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## TENSILE STRENGTH OF PINE AND ASH WOODS - EXPERIMENTAL AND NUMERICAL STUDY

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### ABSTRACT

Timber structures are a competitive solution when compared to steel and concrete structures, showing features and advantages that overcome their competitors: weight/strength ratio, rapid assembly, fire resistance and excellent performance in earthquake scenario, natural aesthetic attractiveness, and ecological rationality which leads to sustainable construction. The main goal of this experimental and numerical study was to evaluate, using tensile tests, the mechanical characteristics of two different wood species: Pine and Ash. For tensile test a total of twelve samples for each wood species were prepared, six of them were cut in the wood transverse to the grain, with dimensions equal to 190×50×9 mm, and the others six were cut in the wood parallel to the grain with the dimensions equal to 210×40×9 mm. A numerical simulation was also conducted in order to assess the stress-strain behaviour of Pine and Ash woods.

**Keywords:** wood, tensile strength.

### INTRODUCTION

The mechanical properties define the behaviour of the timber under external loads, resulting directly from the timber anisotropic and heterogeneity characteristics. Depending upon the type of applied load the failure can be tensile, shear or torsion. When load enter the plastic regime, the stress-strain relationship passes through a maximum called the tensile strength. The tensile strength of wood being constant above the fibre saturation point, it increases with decreasing moisture content below the fibre saturation. This can be related to where the water is absorbed in the microstructure. Their study is of great interest allowing the rational use of different wood species for structural and building purposes. The EN 408 standard defines the test procedure in order to acquire the mechanical properties of wood (EN 408, 2003).

The tensile strength of wood parallel to the grain depends upon the strength of the fibres and is affected by the nature and dimensions of the wood elements, and also by their arrangement. The highest value is obtained in straight-grained specimens with thick-walled fibres. Cross grain of any kind of material reduces the tensile strength of wood, since the tensile strength at right angles to the grain is only a small fraction of that parallel to the grain (White, 1999). The wood properties are as well conditioned by the anatomical characteristics such as knots, cross grain and checks. Different values were obtained depending on four issues: compressive or tensile test, as well as the cut direction (parallel or transverse to the grain). Comparatively, wood exhibits its maximum strength in tension parallel to the grain.

The main goal of the current experimental and numerical study was to evaluate, using tensile tests, the mechanical properties such as tensile strength, ultimate stress, Young's modulus and Poisson's ratio, of two different wood species: Pine and Ash. For tensile tests a total of twelve

samples for each wood species were prepared, six of them were cut in the wood parallel to the grain with the dimensions equal to 210×40×9 mm, and the others six were cut in the wood transversally to the grain with the dimensions 190×50×9 mm. A numerical simulation was also conducted in order to assess the stress-strain behaviour of both Pine and Ash woods.

## EXPERIMENTAL TESTS

Different representative samples have been considered for each wood species: Pine and Ash. Fig. 1 and Fig. 2 show the dimensions of wooden samples cut in directions parallel and transverse to the grain, respectively. The dimensions were established according to standards and publications (NBR 7190, 1997; Martins, 2010).

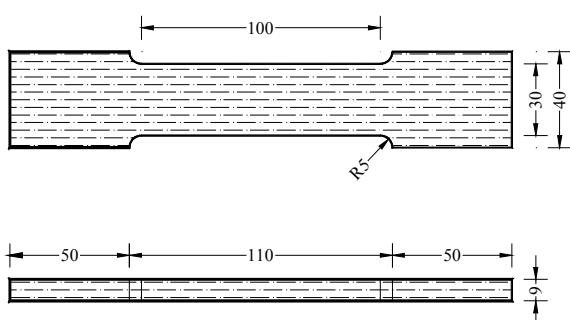


Fig. 1 - Geometry of the specimens cut parallel to the grain (in mm)

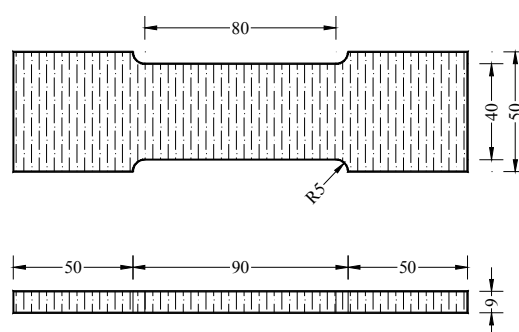


Fig. 2 - Geometry of the specimens cut transversally to the grain (in mm)

Some of the specimens were instrumented with strain gauges connected to a portable P3 strain indicator and recorder in order to calculate the Poisson's ratio (Ferreira, 2014) as can be seen in Fig. 3 and Fig. 4. Tensile tests were conducted using a universal tensile test machine, Instron Model 4400, as depicted in Fig. 4.

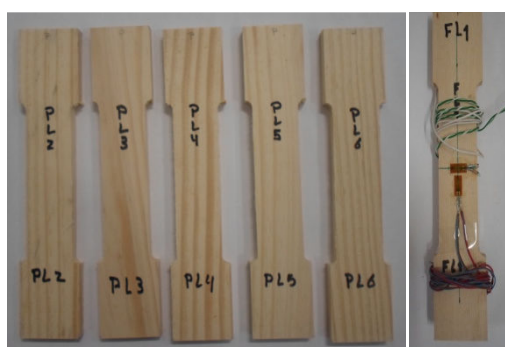


Fig. 3 - Test samples and strain gauges instrumentation

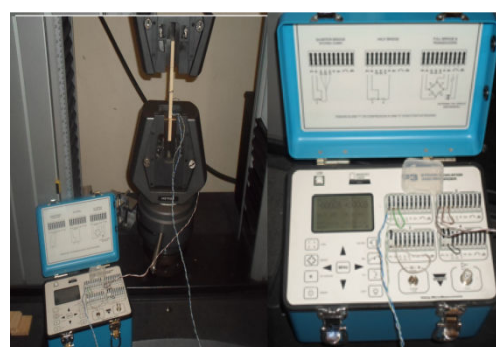


Fig. 4 - Universal tensile test machine and P3 strain indicator and recorder

Typical failures in the wood specimens are expected: combined tensile and shearing stresses, pure shear, or pure tensile. At the end of the tests the samples were analysed. The observed failure patterns for the parallel and transverse to the grain directions are as shown in Fig. 5 and Fig. 6 for Pine and Ash samples, respectively.

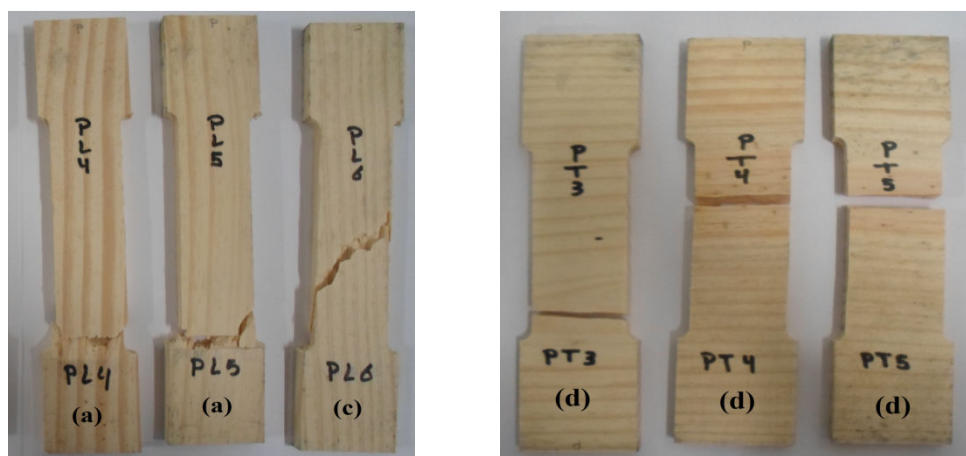


Fig. 5 - Failure patterns of Pine samples

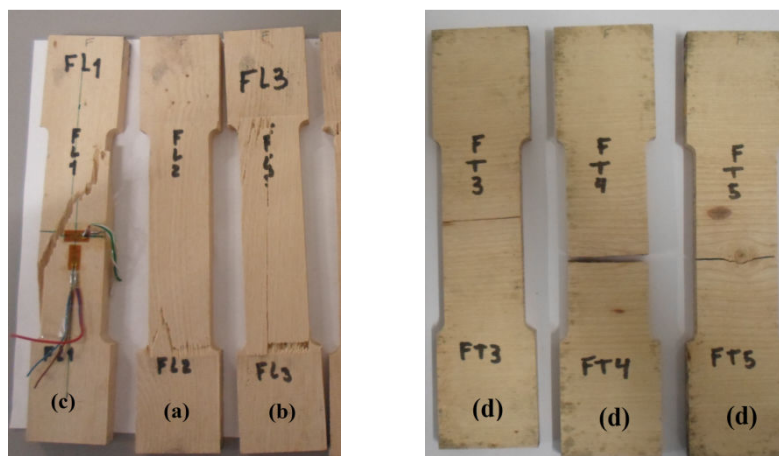


Fig. 6 - Failure patterns of Ash samples

## MECHANICAL PROPERTIES

The characterization of mechanical properties of Pine and Ash woods was conducted making use of tensile tests, aiming to obtain the values for Poisson's ratio ( $\nu$ ), Young's modulus ( $E$ ), tensile strength ( $\sigma_y$ ) and ultimate stress ( $\sigma_u$ ).

### POISSON'S RATIO

When a member is loaded axially, the perpendicular strain is proportional to the parallel strain to the load direction. The ratio of the transverse to axial strains is called Poisson's ratio ( $\nu$ ). The specimens were instrumented with strain gauges which allowed obtaining the transversal and axial strains. The obtained values were  $\nu = 0.49$  and  $0.59$  for Pine and Ash specimens, respectively.

## YOUNG'S MODULUS

The Young's modulus is a parameter which provides a measure of the stiffness of solid material, calculated within the elastic limit as the ratio of the uniaxial tensile load per unit area (stress) and the resulting deformation per unit length (strain) in a given direction. The obtained values for the direction parallel to the grain were  $E = 4141$  MPa and  $6474$  MPa for Pine and Ash specimens, respectively. The values corresponding to the direction transversal to the grain were  $E = 620$  MPa and  $1025$  MPa for Pine and Ash, respectively.

## TENSILE STRENGTH AND ULTIMATE STRESS

Wood exhibits its major strength in tension parallel to the grain. The tensile strength of wood parallel to the grain depends upon the strength of the fibres and is affected not only by the nature and dimensions of the wood elements but also by their arrangement. It is greatest in straight-grained specimens with thick-walled fibres. Cross grain of any kind materially reduces the wood tensile strength since the tensile strength at right angles to the grain is only a small fraction of that parallel to the grain.

The obtained mean values of tensile strength parallel to the grain were  $\sigma_y = 3.9$  MPa and  $9$  MPa for Pine and Ash specimens. The values transversally to the grain were  $\sigma_y = 0.57$  MPa and  $3$  MPa for Pine and Ash, respectively.

The ultimate stresses parallel to the grain were  $\sigma_u = 22.8$  MPa and  $70.9$  MPa for Pine and Ash, respectively. The mean values transversally to the grain were  $\sigma_u = 0.96$  MPa and  $3.6$  MPa for Pine and Ash specimens, respectively.

## NUMERICAL SIMULATION

Performance of a numerical model can be assessed by comparing finite element analysis (FEA) results with known experimental tests properly instrumented. A 3D solid finite element (Solid186) with 20 nodes elements was used for structural analysis with non-linear material and an incremental loading, using ANSYS® software. The non-linear stress strain relationship is a common cause of nonlinear structural behaviour, and the previous mean values of the mechanical properties for each wood specimen were used in all numerical simulations. ANSYS® employs the Newton-Raphson approach to solve nonlinear problems, where the load is subdivided into a series of load increments and over several load steps. Before each solution, the Newton-Raphson method evaluates the out-of-balance load vector and checks for convergence. This is an iterative procedure that continues until the problem converges. In all numerical simulations the Newton-Raphson method was used with a convergence-enhancement procedure as automatic load stepping with a convergence criteria based on displacements.

The solid model was built and a free mesh was used producing an adequate mesh for the numerical simulation. Fig. 7 shows the element mesh and the applied boundary conditions used in all numerical simulations. The solid model was fully constrained ( $U_x=U_y=U_z=0$ ) on bottom side and laterally constrained ( $U_x=0$ ), while an axial load was distributed on top with a

value between 0-40 kN. The experimental results were used to calibrate the conducted FEA simulations. As wood is a relatively low stiffness material, the movable end of the numerical model incorporated a high stiffness material layer in order to correctly model the loading path, as shown in Fig. 7.

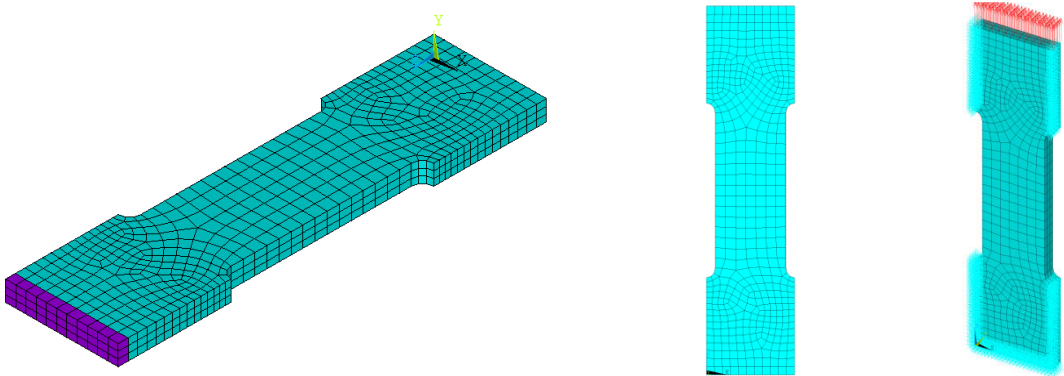


Fig 7 - Solid mesh and boundary conditions

The obtained axial displacements for Pine and Ash in directions along and across to the grain are presented in Fig. 8 and Fig. 9, respectively. These displacements correspond to the ultimate applied load condition for each solid model.

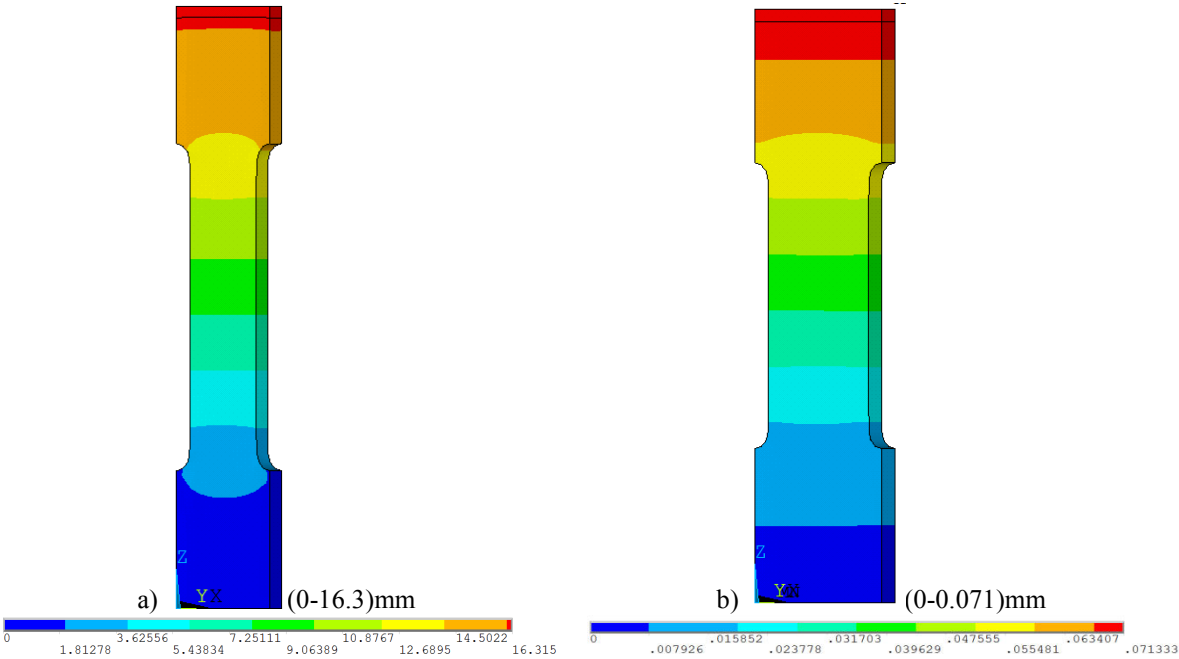


Fig. 8 - Axial displacements in Pine numerical model: a) along the grain, and b) across to the grain

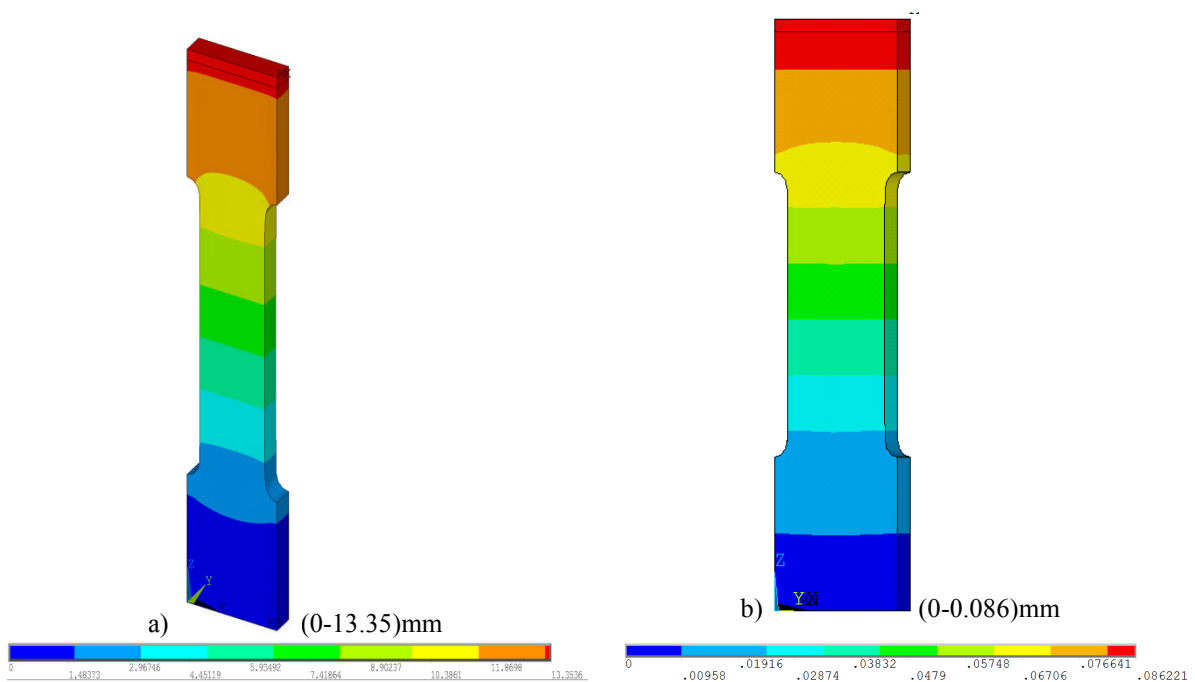


Fig. 9 - Axial displacements in Ash numerical model: a) along the grain, and b) across to the grain

The highest value of displacement occurred for Pine wood with 16.32 mm in direction along the grain. The Ash wood attained 13.35 mm on the same direction. As expected, in the direction across to the grain, the obtained values for displacements were much lower: 0.071 mm and 0.086 mm for Pine and Ash numerical models, respectively.

The experimental and FEA numerical results from the tensile tests in the direction parallel to the grain ( $f_{t0}$ ) can be compared in Fig. 10 and Fig. 11 for Pine and Ash specimens, respectively.

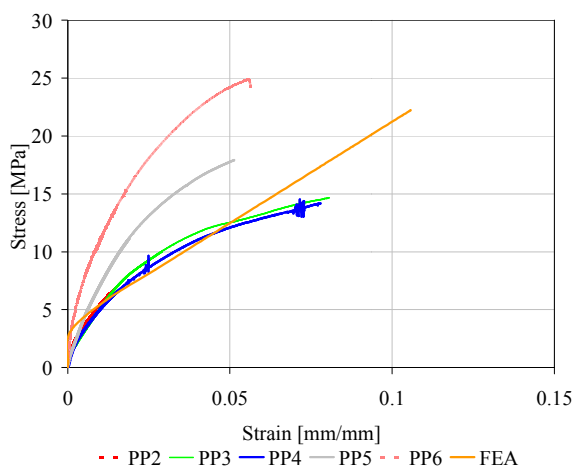


Fig. 10 - Stress-strain behaviour in Pine cut parallel to the grain

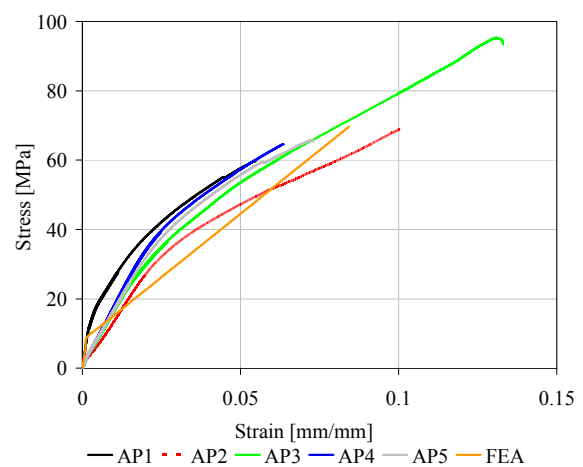


Fig. 11 - Stress-strain behaviour in Ash cut parallel to the grain

From the analysis of the stress-strain relationships one can verify at an early stage a linear elastic zone increase up to strains of approximately 0.005 mm/mm which correspond to a stress of 2.5 MPa and of 0.02 mm/mm corresponding to a stress of 25 MPa for Pine and Ash, specimens, respectively.

Beyond these values the tested specimens entered a non-linear zone up to failure, with no evidence of a transition region between zones. The wooden samples revealed different ultimate strains corresponding to ultimate stress comprised between  $f_{t0} = 7$  MPa and  $f_{t0} = 25$  MPa and larger than  $f_{t0} = 60$  MPa for Pine and Ash, respectively.

The experimental and FEA results obtained from the tensile tests regarding the direction transverse to the grain ( $f_{t90}$ ) are shown in Fig. 12 and Fig. 13 for Pine and Ash Pine specimens, respectively.

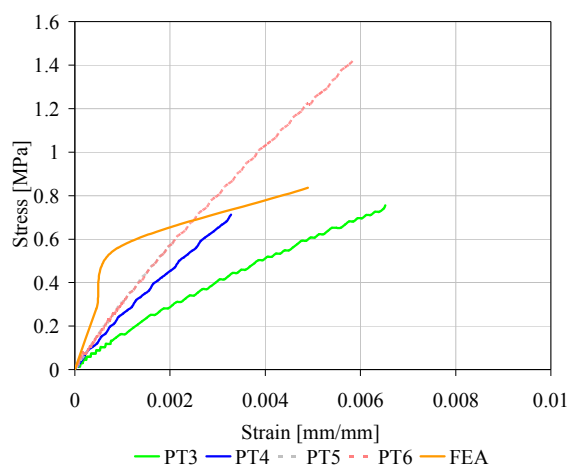


Fig. 12 - Stress-strain behaviour in Pine cut transverse to the grain

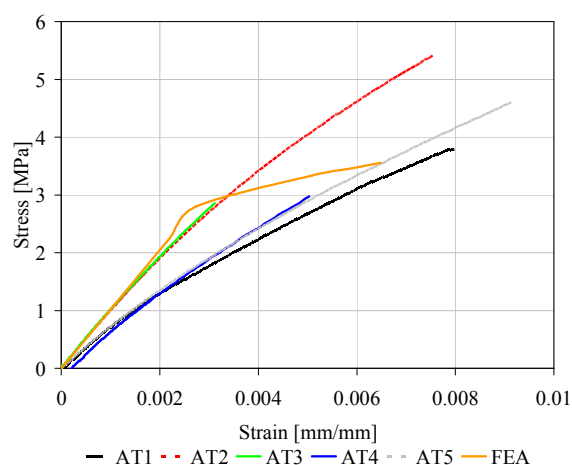


Fig. 13 – Stress-strain behaviour in Ash cut transverse to the grain

As expected, the recorded stresses and strains in transverse direction to the grain were lower than those in the parallel direction to the grain. From the analysis of the stress-strain curves at an early stage, one can observe an elastic region up to strains of approximately 0.0005 mm/mm corresponding to a stress of 0.19 MPa and of 0.001 mm/mm corresponding to a stress of 0.9 MPa for Pine and Ash samples, respectively. Beyond this value the tested samples entered a non-linear zone until failure. The tested specimens revealed different ultimate tensile strengths ranging from  $f_{t90} = 0.6$  MPa to  $f_{t90} = 1.4$  MPa and from  $f_{t90} = 1.8$  MPa to  $f_{t90} = 5.3$  MPa for Pine and Ash specimens, respectively.

For both the parallel and transverse to the grain directions the FEA numerical responses are in good agreement with the experimental results.

## RESULTS AND CONCLUSIONS

From current results one can confirm a highest tensile strength in woods in the parallel direction when compared with the one perpendicular to the grain. The specimens reached different tensile stress values corresponding to different strains. Regarding specimens cut in the longitudinal direction, tensile strengths of  $f_{t0} = 25$  MPa and  $f_{t0} = 60$  MPa were attained for

Pine and Ash woods, respectively, while for specimens cut in the transverse direction to the grain, the mean tensile strengths were less than  $f_{t90} = 1.4$  MPa and  $f_{t90} = 5.3$  MPa for Pine and Ash woods, respectively. In both cases the wood presented a brittle behaviour. The obtained FEA numerical responses are in accordance with the experimental results.

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