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## **FIRE BEHAVIOUR OF MORTARS WITH PORTLAND CEMENT AND RESIDUAL DIATOMACEOUS EARTH**

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### **1. INTRODUCTION**

The high levels of pollution produced by the manufacture of Portland cement associated to high carbon dioxide emissions, and the entry of the Kyoto protocol in 1997, resulted in a series of attempts to modernise the cement manufacture, where the use of cement with alternative binders has become a target of research in recent years [1].

The main examples of alternative binders currently used in construction are metakaolin, slag obtained from blast furnaces, and fly ash obtained from burning coal in thermoelectric power plants, also known as aluminosilicates [2]. As well as these aluminosilicates, it is believed to be possible the use of residual diatomaceous earth as an alternative cement binder. The main characteristics of this material are high porosity and low thermal conductivity. However, it also has pozzolanic properties very similar to fly ash and metakaolin [3]. Diatomaceous earth is a natural material formed by diatomites deposited in the ocean and in lakes over thousands of years. It is a mineral of biogenic and sedimentary origin, formed by the accumulation of fossilised diatomaceous algae, presenting a white colour and highly rich in silica. Several physical properties of diatomite add commercial value to this raw material, such as low bulk density, high porosity and apparent surface area, which are extremely necessary and important for different types of industries [4].

According to the purpose for which diatomaceous earth is used, it is marketed in two different ways: calcined and non-calcined. Calcined diatomaceous earth is treated at a temperature higher than 1000 °C. The purpose of this is to harden the exoskeletons of the diatoms further in order to create a better filtering agent. They are mainly used as water filters in swimming pools and as

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absorbents for heavy liquids. Non-calcined diatomaceous earth is not treated at high temperatures, and it is marketed in dry state, as a fine white powder, and used in the agricultural sector as an insecticide and/or ecological fertilizer [5]. This research arises in the scope of the project BacchusTech - Integrated Approach for the Valorisation of Winemaking Residues. The consortium led by Caves Campelo S.A. includes the Polytechnic Institute of Bragança, the Polytechnic Institute of Viseu, the University of Applied Sciences of Hanze and the University College of Copenhagen. Additionally, companies from the cosmetics (Cosmetek Lda.), building materials (Pavimir Lda.) and food (BEPPO Gelados Lda.), sectors also joined to the consortium. The main goal of this research work is to study the behaviour and reaction to fire of mortars manufactured with the introduction of residual diatomaceous earth, and investigate the possibility of using this residue as an improvement in the abrasive resistance of mortars. The characterisation of these mortars regarding their reaction to fire is performed using the cone calorimeter equipment. Other works have also used this type of test to characterise the fire behaviour of different materials [6,7] using the test method established in accordance with ISO 13927 [8]. The specimens manufactured with mortar and brick were tested under a radiant heat flux of  $75 \text{ kW/m}^2$ , where a fully developed fire is simulated [8].

## **2. MATERIALS CHARACTERISATION**

### **2.1. Residual diatomaceous earth**

Caves Campelo S.A. currently uses Silite Mini Speed diatomaceous earth in wine filtrations, a very fine material with white colour and low flow velocity. This material is used in earth filters during the filtration of white and red wines. After the filtrations, the diatomaceous earth is collected in its residual state, completely saturated by wine and organic matter. The residual diatomaceous earth is calcined at  $700 \text{ }^\circ\text{C}$  for two hours, which is necessary to obtain a completely inorganic material [9,10], Figure 1. After being calcined, the material is very similar to the one used before the wine filtrations.



Figure 1: Calcined diatomaceous earth

## 2.2. Composition of mortars

The cement used in the manufacture of mortars in this research is Portland cement II B-L 32.5 N. The mortars' trace can be consulted in Table 1. Three mortar compositions were studied. A reference composition (REF) with cement, sand and water, and two compositions with introduction of residual diatomaceous earth (RC and RS). In the RC composition 15% of the amount of cement is removed and 15% of residual diatomaceous earth is introduced. In the RS composition 5% of sand is removed and 5% of residual diatomaceous earth is introduced.

Table 1: Mortars trace

Compositions	Cement	Sand	Diatomaceous earth	Water
REF	1	3	-	0.61
RC	0.85	3	0.15	0.61
RS	1	2.85	0.15	0.61

## 3. EXPERIMENTAL PROGRAM

### 3.1. Specimens manufacture

The specimens prepared for the experimental program were manufactured with mortar, Figure 2, and ceramic brick. The mortar was applied with 1 cm of thickness in a ceramic brick with dimensions of 10×10 cm and 3 cm of thickness, Figure 3. Nine specimens were manufactured. Three specimens with REF composition (REF1, REF2, REF3), three with RC composition (RC1, RC2, RC3), and other three specimens with RS composition (RS1, RS2, RS3).



Figure 2: Mortar manufacture      Figure 3: Specimens of mortar and brick

### 3.2. Cone calorimeter

The cone calorimeter is an instrument that evaluates in a small scale the fire behaviour of different materials through the specifications presented in ISO 13927 [8], Figure 4. It is an instrument that measures the fire reaction properties of a material, evaluating the heat release rate (HRR) of a sample exposed to controlled levels of radiant heat fluxes, from 0 kW/m<sup>2</sup> to 100 kW/m<sup>2</sup>. In this work, the samples were exposed in a horizontal position to a constant heat flux of 75 kW/m<sup>2</sup>,

which simulates a fully developed fire [8]. The specimens were wrapped in aluminium foil on all sides except on the exposed surface, Figures 5 and 6. The test starts by exposing the specimen to a constant radiant heat flux and ends after flameout and mass loss stabilization. In this research, no ignition was observed, hence the tests were performed between 25-30 minutes, time considered adequate for the analysis of the heat release rate and the temperatures acquired by the thermocouples. Over the test, the heat release rate (HRR), the mean of heat release rate (MHRR), the peak heat release (PHR), and the total heat release (THR), were measured [8].

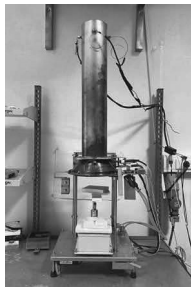


Figure 4: Cone calorimeter

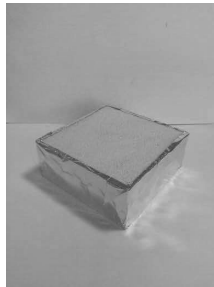


Figure 5: Specimen wrapped in aluminium foil

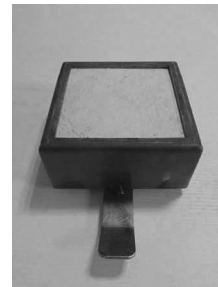


Figure 6: Specimen prepared for cone calorimeter test

### 3.3. Experimental results

During the tests the heat release rate and the total heat release rate were measured. These fire reaction properties are summarized in Table 2.

Table 2: Results of heat release of mortars

Specimens	MHRR (kW/m <sup>2</sup> )	PHR (kW/m <sup>2</sup> )	THR (MJ/m <sup>2</sup> )
REF1	5.75	9.49	7.83
REF2	8.81	11.87	12.92
REF3	8.46	12.00	12.22
Mean	7.67	11.12	10.99
RC1	5.70	8.80	9.22
RC2	6.04	10.03	10.52
RC3	-	-	-
Mean	5.87	9.42	9.87
RS1	6.51	9.47	9.88
RS2	3.63	6.36	5.39
RS3	-	-	-
Mean	5.07	7.92	7.64

There was no ignition in all specimens during the test. For a heat flux of  $75 \text{ kW/m}^2$ , the specimens with REF composition present an average value for the heat release rate (MHRR) equal to  $7.67 \text{ kW/m}^2$ , an average value of the peak heat release rate (PHR) equal to  $11.12 \text{ kW/m}^2$ , and an average value of the total heat release rate (THR) equal to  $10.99 \text{ MJ/m}^2$ . The specimens with RC composition present an average value of MHRR equal to  $5.87 \text{ kW/m}^2$ , an average value of PHR equal to  $9.42 \text{ kW/m}^2$ , and an average value of THR equal to  $9.87 \text{ MJ/m}^2$ , and finally, the specimens with RS composition present an average value of MHRR equal to  $5.07 \text{ kW/m}^2$ , an average value of PHR equal to  $7.92 \text{ kW/m}^2$ , and an average value of THR equal to  $7.64 \text{ MJ/m}^2$ .

#### **4. CONCLUSIONS**

The results obtained confirm the possibility of an effective use of residual diatomaceous earth in Portland cement mortars [11] and the improvement in the abrasive resistance of mortars. The specimens produced with mortars based on residual diatomaceous earth show an average value for the heat release rate (HRR) around 25% lower when compared to the reference mortar, an average value of the peak heat release rate (PHR) around 20% lower, and an average value of the total heat release rate (THR) around 20% lower when comparing the different mortars. The HRR, PHR and THR results obtained for the different mortars with residual diatomaceous earth also showed a behaviour of the tested specimens reliable to the results verified by other authors [12,13,14]. These results allow to conclude that, in general, the specimens manufactured with mortars based on residual diatomaceous earth obtained a quite satisfactory behaviour to fire in the cone calorimeter tests. This residue is an option for the sustainability in mortars, in an attempt to reduce cement consumption and minimize impacts on the environment, promoting a sustainable construction technique, and contributing to the improvement of the reaction to fire of mortars in a fire situation.

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