional Information | | | |
| N - The temperature curves obtained through MATLAB; S - The temperatures using the Eurocode Simplified Method; Upper, Web, Lower, and Rebar refer to the average temperature calculated in each of the following steel components. | | | |
| Steel Deck Components | | Isolation Criterion (I) | |
| Finite Element - Temperature Distribution at 7200 s | | Fire resistance [min] | $t_{fi, \text{Max}}$: - $t_{fi, \text{Ave}}$: - |
| | | | |
| a) Temperature Graph - R | | b) Temperature Graph - I | |
| | | | |

Appendix C

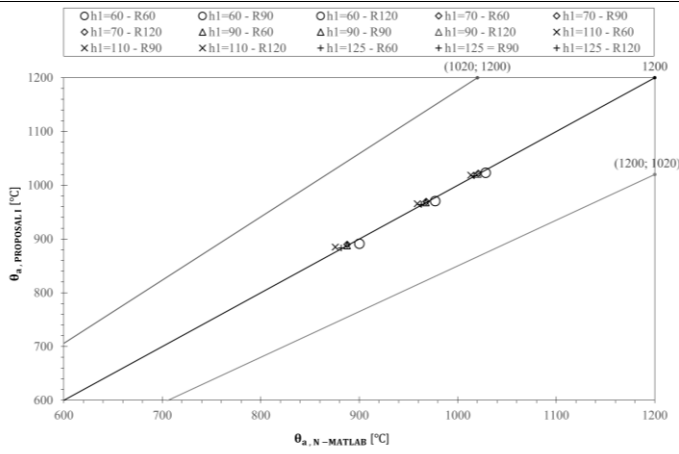
Annex C - Comparison proposed rules versus model predictions.

Relationship between the temperature of the flanges of the steel deck θ_a for numerical analysis (N) and the New Proposals (NP).

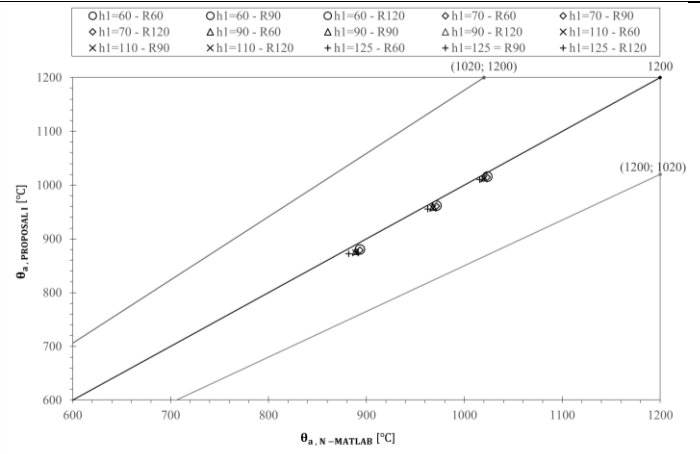
NP1 – N: Lower Flange



Polideck 59 S (TRA)



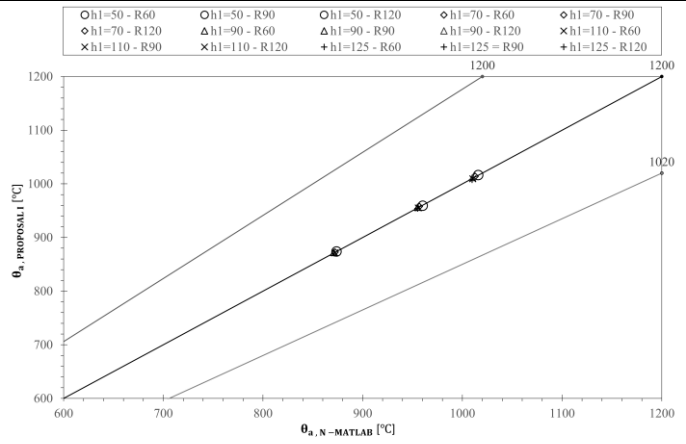
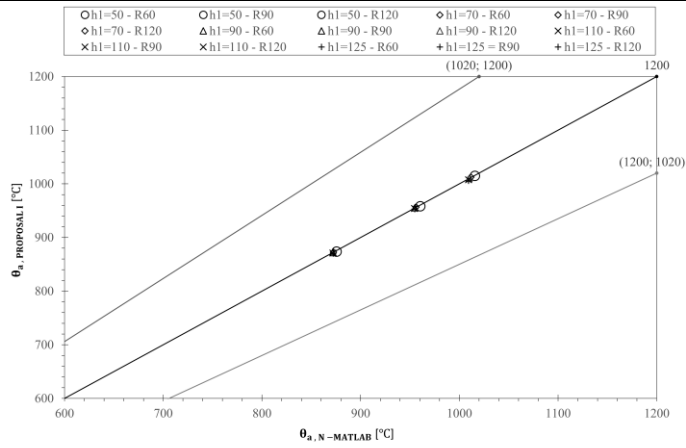
Cofraplus 60 (TRA)



Multideck (REE)

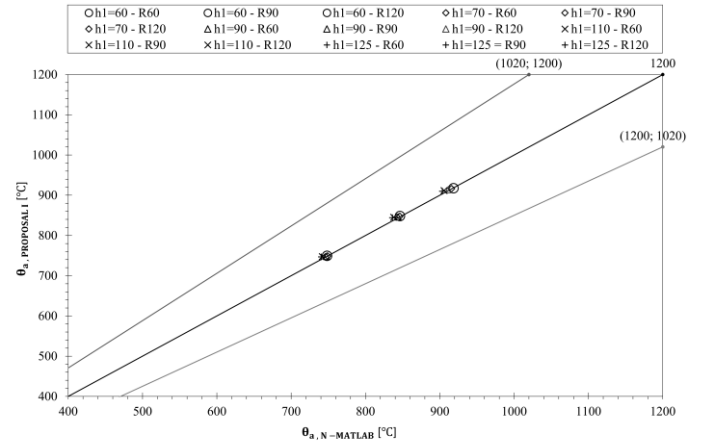
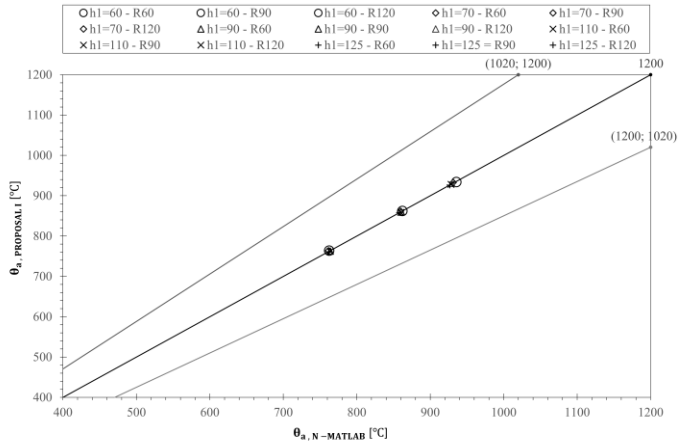
Bondeck (REE)

NPI – N: Web



Polideck 59 S (TRA)

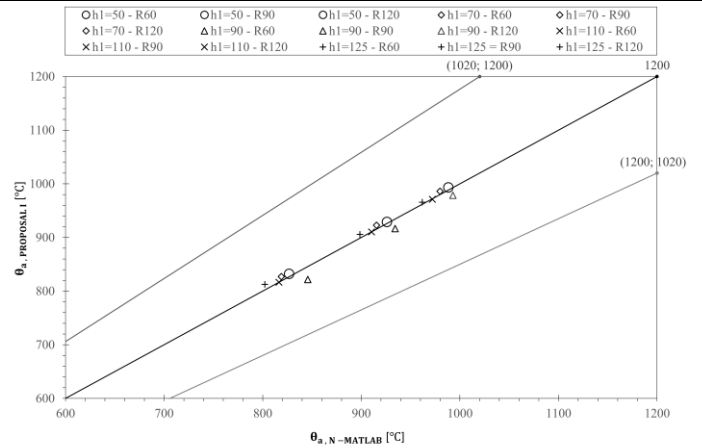
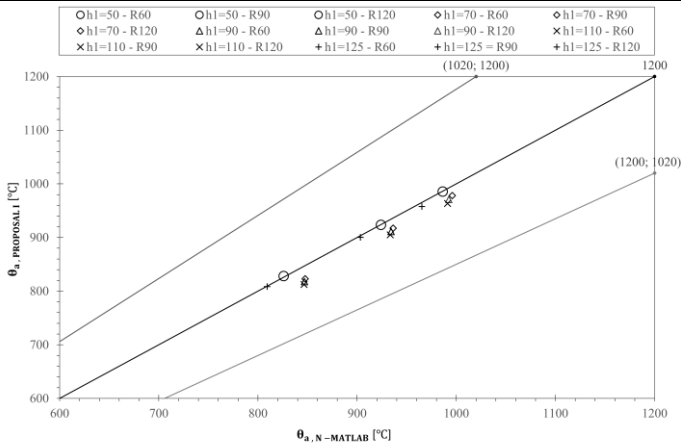
Cofraplus 60 (TRA)



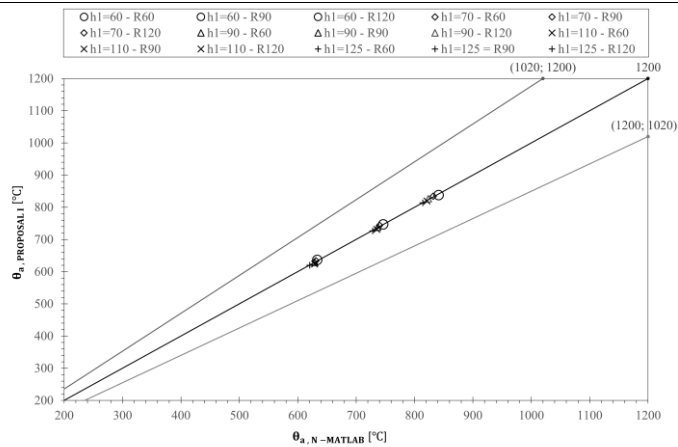
Multideck (REE)

Bondeck (REE)

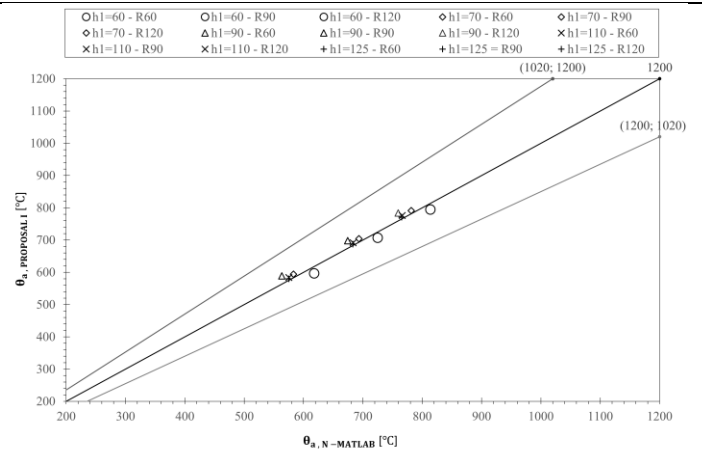
NPI – N: Upper Flange



Polideck 59 S (TRA)



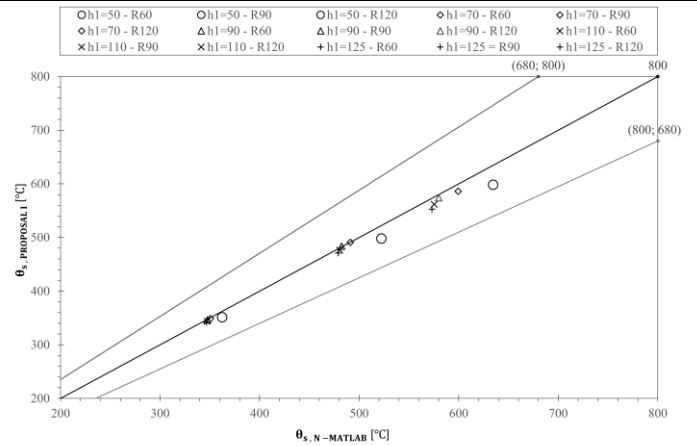
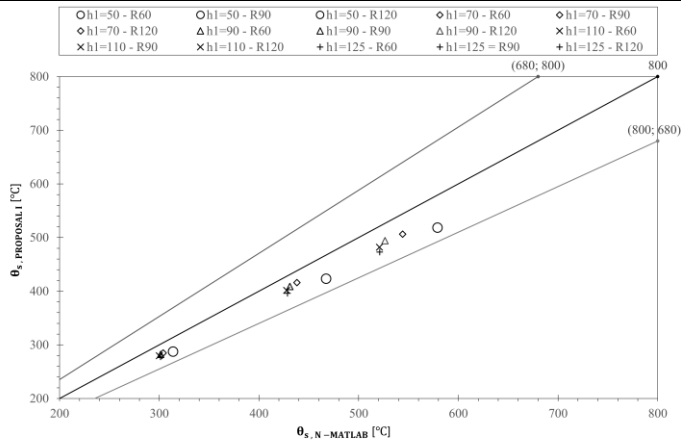
Cofraplus 60 (TRA)



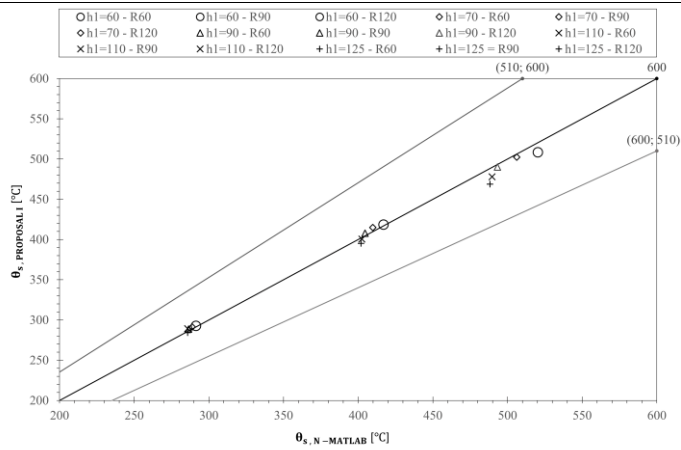
Multideck (REE)

Bondeck (REE)

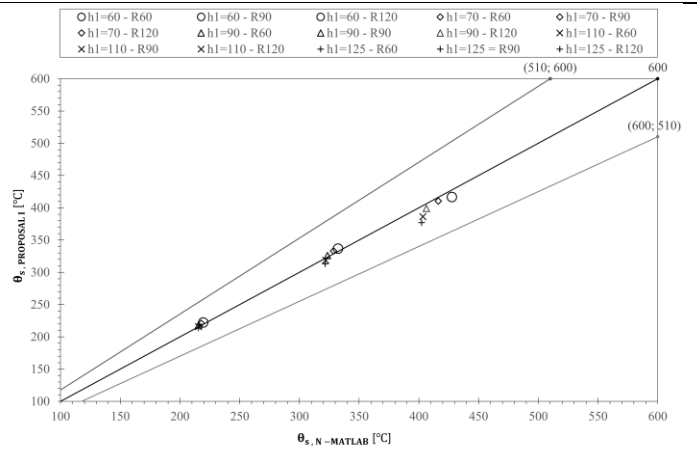
NPI – N: Rebar



Polideck 59 S (TRA)



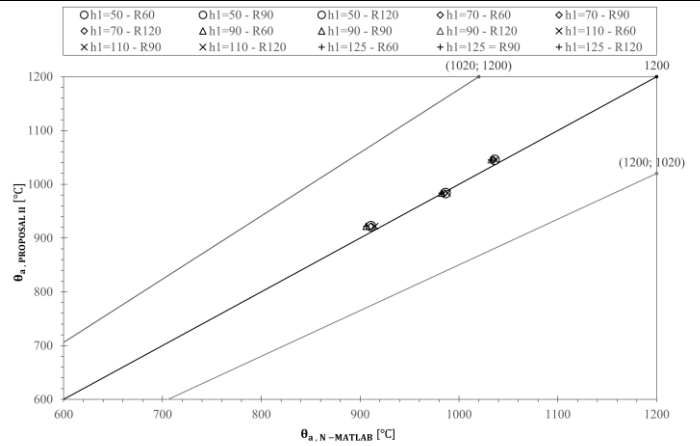
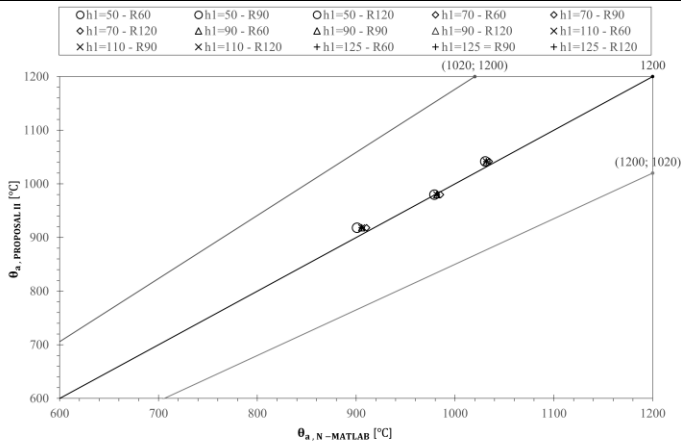
Cofraplus 60 (TRA)



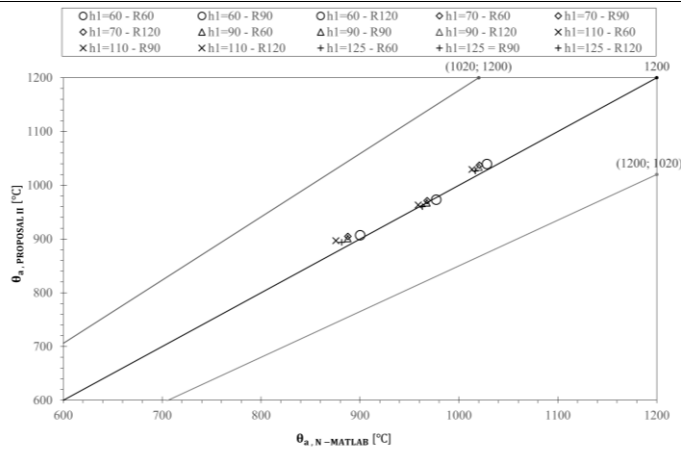
Multideck (REE)

Bondeck (REE)

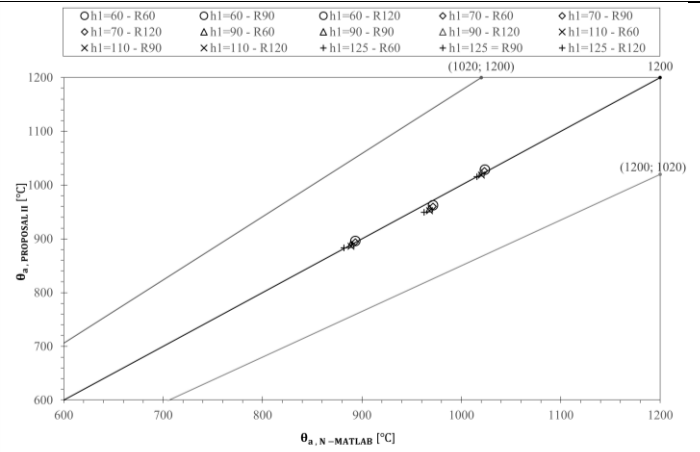
NP11 – N: Lower Flange



Polideck 59 S (TRA)



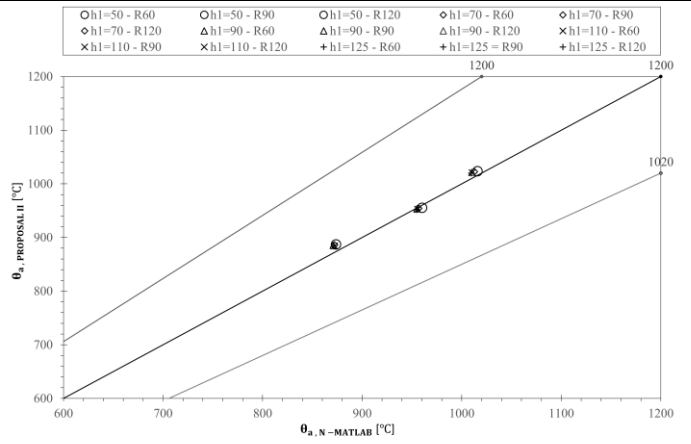
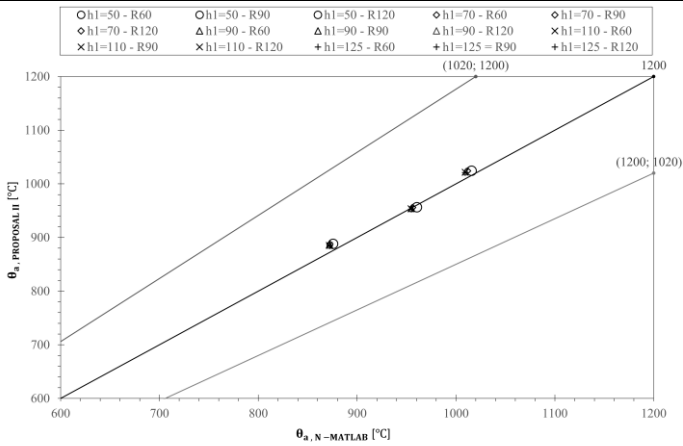
Cofraplus 60 (TRA)



Multideck (REE)

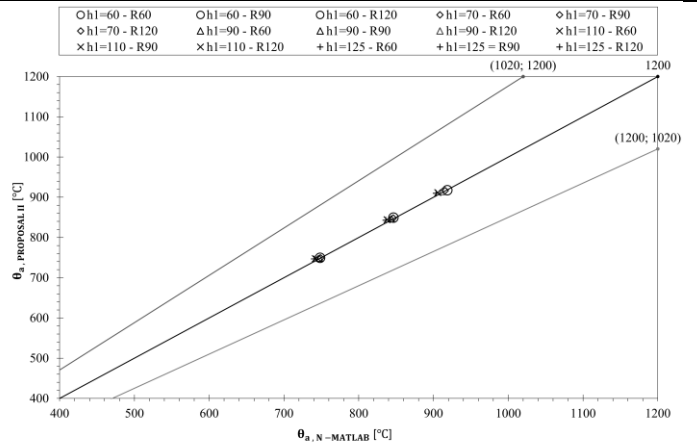
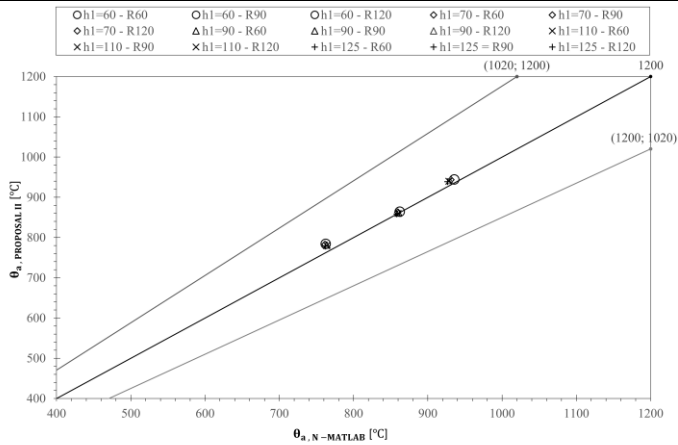
Bondeck (REE)

NP II – N: Web



Polideck 59 S (TRA)

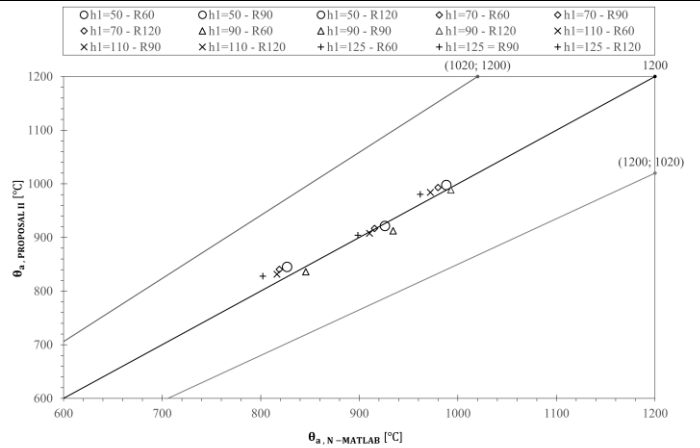
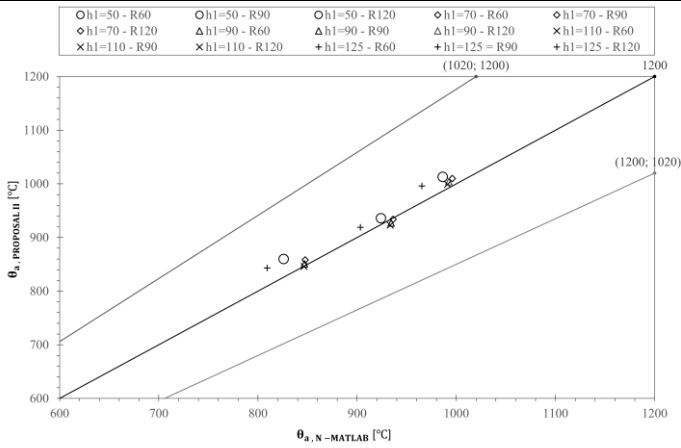
Cofraplus 60 (TRA)



Multideck (REE)

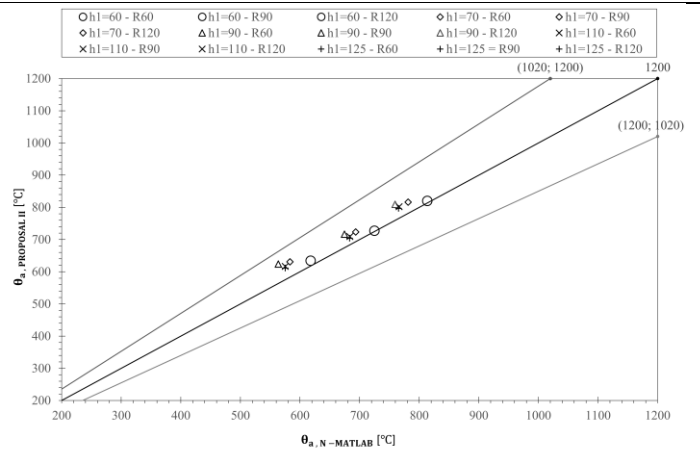
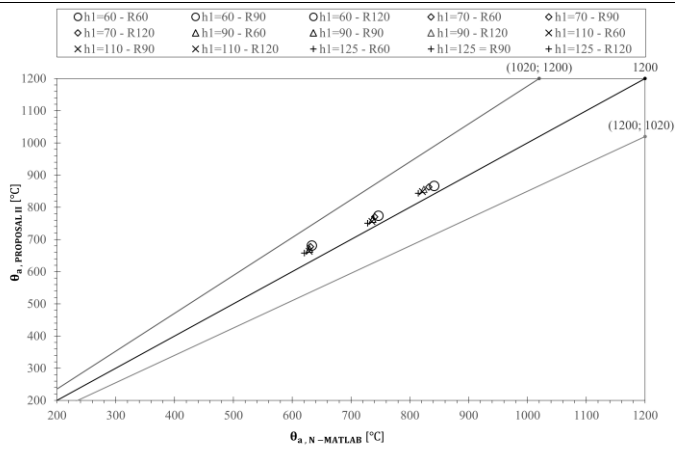
Bondeck (REE)

NP II – N: Upper



Polideck 59 S (TRA)

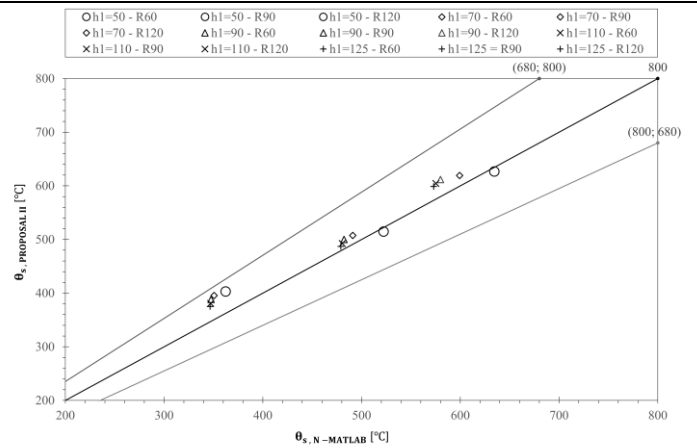
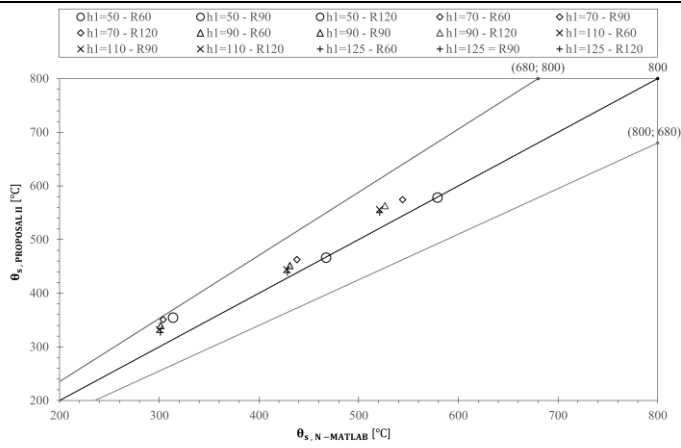
Cofraplus 60 (TRA)



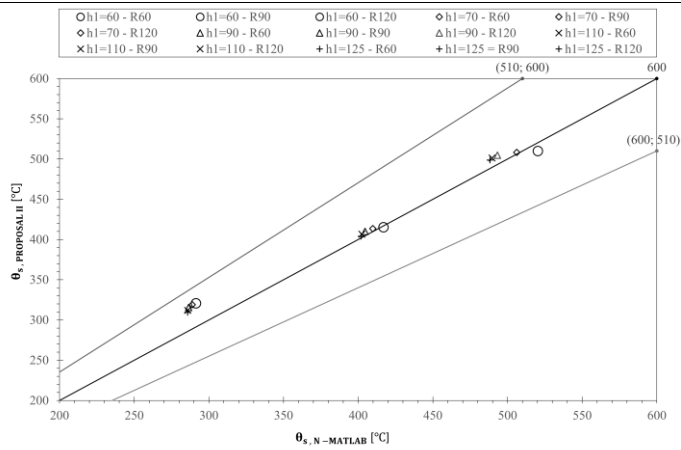
Multideck (REE)

Bondeck (REE)

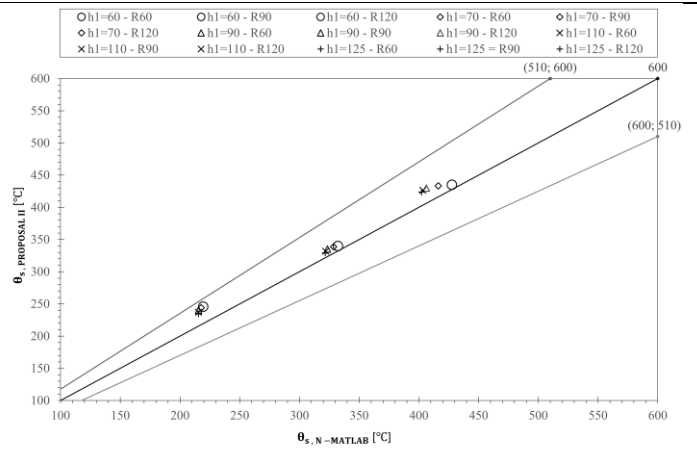
NP II – N: Rebar



Polideck 59 S (TRA)



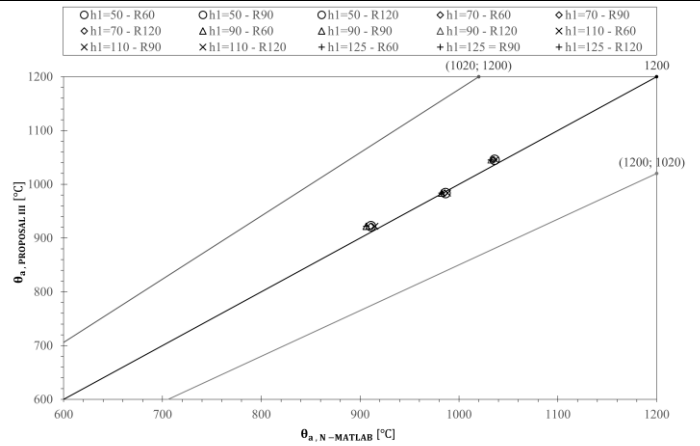
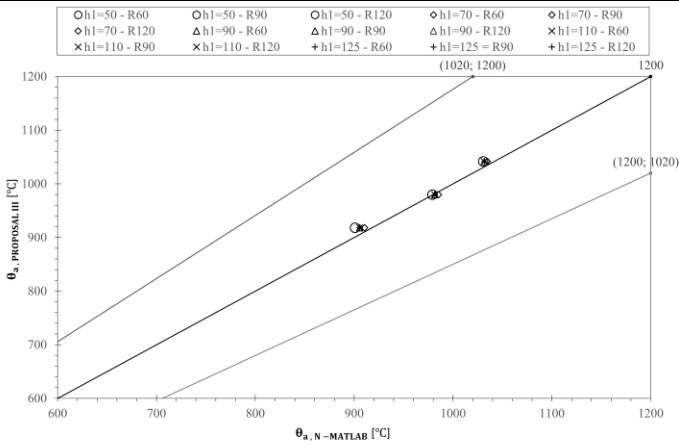
Cofraplus 60 (TRA)



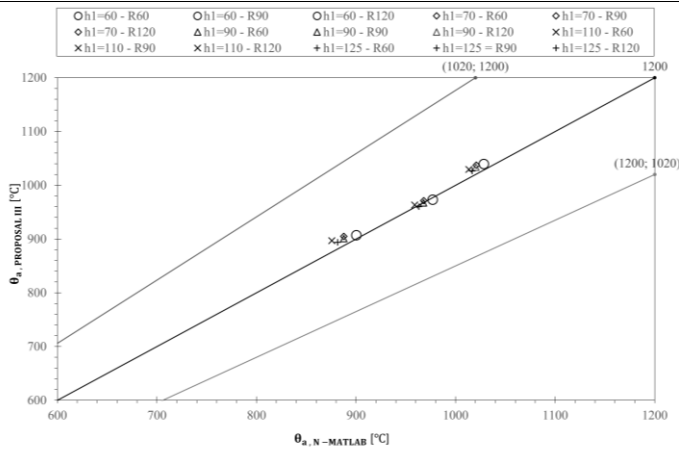
Multideck (REE)

Bondeck (REE)

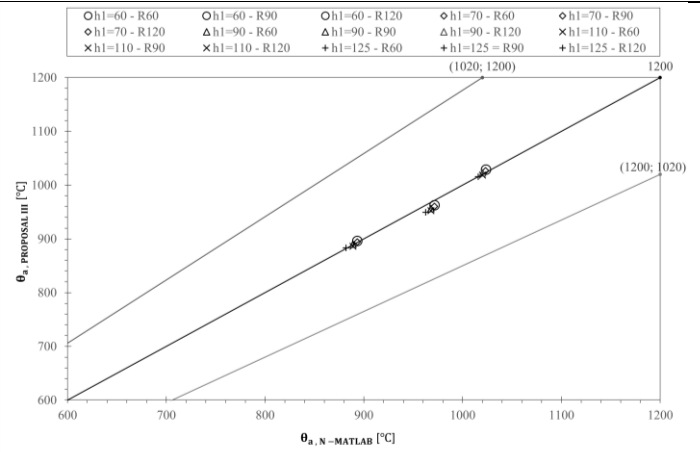
NPIII – N: Lower Flange



Polideck 59 S (TRA)



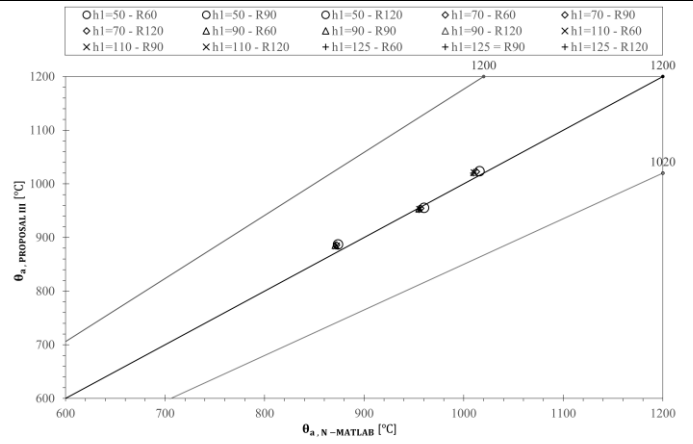
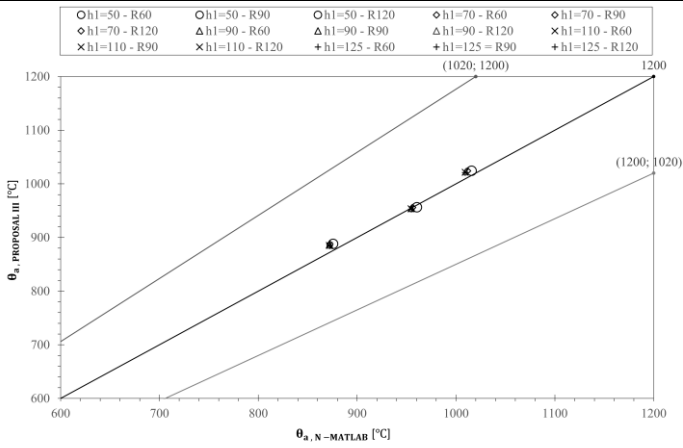
Cofraplus 60 (TRA)



Multideck (REE)

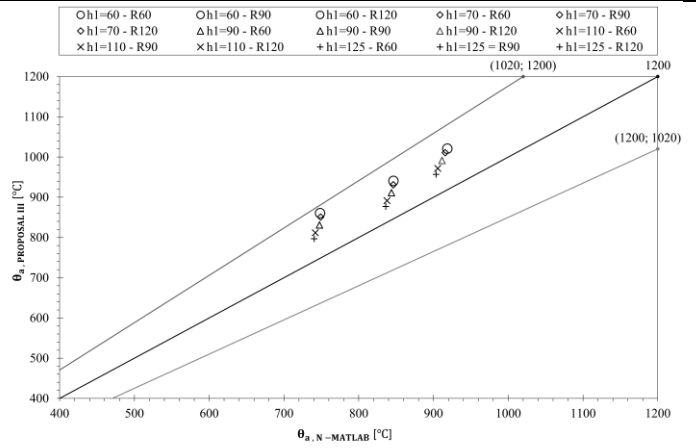
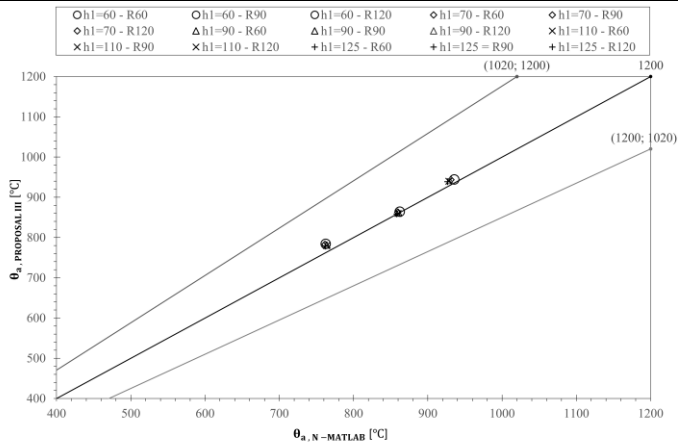
Bondeck (REE)

NP III – N: Web



Polideck 59 S (TRA)

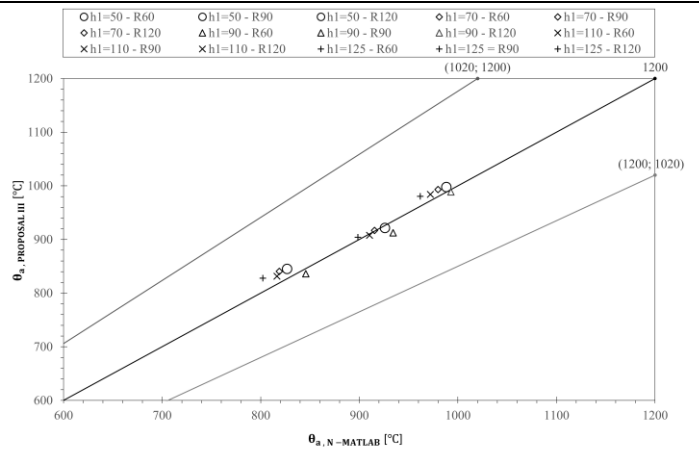
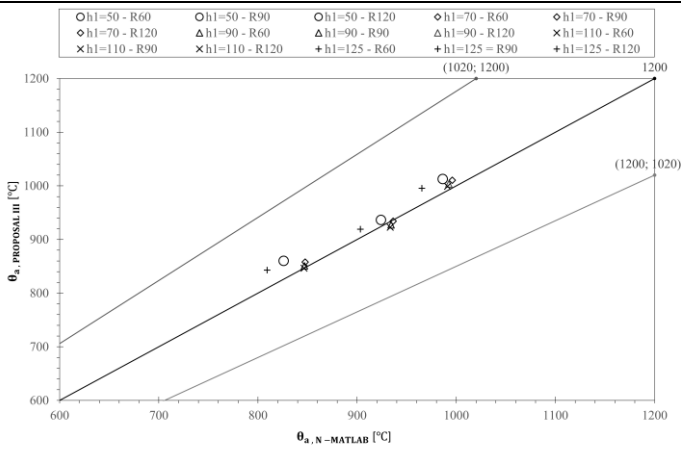
Cofraplus 60 (TRA)



Multideck (REE)

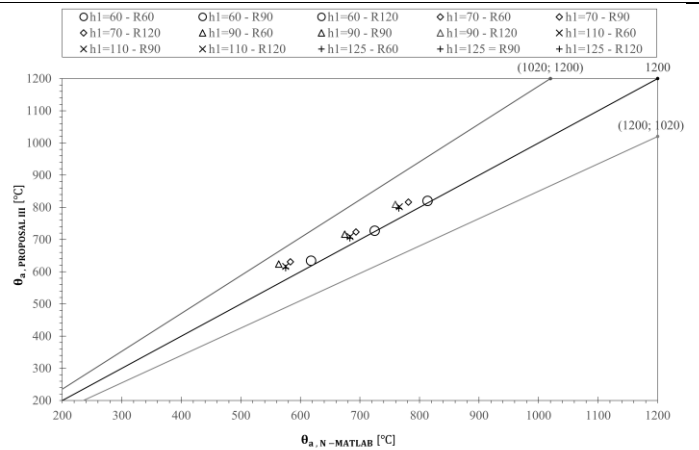
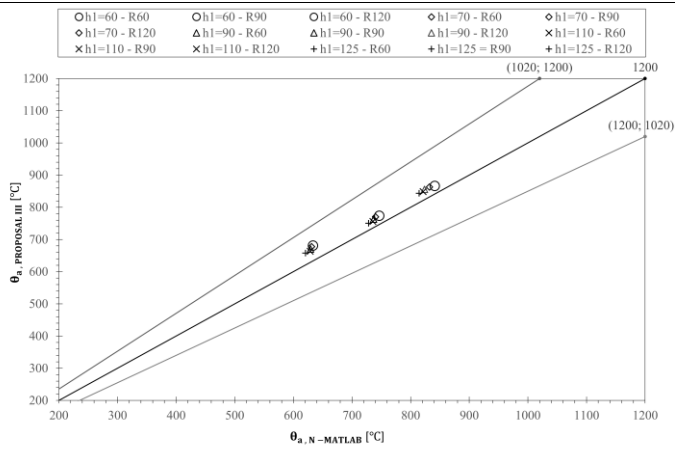
Bondeck (REE)

NP III – N: Upper



Polideck 59 S (TRA)

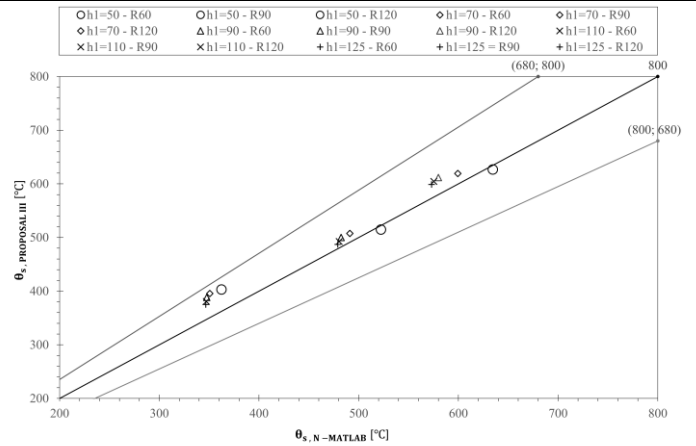
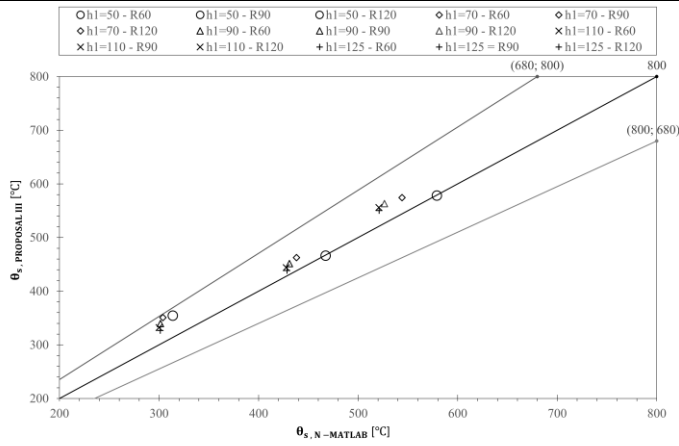
Cofraplus 60 (TRA)



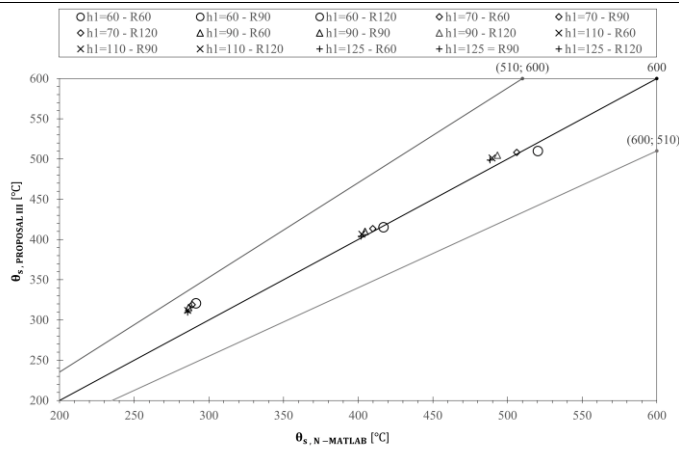
Multideck (REE)

Bondeck (REE)

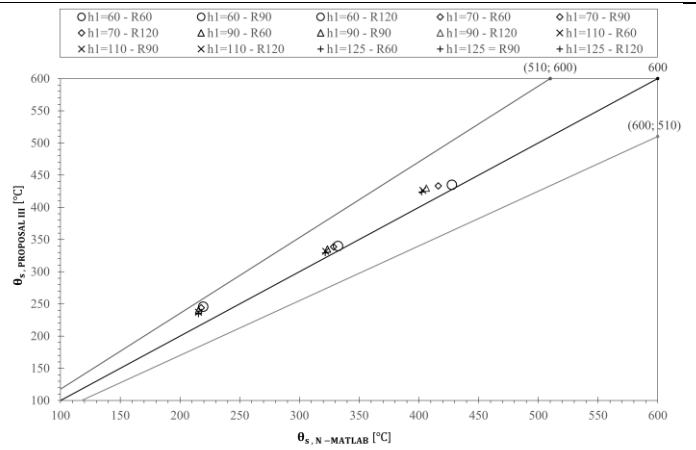
NP III – N: Rebar



Polideck 59 S (TRA)



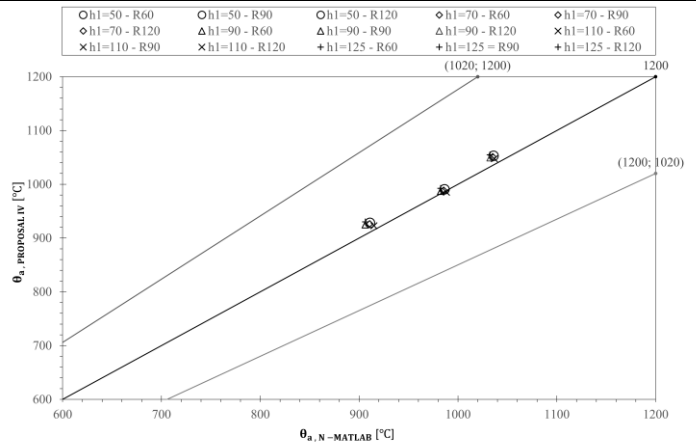
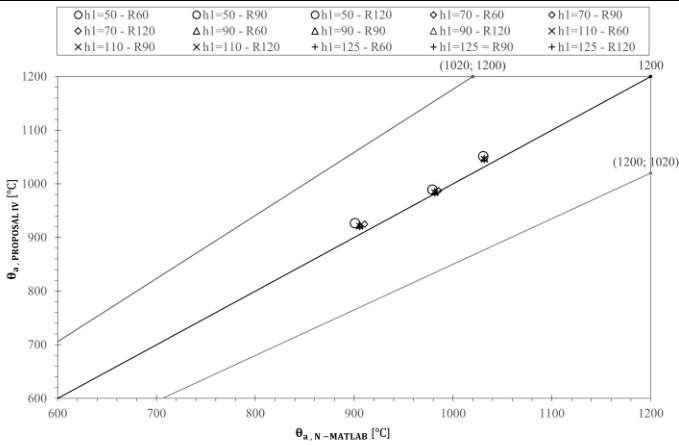
Cofraplus 60 (TRA)



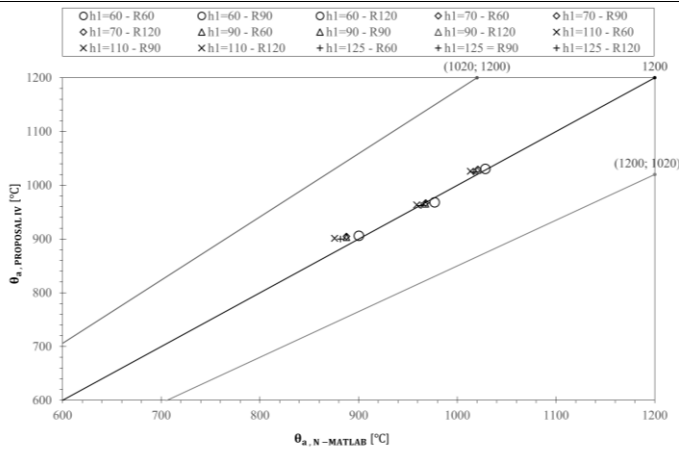
Multideck (REE)

Bondeck (REE)

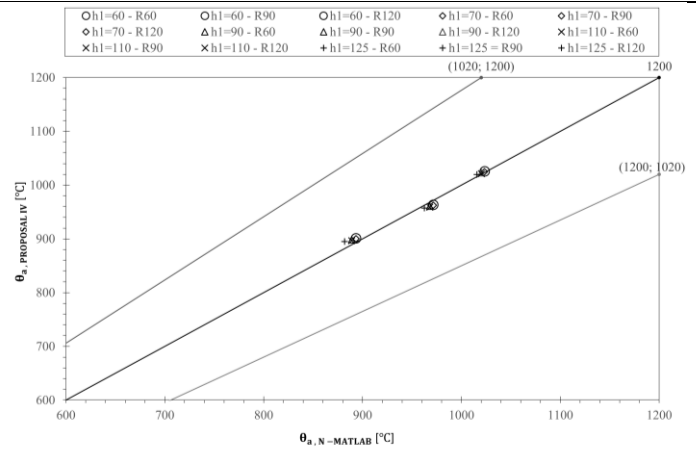
NPIV – N: Lower Flange



Polideck 59 S (TRA)



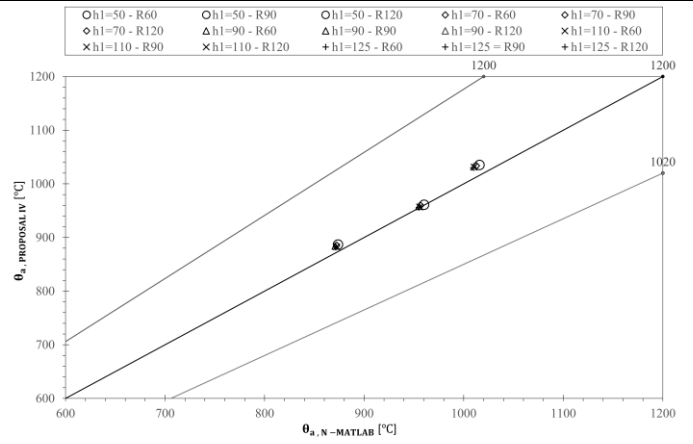
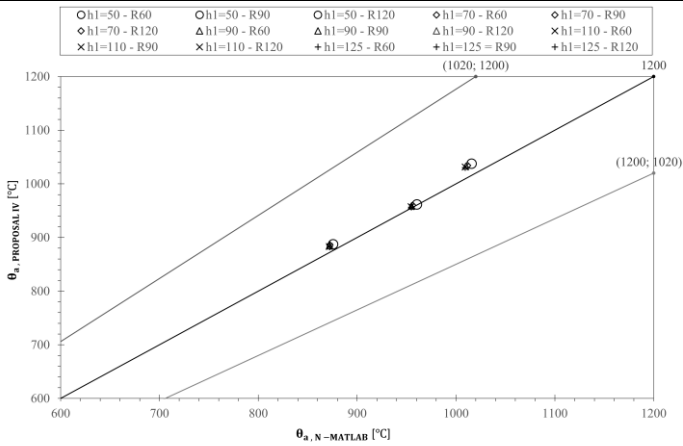
Cofraplus 60 (TRA)



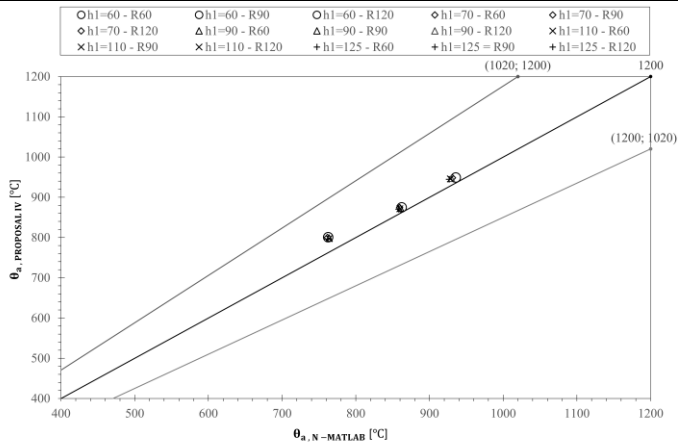
Multideck (REE)

Bondeck (REE)

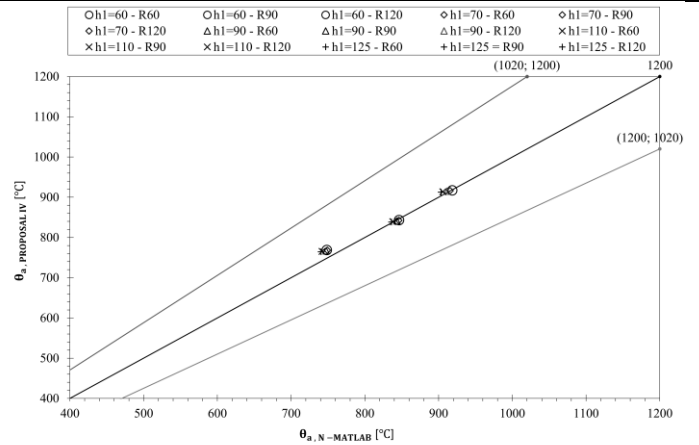
NP IV – N: Web



Polideck 59 S (TRA)



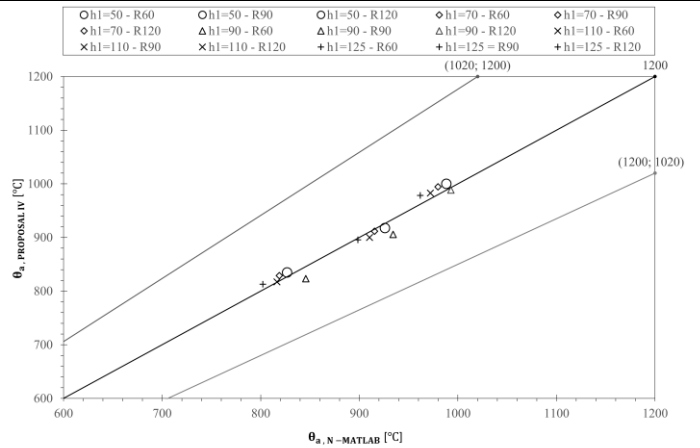
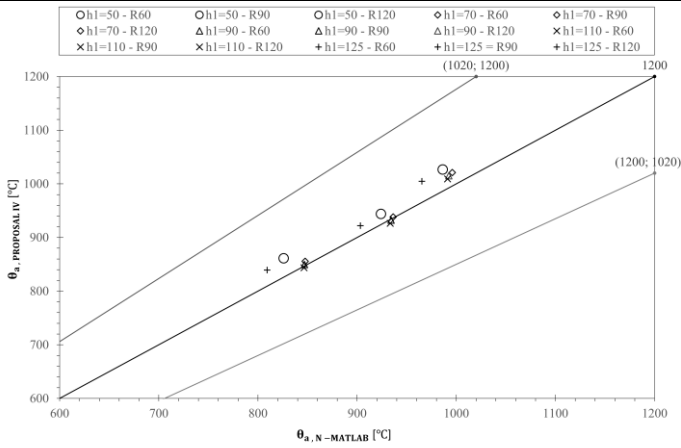
Cofraplus 60 (TRA)



Multideck (REE)

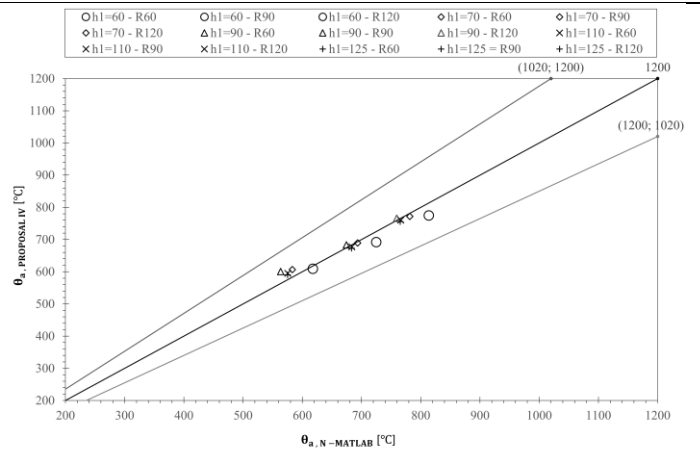
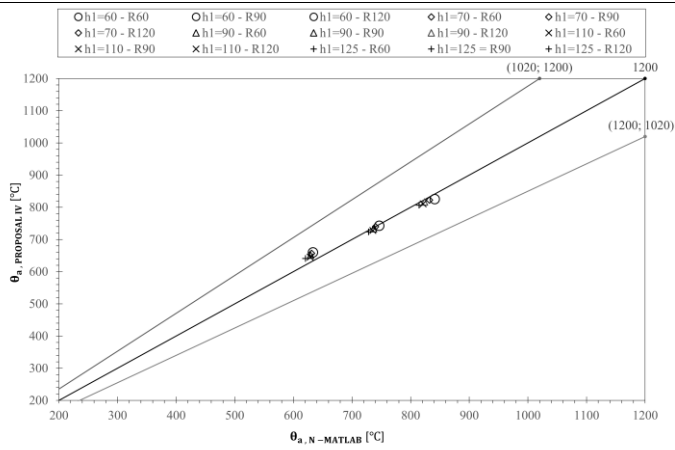
Bondeck (REE)

NP IV – N: Upper



Polideck 59 S (TRA)

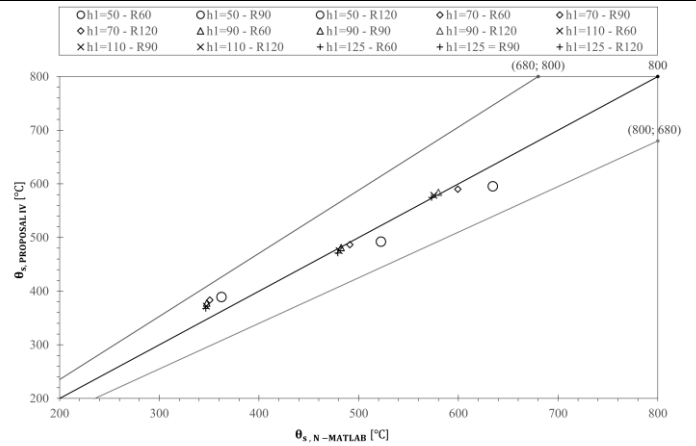
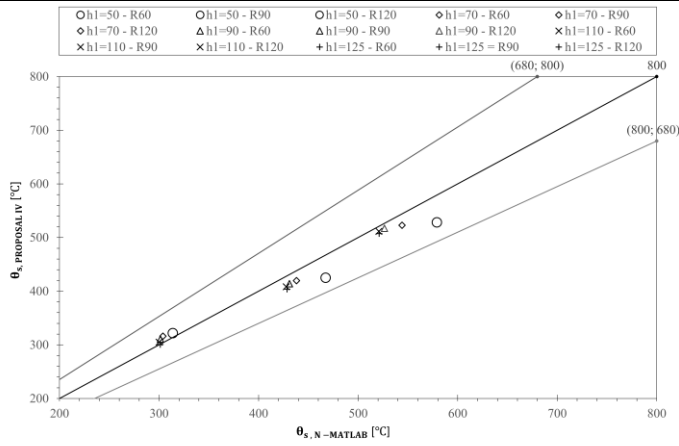
Cofraplus 60 (TRA)



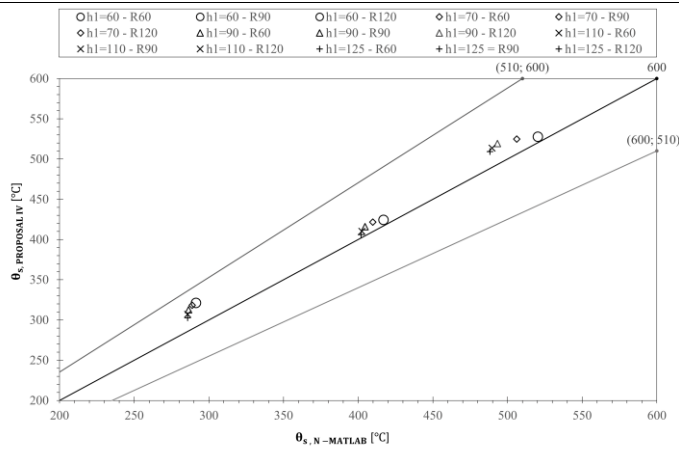
Multideck (REE)

Bondeck (REE)

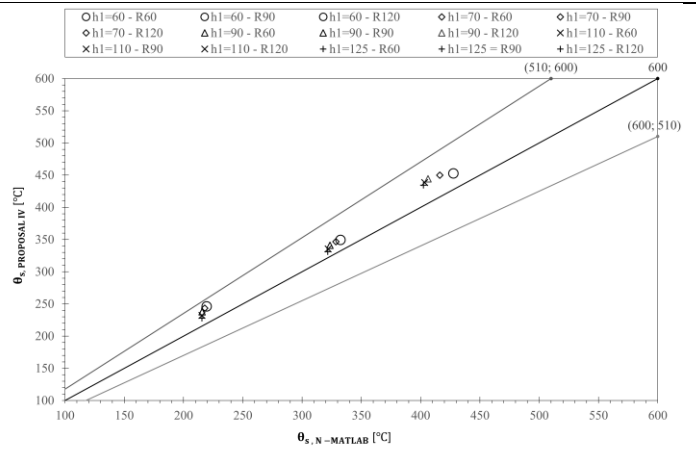
NP IV – N: Rebar



Polideck 59 S (TRA)



Cofraplus 60 (TRA)



Multideck (REE)

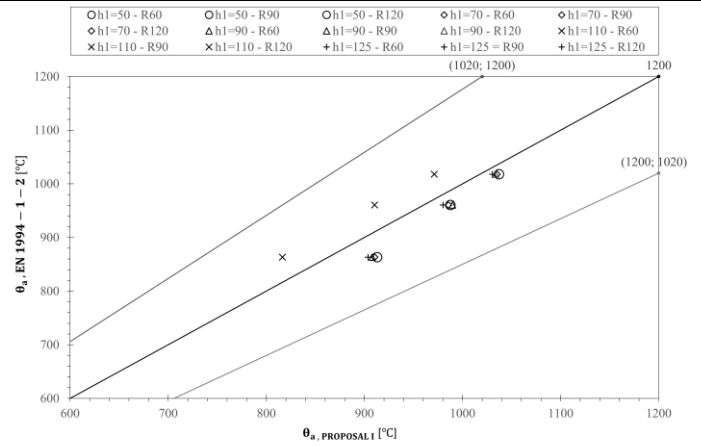
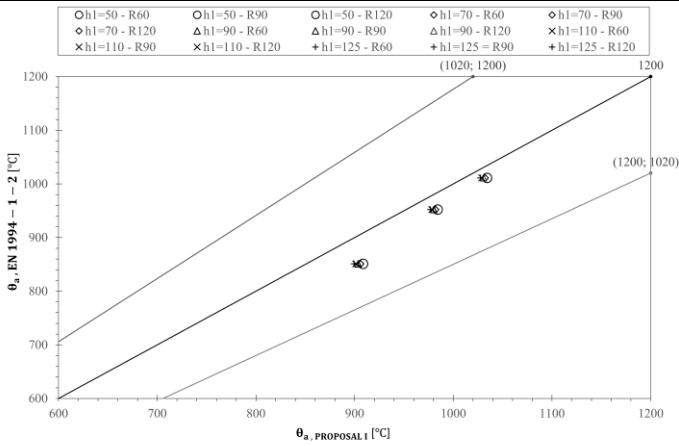
Bondeck (REE)

Appendix D

Annex D - Comparison EN-1994-1-2 rule versus proposed rules.

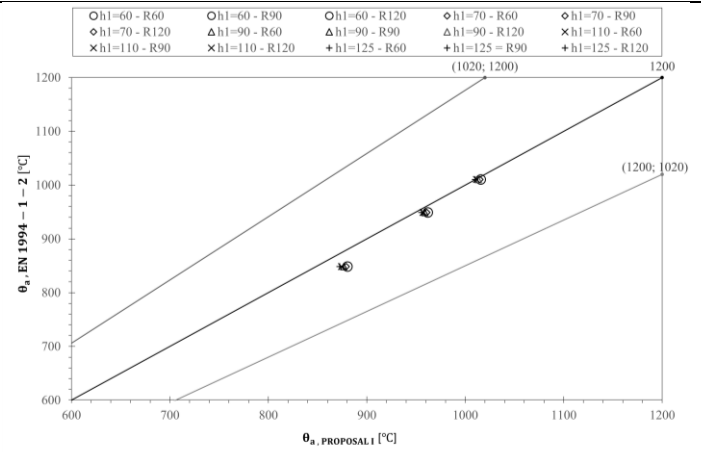
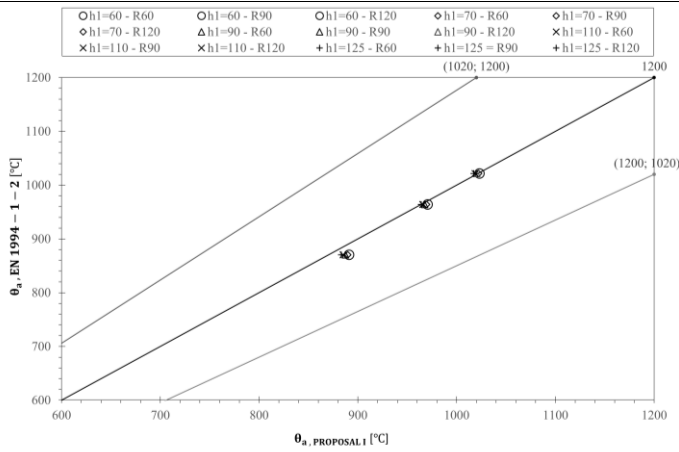
Relationship between the temperature of the flanges of the steel deck θ_a and reinforcement bar θ_s for EN-1994-1-2 (S) and the New Proposals (NP)

EN 1994-1-2 – NP I: Lower Flange



Polideck 59 S (TRA)

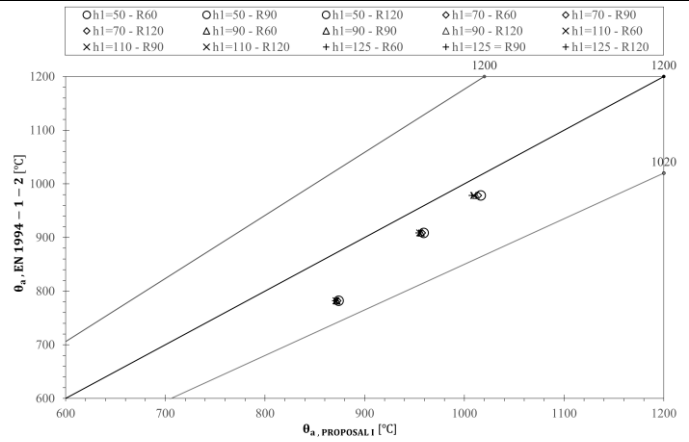
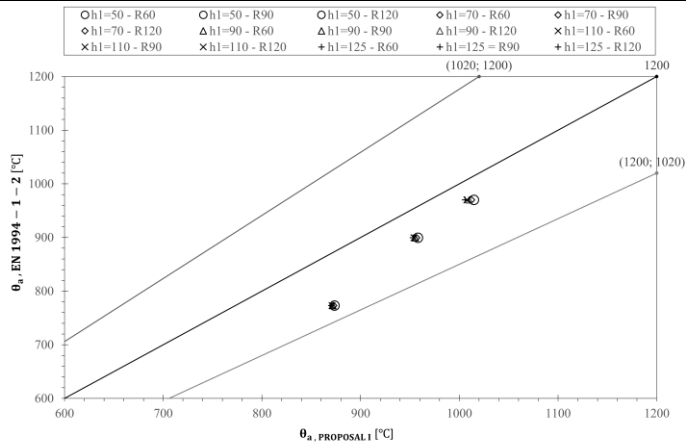
Cofraplus 60 (TRA)



Multideck (REE)

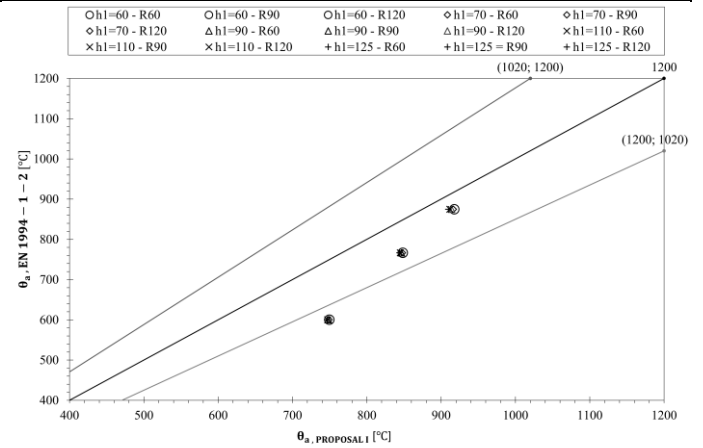
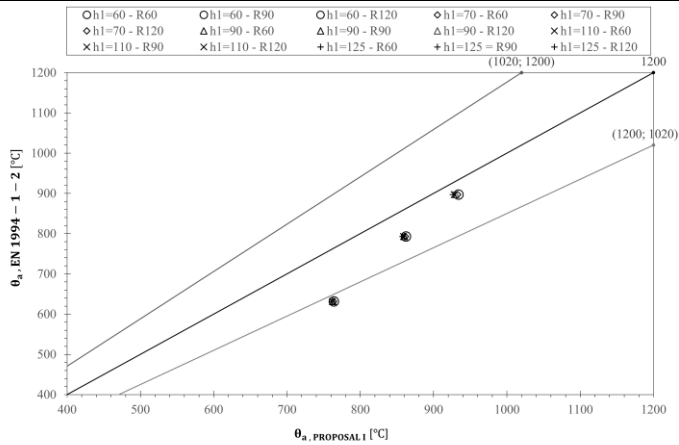
Bondeck (REE)

EN 1994-1-2 – NP I: Web



Polideck 59 S (TRA)

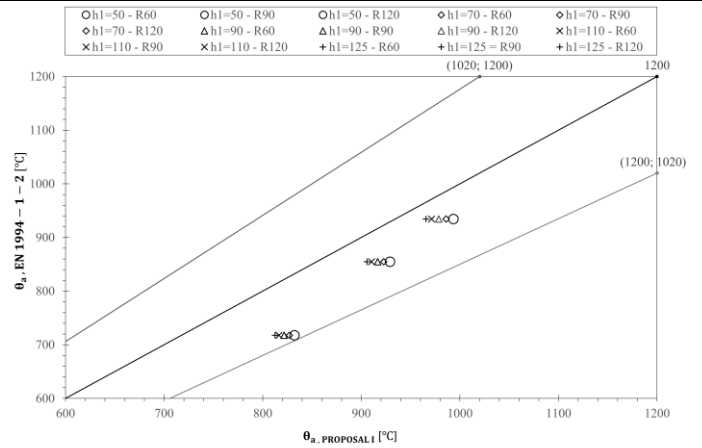
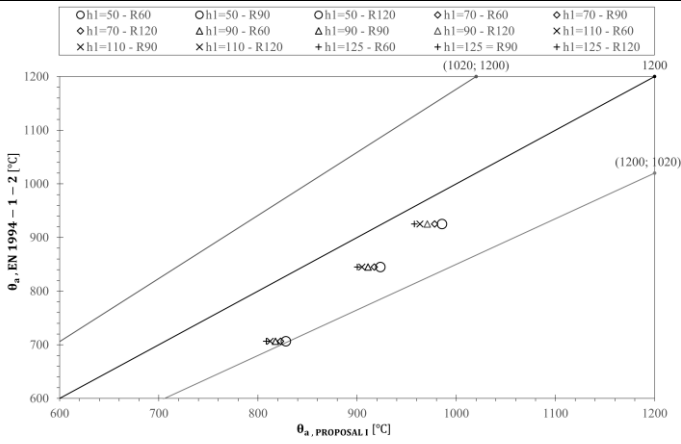
Cofraplus 60 (TRA)



Multideck (REE)

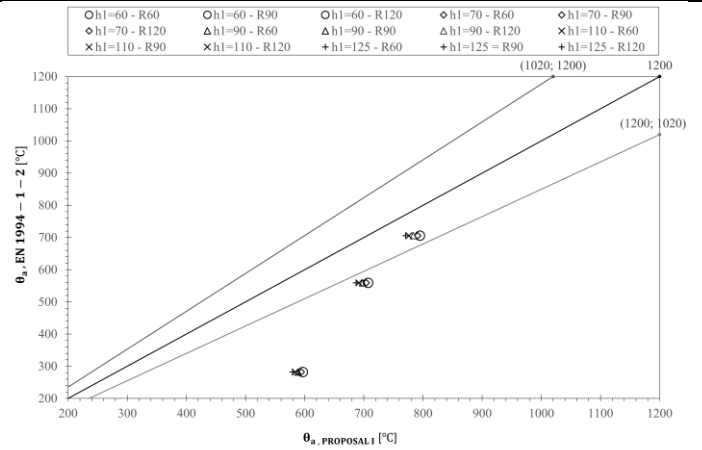
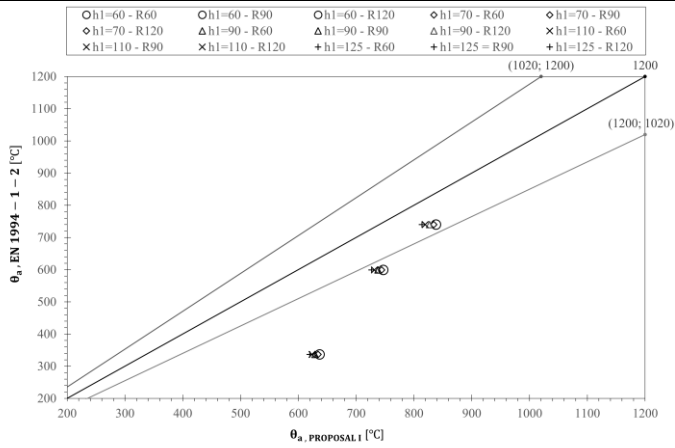
Bondeck (REE)

EN 1994-1-2 – NP I: Upper Flange



Polideck 59 S (TRA)

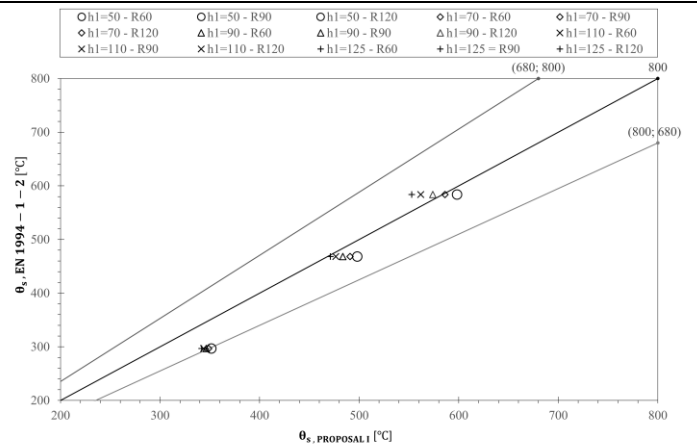
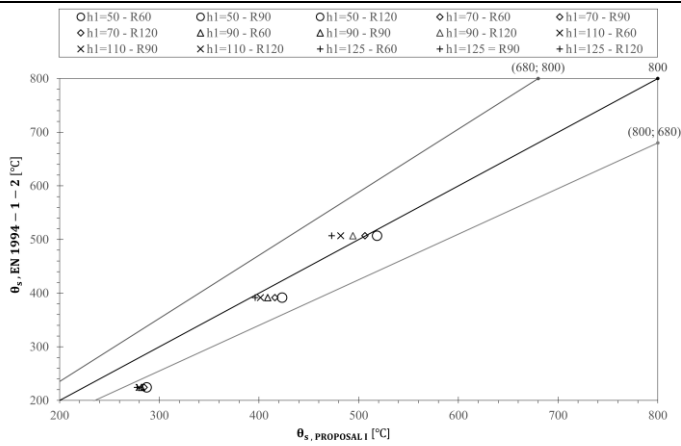
Cofraplus 60 (TRA)



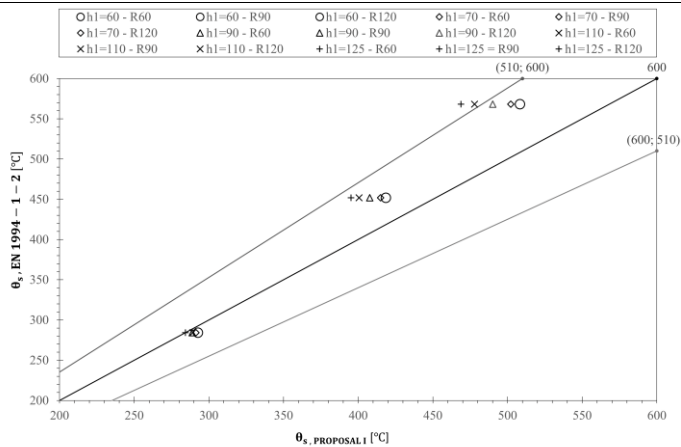
Multideck (REE)

Bondeck (REE)

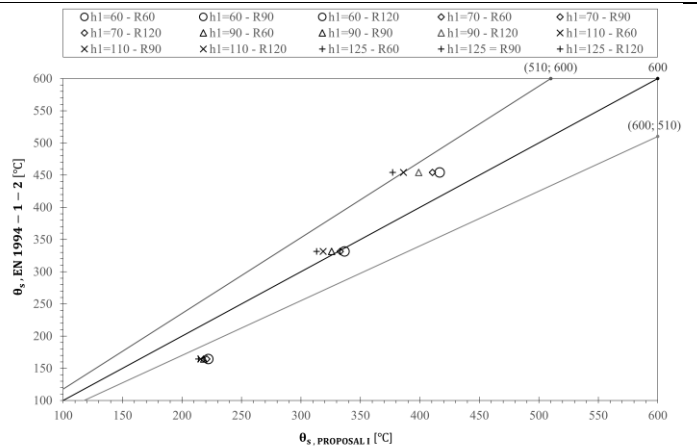
EN 1994-1-2 – NP I: Rebar



Polideck 59 S (TRA)



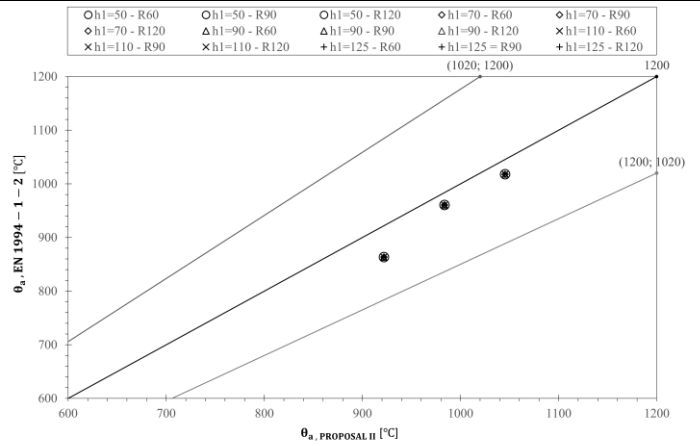
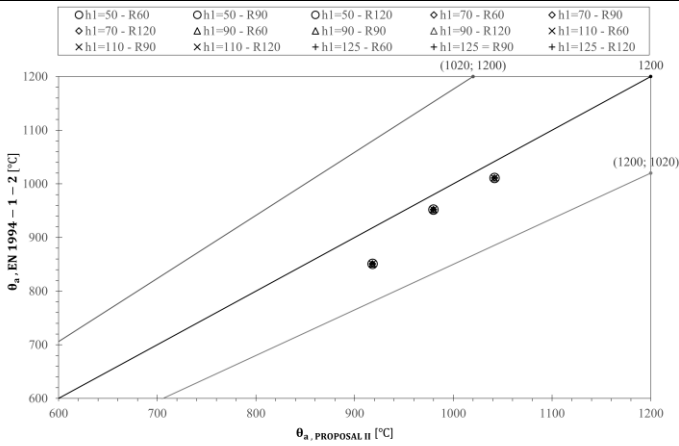
Cofraplus 60 (TRA)



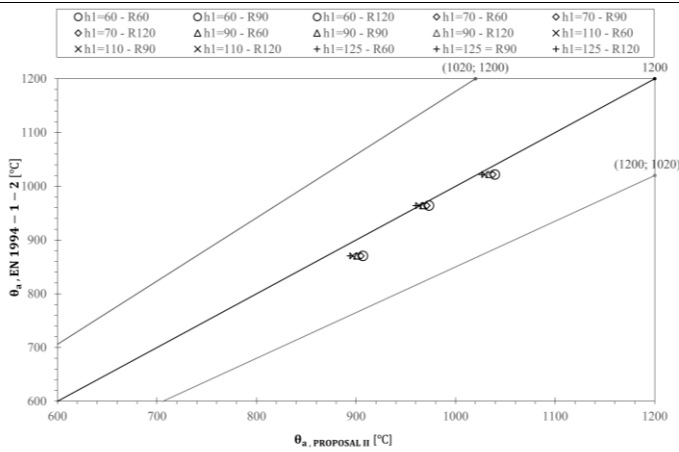
Multideck (REE)

Bondeck (REE)

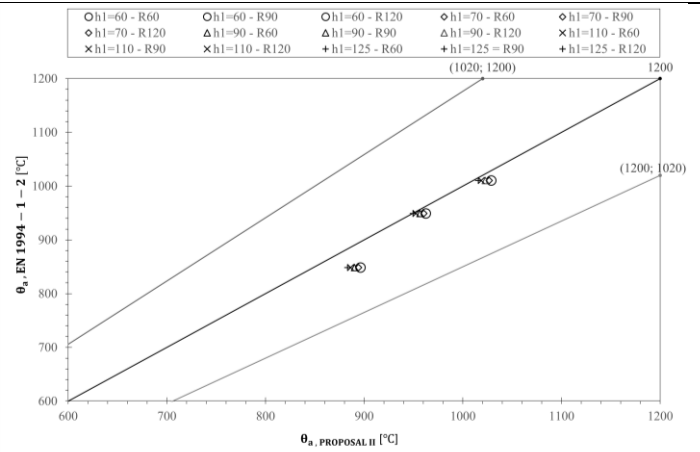
EN 1994-1-2 – NP II: Lower Flange



Polideck 59 S (TRA)



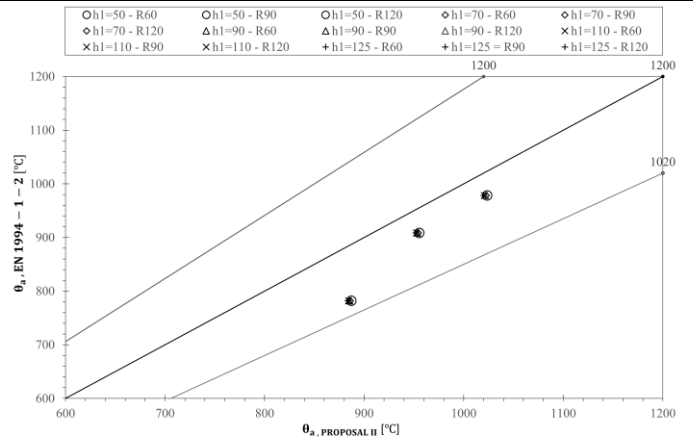
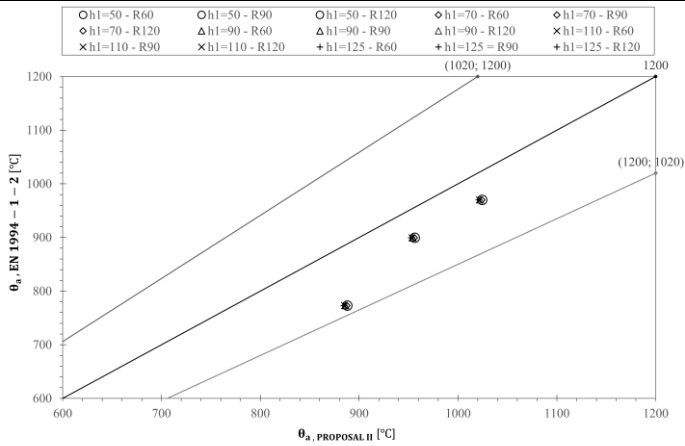
Cofraplus 60 (TRA)



Multideck (REE)

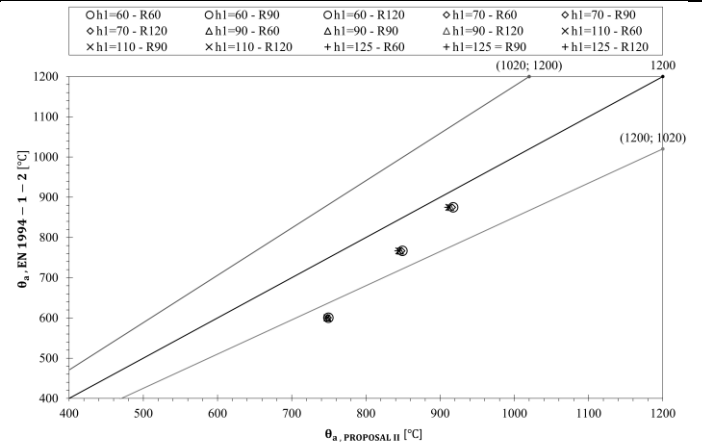
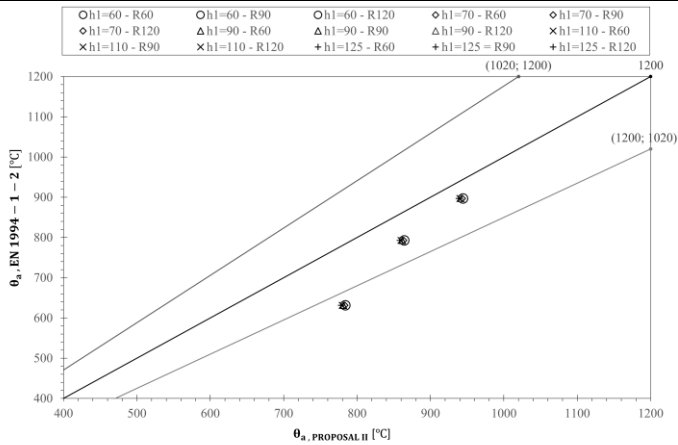
Bondeck (REE)

EN 1994-1-2 – NP II: Web



Polideck 59 S (TRA)

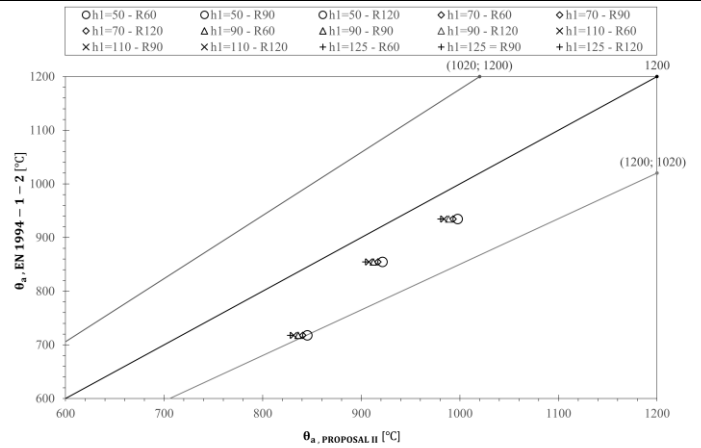
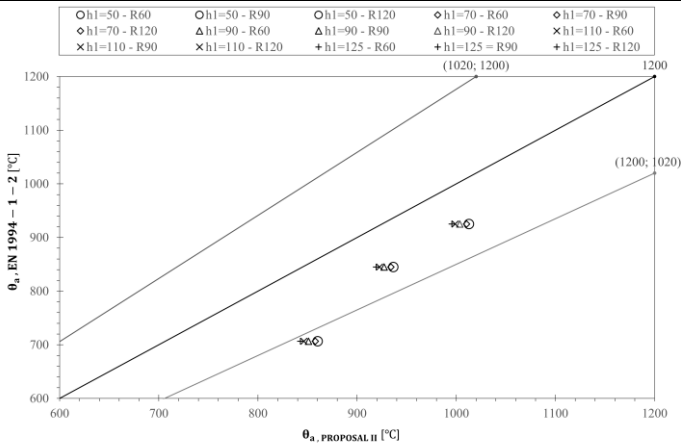
Cofraplus 60 (TRA)



Multideck (REE)

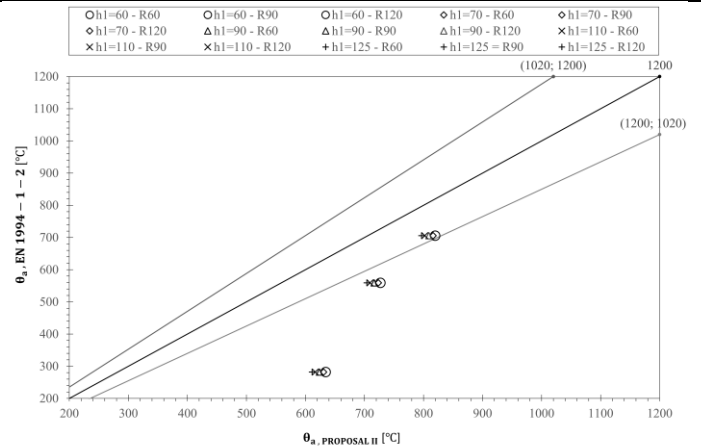
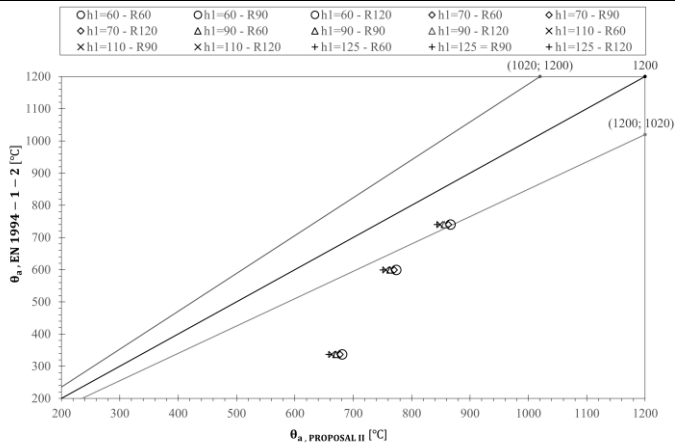
Bondeck (REE)

EN 1994-1-2 – NP II: Upper



Polideck 59 S (TRA)

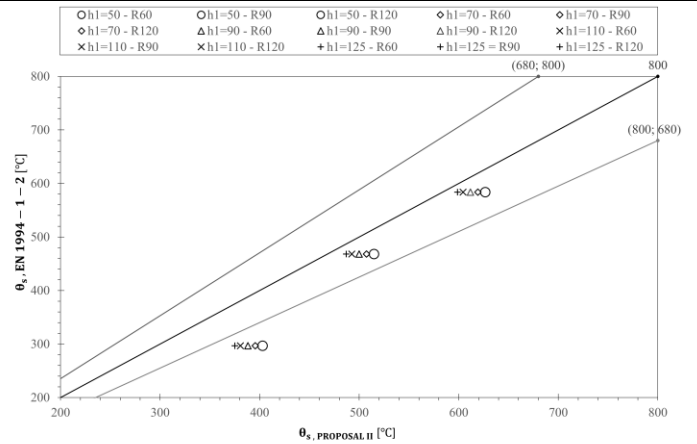
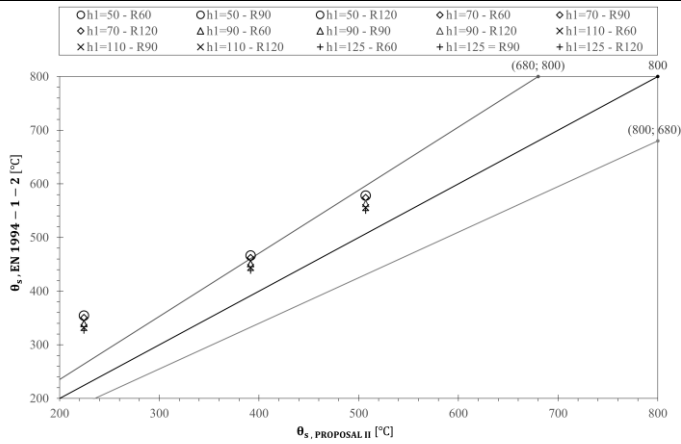
Cofraplus 60 (TRA)



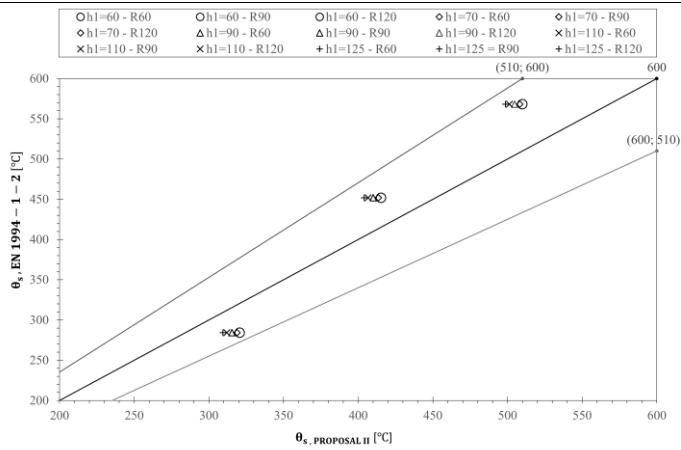
Multideck (REE)

Bondeck (REE)

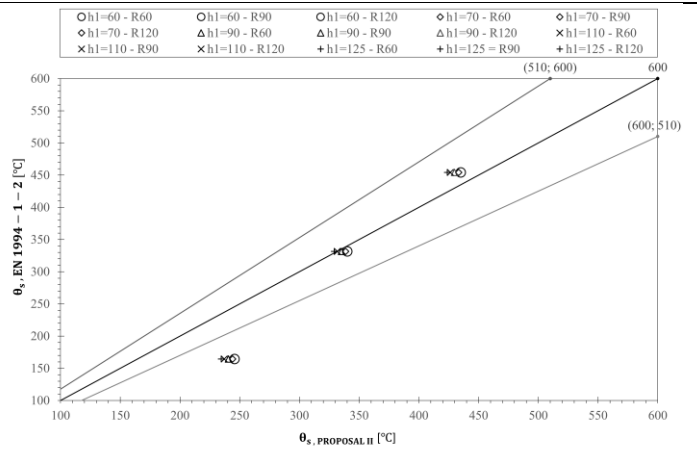
EN 1994-1-2 – NP II: Rebar



Polideck 59 S (TRA)



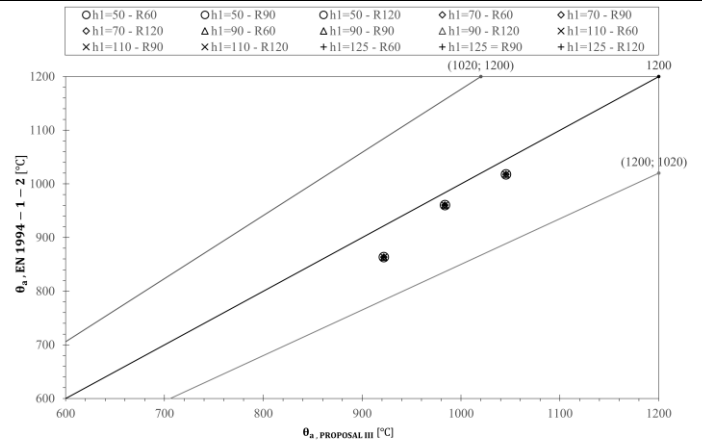
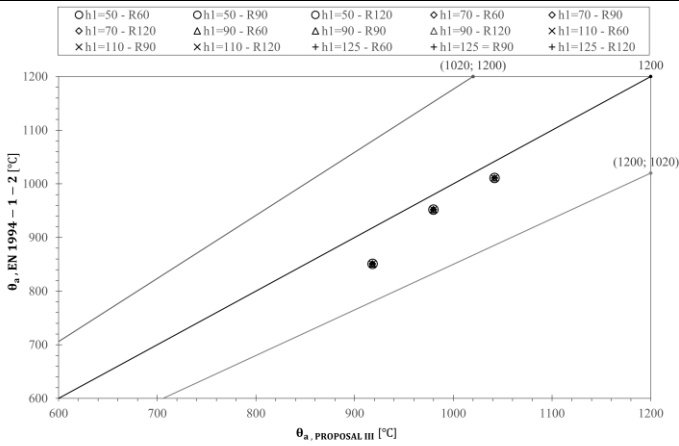
Cofraplus 60 (TRA)



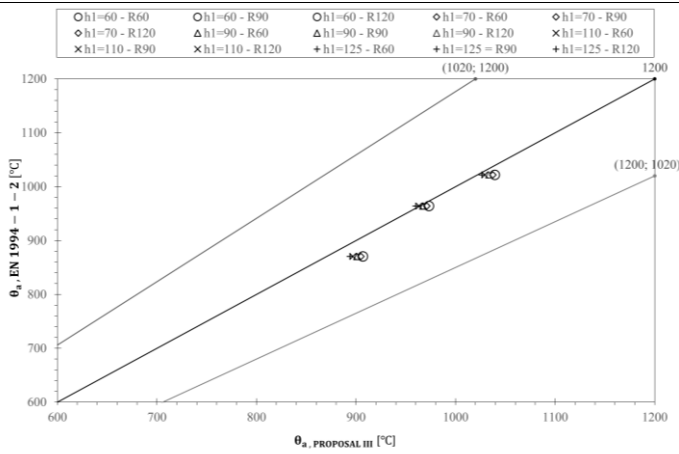
Multideck (REE)

Bondeck (REE)

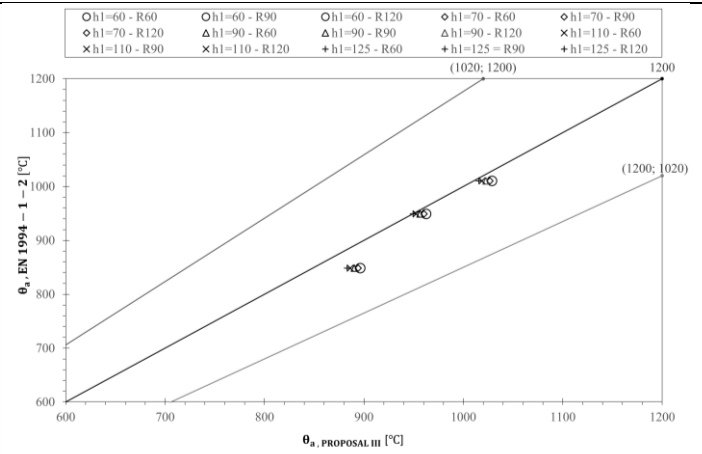
EN 1994-1-2 – NP III: Lower Flange



Polideck 59 S (TRA)



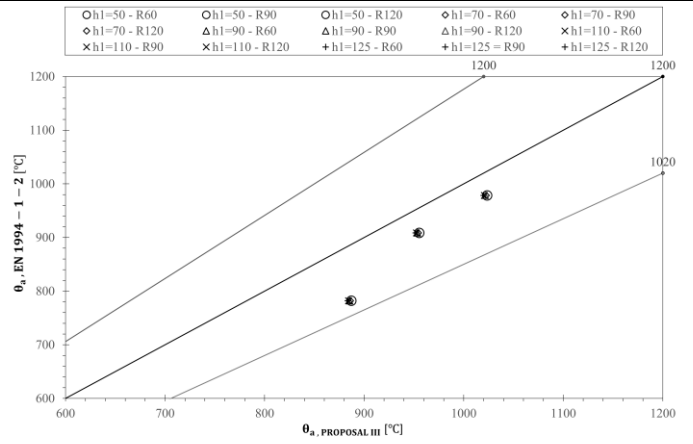
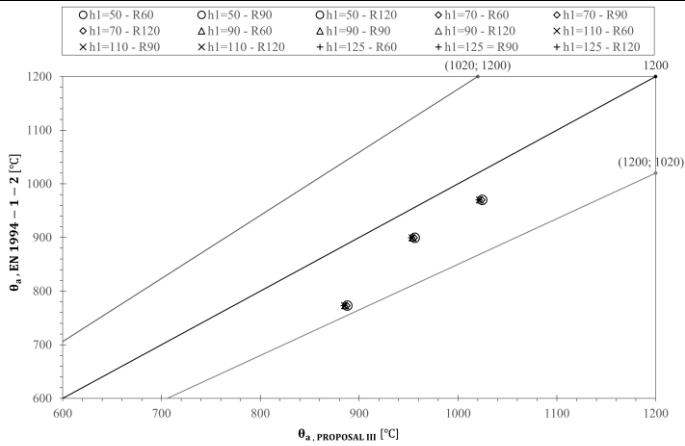
Cofraplus 60 (TRA)



Multideck (REE)

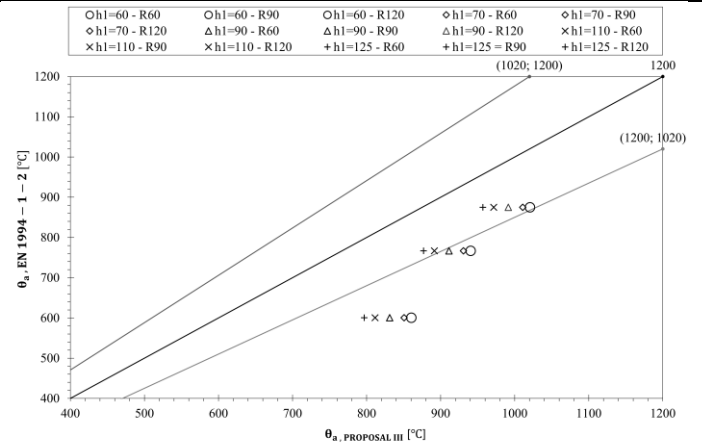
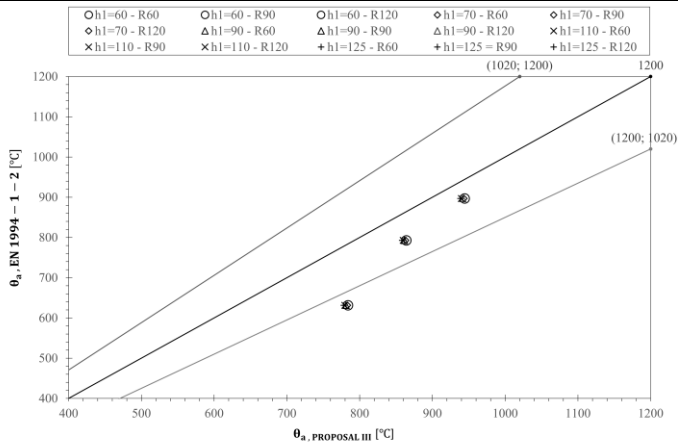
Bondeck (REE)

EN 1994-1-2 – NP III: Web



Polideck 59 S (TRA)

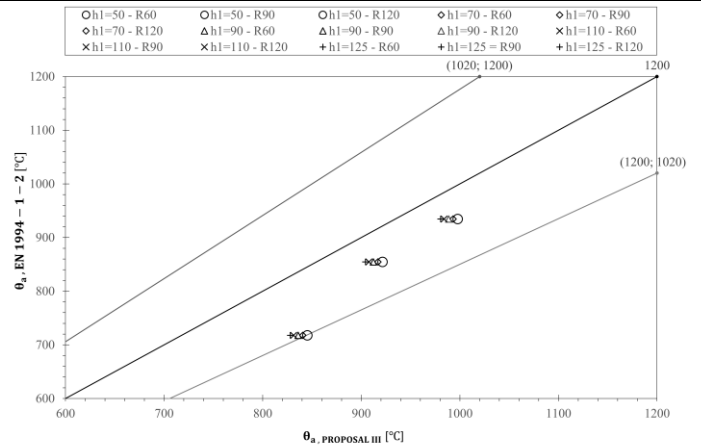
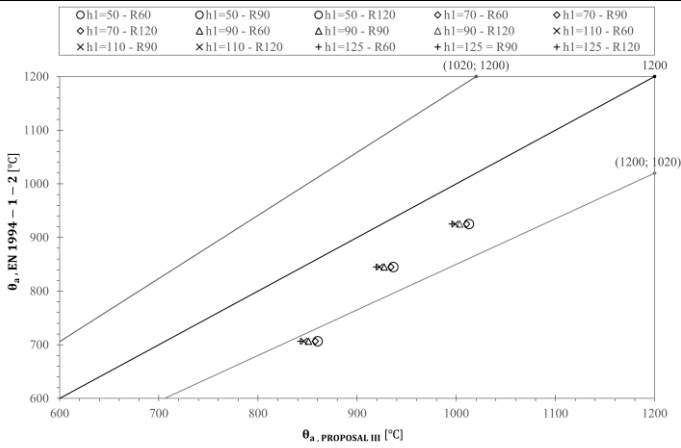
Cofraplus 60 (TRA)



Multideck (REE)

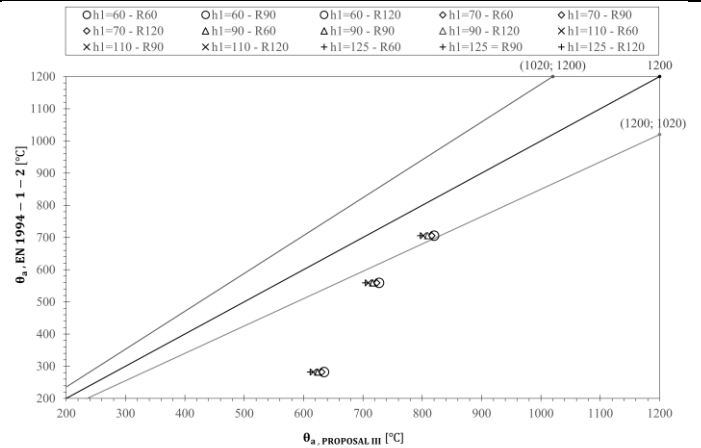
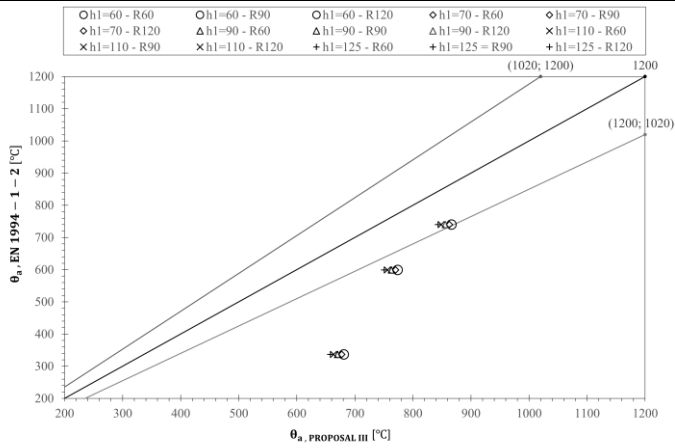
Bondeck (REE)

EN 1994-1-2 – NP III: Upper



Polideck 59 S (TRA)

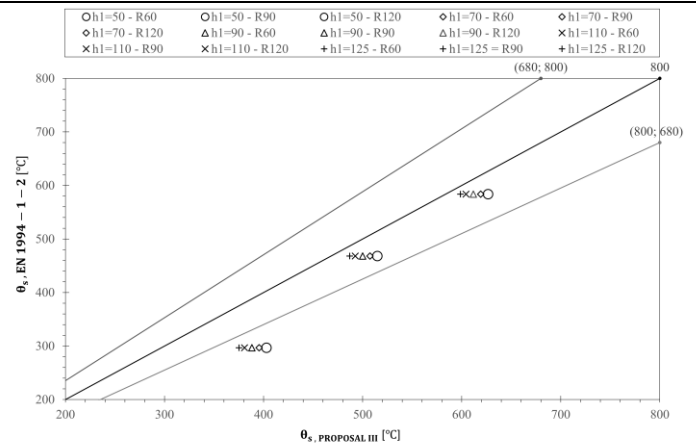
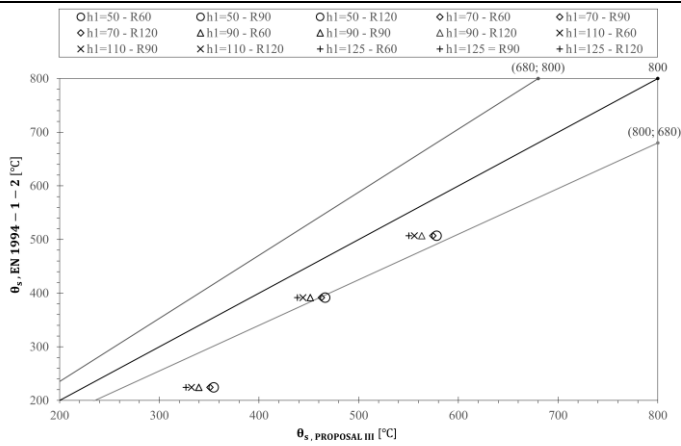
Cofraplus 60 (TRA)



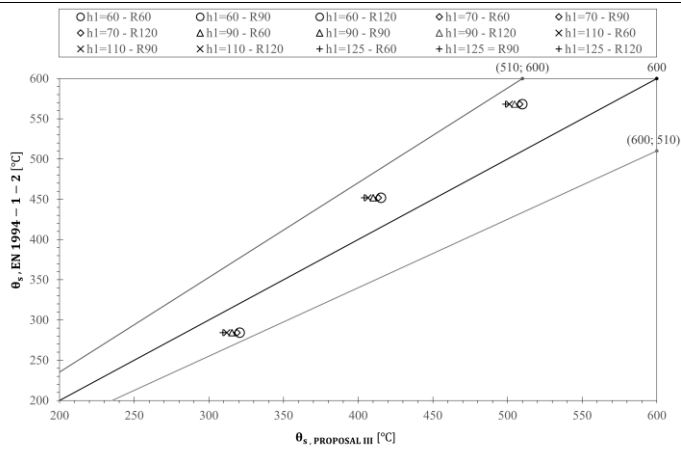
Multideck (REE)

Bondeck (REE)

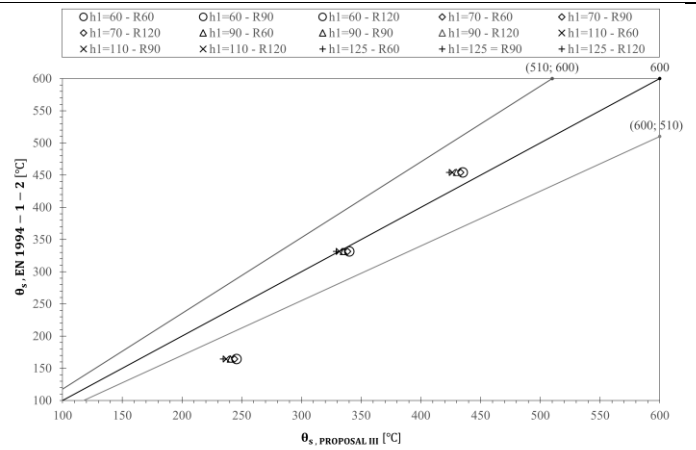
EN 1994-1-2 – NP III: Rebar



Polideck 59 S (TRA)



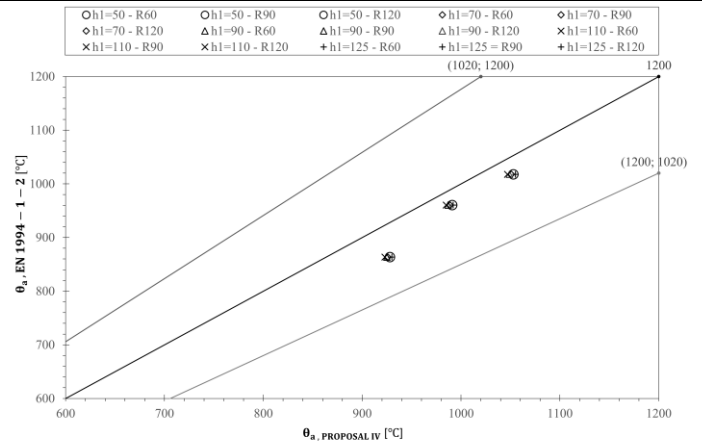
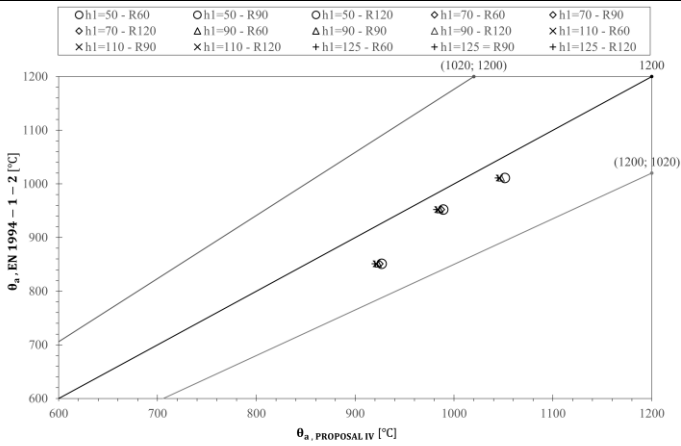
Cofraplus 60 (TRA)



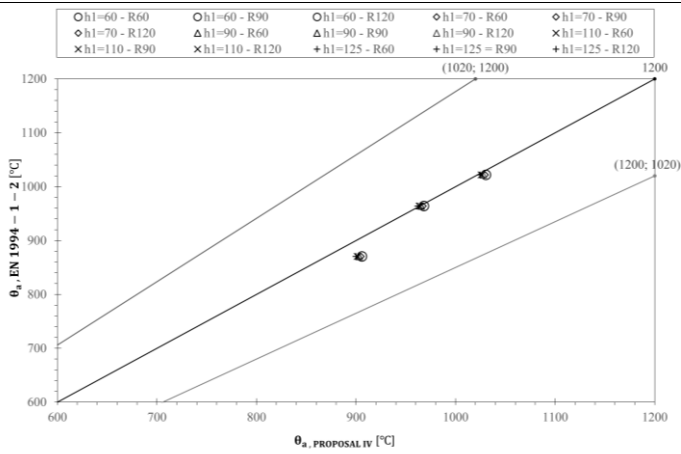
Multideck (REE)

Bondeck (REE)

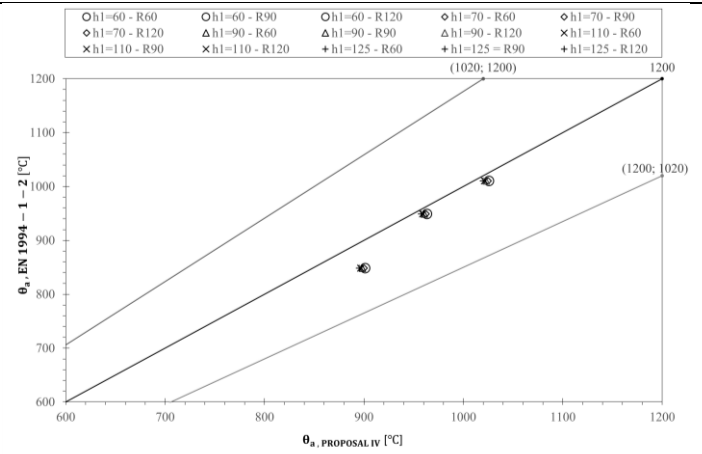
EN 1994-1-2 – NP IV: Lower Flange



Polideck 59 S (TRA)



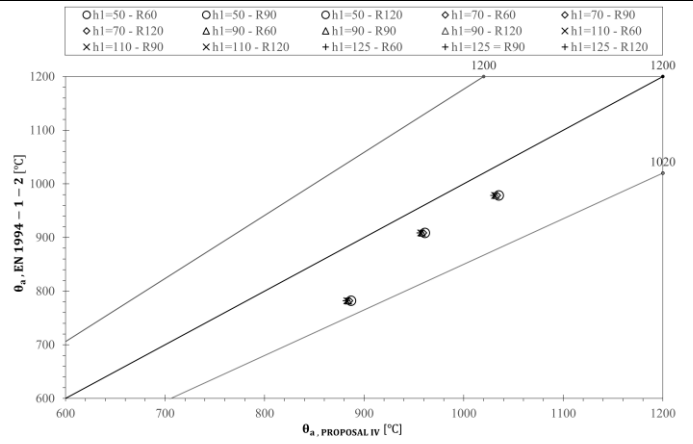
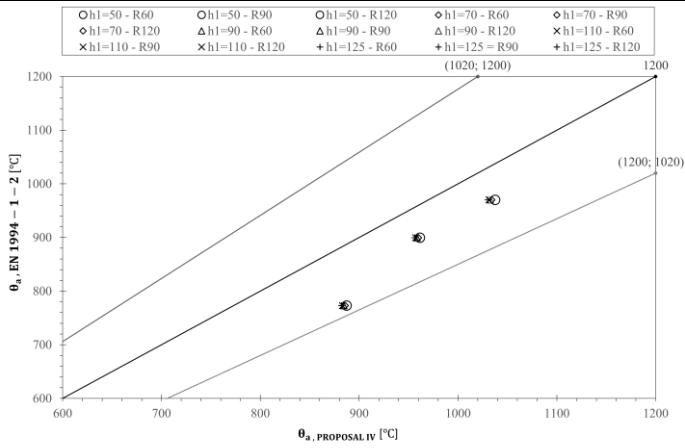
Cofraplus 60 (TRA)



Multideck (REE)

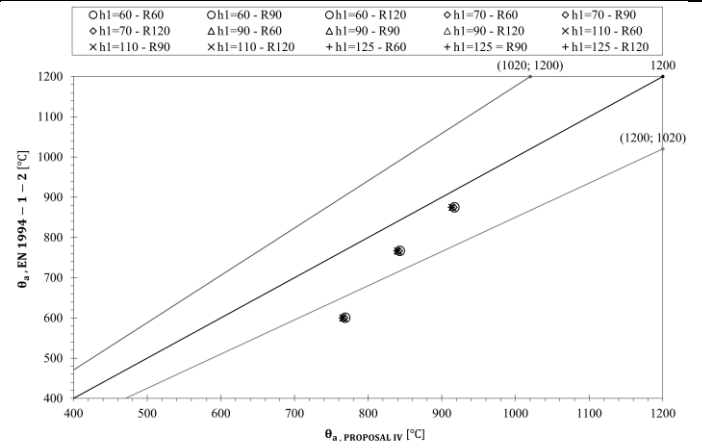
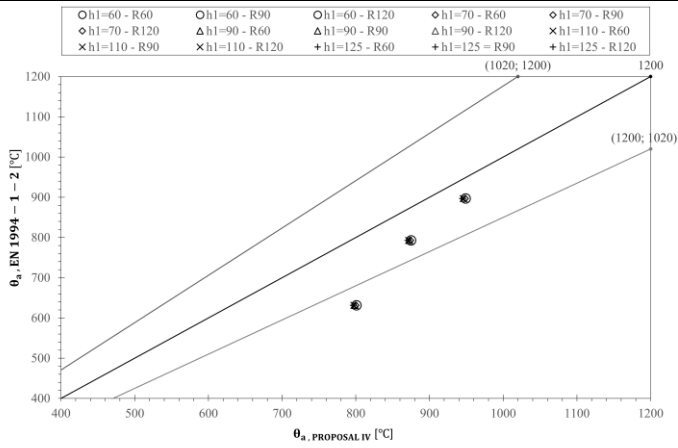
Bondeck (REE)

EN 1994-1-2 – NP IV: Web



Polideck 59 S (TRA)

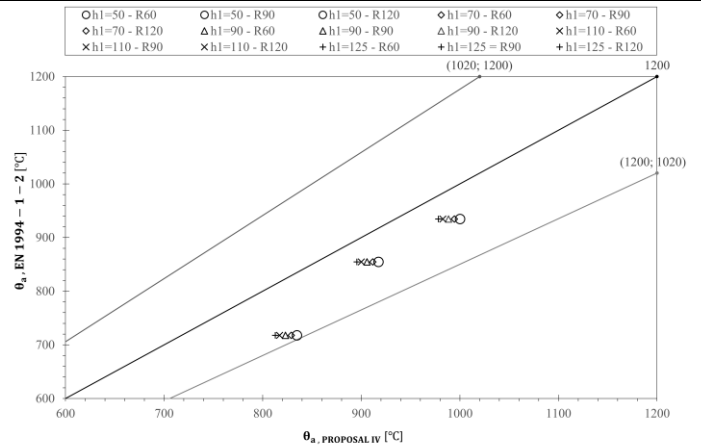
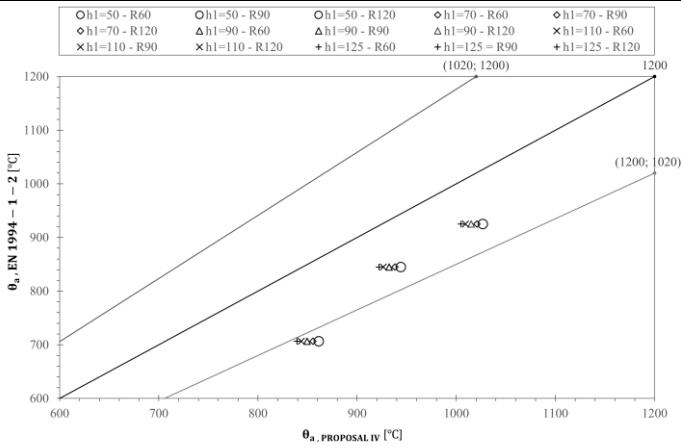
Cofraplus 60 (TRA)



Multideck (REE)

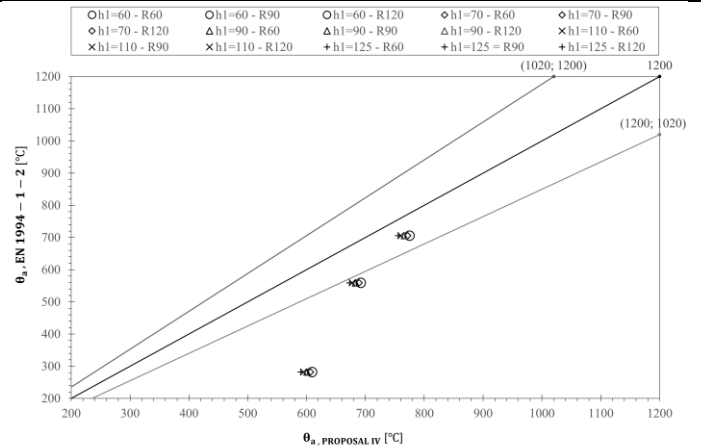
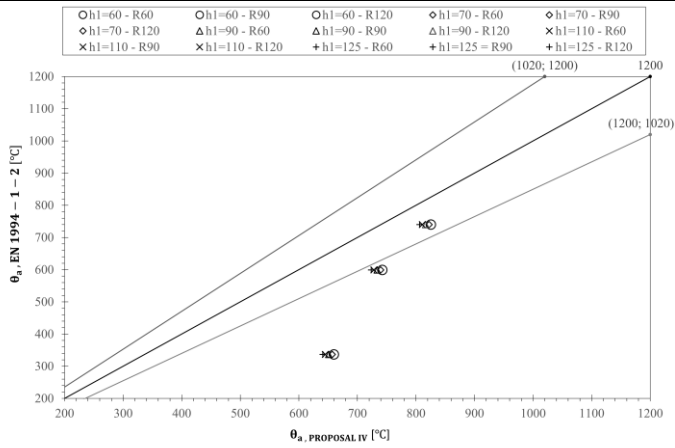
Bondeck (REE)

EN 1994-1-2 – NP IV: Upper



Polideck 59 S (TRA)

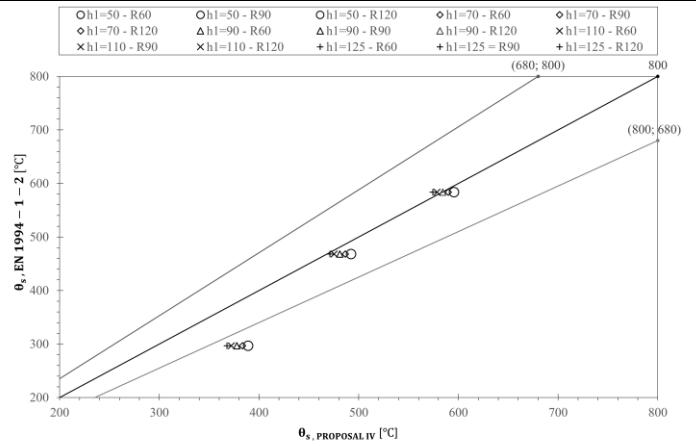
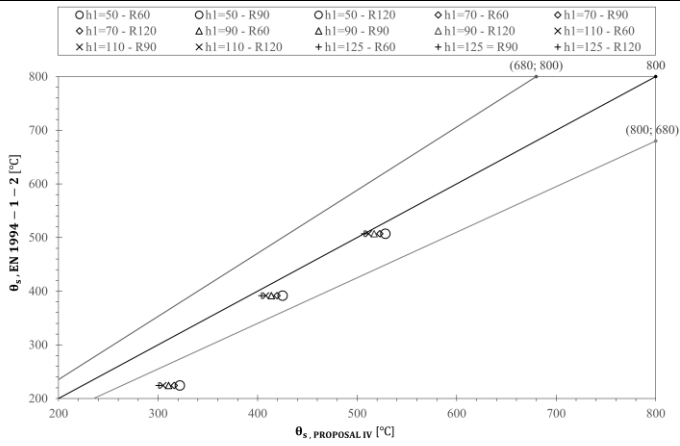
Cofraplus 60 (TRA)



Multideck (REE)

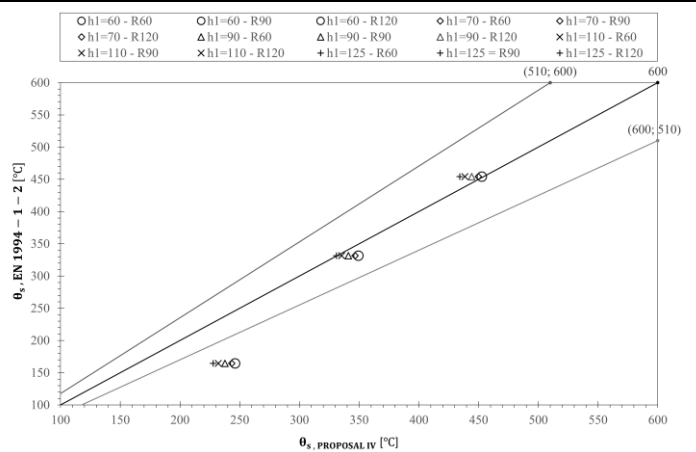
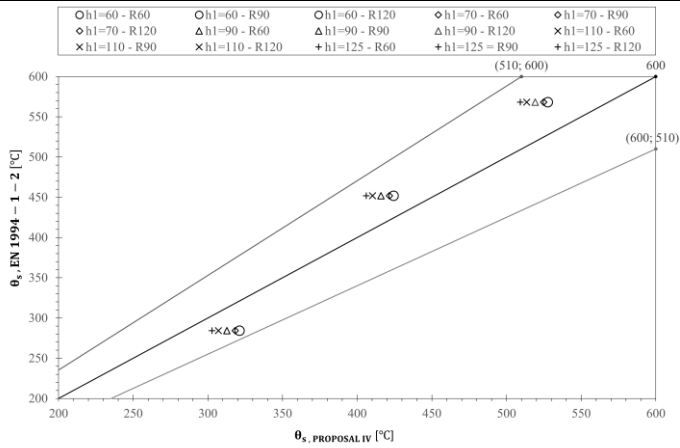
Bondeck (REE)

EN 1994-1-2 – NP IV: Rebar



Polideck 59 S (TRA)

Cofraplus 60 (TRA)



Multideck (REE)

Bondeck (REE)