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New Advances for the Application of Eucalyptus as a Structural Wood

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Abstract. The authors of this paper intend to present the techniques being developed through laboratory experiments in the mechanical characterization of one species wood, namely eucalyptus (blue gum) aimed at new structural applications, using reconstructed glued components. Knowledge in this field dealing with wooden structures is innovative for fast grown Hardwoods. Bibliographic research revealed very little information on this subject and that which is available, is still based on empirical knowledge referring the possibilities and interest of glued components of this species. This presentation is considered relevant since this material is abundant in Portugal and has been introduced in many other countries, but primarily for the purpose of pulp production. In this work the first results of tests on eucalyptus wood will be presented, namely static bending tests of glued lamellas of eucalyptus and tests on small clear specimens. The values of the global modulus of elasticity in bending and the yield strength are presented for both glued specimens and for small solid, defect free specimens, in accordance with procedures defined in recent European standards for these types of structural components.
Key words: *Eucalyptus globulus*; wood glued structures; bending strength; modulus of elasticity

Recentes Desenvolvimentos para Aplicação do Eucalipto em Utilizações Estruturais

Sumário. Os autores descrevem neste artigo acções desenvolvidas a nível de ensaios laboratoriais para a caracterização mecânica da madeira de eucalipto comum, com vista à sua aplicação em componentes estruturais, nomeadamente por meio de perfis reconstituídos por colagem. Esta área é inovadora no que diz respeito a utilização estrutural de espécies Folhosas de rápido crescimento, nomeadamente o eucalipto comum. Não foi encontrada informação consistente sobre a utilização estrutural do eucalipto, nomeadamente em componentes colados, tendo-se apenas detectado referências ao seu potencial interesse. Esta espécie de eucalipto é abundante em Portugal, e tem também tido forte incremento noutros países, mas a sua utilização pouco vai além da fabricação de pasta para papel. Os ensaios realizados constam essencialmente de ensaios de flexão, com determinação do módulo global de elasticidade e

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tensão de cedência tanto em perfis colados como em amostras de pequenas dimensões de madeira maciça e limpa de defeitos, em ensaios realizados de acordo com normas Europeias recentes.
Palavras-chave: *Eucalipto globulus*; perfis de madeira colados; resistência à flexão; módulo de elasticidade, madeira lamelada colada.

Nouvelles Technologies pour l'Application de l'Eucalyptus Comme Bois Structurel

Résumé. Les auteurs présentent dans cet article les actions développées au niveau des essais de laboratoire pour la caractérisation mécanique du bois d'*Eucalyptus globulus* ayant comme finalité son utilisation en bois structurel, nommément pour la fabrication des lamellés collés. Ce sujet est innovateur pour le bois dur de Feuillus d'accroissement rapide comme l'eucalyptus. L'*Eucalyptus globulus* est très abondante au Portugal de même il a été introduit en plusieurs autres pays. Cependant il est surtout utilisé pour la fabrication de pâte à papier. Les essais qui ont été faits avaient essentiellement pour objectif la détermination du module d'élasticité et de la tension maximale à la flexion aussi bien pour les components collés que pour les petites éprouvettes massives sans défauts. Des valeurs du module d'élasticité global et de la tension maximale en flexion ont été obtenues en accord avec les plus récentes normes européennes pour les bois structurels.
Mots clés: Eucalyptus; bois lamellé collé; résistance à la flexion; module d'élasticité

Introduction

In the last years, production of the eucalyptus wood (*Eucalyptus globulus* Labill.) has considerably increased in Portugal, mainly due to the investment carried out by wood pulp companies, which use eucalyptus as the main source.

However, this increase has not been reflected in a wide use of this wood in noble applications, whether in carpentry, or in furniture. This fact can be explained not only by some difficulties existing in techniques and technological operations linked to the transformation process, but also because eucalyptus wood has been associated with low-grade quality. The general idea is that this wood serves only for paper manufacturing and heating or even worse, that it has a poor mechanical behaviour and degrades the soils.

Although some difficulties in manufacturing eucalyptus exist they can be overtaken with the use of adjusted techniques along the process (HILLIS *at al*., 1988).

The main objective of this paper is to disseminate the results of laboratory studies focused in the mechanical properties of eucalyptus, namely static bending tests of small clear specimens and glued profiles. At the same time the global modulus of elasticity in bending and the bending strength were evaluated and the deformations along time were monitored.

Theory

Mechanical properties

The knowledge of wood mechanical properties is of primordial importance for its selection and application in the various domains of engineering. This material is fully anisotropic and its properties depend also on the environment conditions in service.

The knowledge of the mechanical properties allows the characterisation of material behaviour when submitted to mechanical solicitations. But the mechanical tests not only aim to determine the mechanical properties of the material, but also to compare them in diverse reconstructed materials, to evidence the influence of the manufacturing conditions and to determine which is best adapted to the operating conditions.

The choice of the mechanical test that will better determine the mechanical properties of the material depends also on its purpose, the type of efforts in state and on the properties that are intended to evaluate. Whenever possible, the mechanical properties should be determined in equal or very approximate conditions to the ones the real components will face in service. Modulus of elasticity is a very useful characteristic since it is evaluated in non destructive tests, allowing it to be used in quality control for structural wood components (SANTOS, 1998).

The state of stresses can be summarised by the discrete following model, Figure 1.

The equations for the stress state are,

T = T(F,x,y) (tension stresses)

C = C(F,x,y) (compression stresses)

t = t (F,x,y, α) (shear stresses) 0< α <90

Experimental

Equipment

As it has been mentioned before, one of the objectives of this work was the testing of glue-laminated samples made of eucalyptus (*Eucalyptus globulus* Labill.). The glued beams were composed by three glued lamellas where the central was, in some of the profiles, constituted of several finger-joint lamellas glued on the top. This procedure constitutes the yield optimization of wood, reserving the best quality to the surface lamellas and the worst quality to interior lamellas.

The objective of the study was the determination of global modulus of elasticity in bending (E) and the bending strength (f_m), in accordance to the European pre-standard EN 408:2003 - - "Timber structures – Structural timber and glue laminated to timber – - Determination of some physical and mechanical properties".

Tests were performed by a servohydraulic machine, with capacity up to 600 kN, as well as complementary measure equipment including a data acquisition software and a bridge of extensometers, in the Materials Test Laboratory of the Department of Mechanical Engineering at the Minho University.

Samples characterization, test conditions and data acquisition

Glued laminated timber profiles, with 3 lamellas, of common eucalyptus 73 x 86 x 2000 mm (h x b x l), without defects were tested. The glue was a structural glue type resorcine formaldeide.

The tests were made according to EN 408: 2003 standard, the schematically representation of which is in Figure 2.

The room temperature at the time of tests was 20ºC and the relative humidity was 65%. These conditions are essential, since the mechanical characteristics of wood depend greatly on ambient conditions and moisture content.

The speed of load application was in the order of 0.08 mm/s, which fulfilled the standard speed requirement, which must be lower than 0,003 h (0,219 mm/s) in the tests for determination of (E). Cylindrical coils and steel plates were used between the machine table and the wood, so that the test piece could bow without friction, no stress concentration or no other significant restrictions.

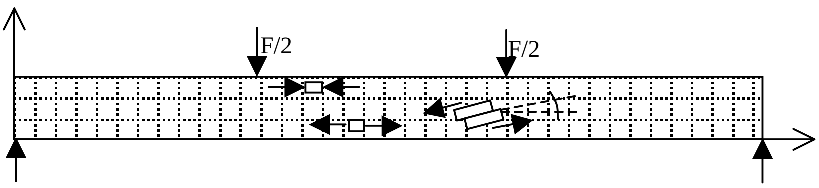

Figure 1 – Model of stresses present in a beam under bending

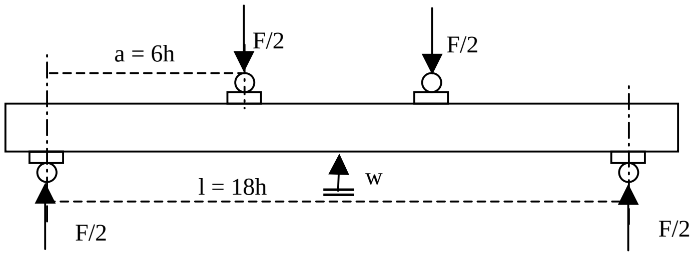

Figure 2 – Test configuration

Although the testing machine automatically registers the load and displacement of the upper table of the press, manual registers were made in order to monitor the maximum deformation applied. For this a gauge with 50mm maximum movement and 0.01mm accuracy was used, located at mid span. For each 2mm deformation the load applied was also registered.

Methodology

Tests were performed with samples in different positions of the glued layer and for some samples the same tests were repeated. For modulus of elasticity determination the same sample were tested with gluing layers horizontally and some days after the same samples were tested with gluing layer in vertical position.

In preliminary tests same few sample were loaded until rupture in order to have an estimation of maximum load for the other samples and at the same time to establish the test speed, because the standard defines the total test duration in about 5 minutes. Afterwards the sequence of the load applied and the corresponding bending deformation allowed the calculation of global modulus of elasticity.

For small clear specimens tests samples, 50mm long and 20x20mm^2 section were prepared, cut along a radial direction covering all the diameter of the tree at the same level. These samples were tested in a three point load system.

Results

The results obtained with glued beams were very satisfying. In some occurrences the values obtained were higher than those refered in the bibliography and experienced in other tests and for small clear specimens and (CARVALHO, 1996).

For the calculation of bending

modulus of elasticity with gluing layers in the horizontal position average results are: average E=19,2GPa with standard deviation Std=1,6GPa;

In Figure 3 it is presented the evolution of the test of first set of samples.

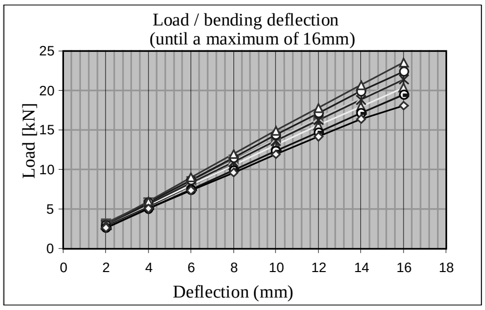

Figure 3 – Load / deflection relation for different samples

Figure 4 shows the comparison of tests for the same samples, first with gluing layers horizontally and second vertically. The objective of this non-destructive evaluation of modulus of elasticity was to evaluate the rigidity of the glued beams in two possible positions of gluing layers. At the same time we repeated the test of evaluation of modulus of elasticity with the same samples again in the horizontal position. It is remarkable that repetition tests in the same sample gave a very close result, which validates the possibility of using modulus of elasticity as a non-destructive mechanical behaviour evaluation.

Three series of tests were made to evaluate possible variations of modulus of elasticity along short time of loading cycles. The objective was to find the influence of fatigue, possible damage by previous test and/or plastic deformation. The samples were divided randomly in three groups A, B, C, and D. The first test was made on all samples of each group in a defined position (glued layers horizontally). Second test was made six hours later on all samples rotated 180º to its first test position. Third test was made after 24 hours on all samples in the same position of first test.

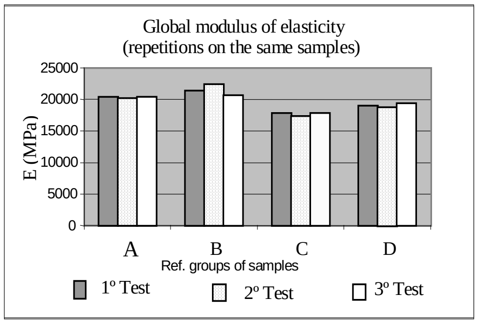

Figure 4 – Comparison of E values in repetition tests on same samples. (1st test) - glued layers horizontally; (2nd test) repetition horizontally rotated 180º; (3rd test) repetition horizontally

In Figure 5 we set for the radial profile of apparent modulus of elasticity resulting from tests of small clear specimens 20x20mm² section and 350mm long, tested in bending with one central load applied and two free supports.

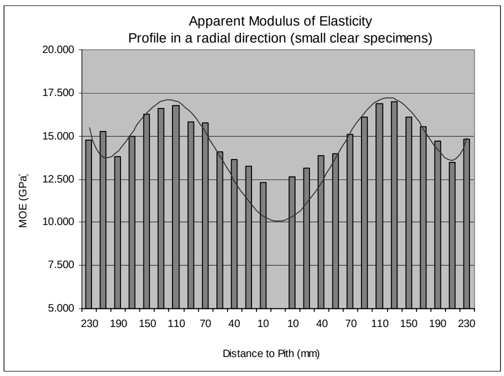

Figure 5 – Radial profile of apparent modulus of elasticity for small clear specimens of *Eucalyptus globulus*

Rupture tests

For bending rupture some tests were also performed with gluing layers in the horizontal position and other tests in the vertical position. The results are presented in Table 1 and Table 2, respectively. Due to the fact that bending strength is a destructive test we had to decide the group to test with gluing layers horizontally and gluing layers vertically. We would never know if one individual sample was stronger in one position or in another. Anyway, the rupture strength difference between horizontal and vertical tests differed about 12%, which is in our opinion inconclusive.

After the samples had been submitted to modulus of elasticity tests, these same samples were loaded until rupture. The results were grouped and for each group a graph were made with modulus of elasticity and rupture load in the same column, Figure 6. This way we tried to establish the correlation between modulus of elasticity and rupture load, for a specific sample. In the graph, modulus of elasticity was sorted by ascending order and at the same time a linear trend line was calculated to the rupture load.

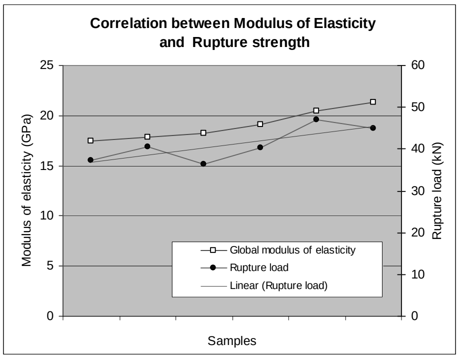

Figure 6 – Correlation between modulus of elasticity (E) and rupture strength (f_m) for five different groups of samples

Discussion and comments

It was verified a great uniformity in the modulus of elasticity results obtained in different series of tests. A very remarkable observation was related to repetition tests (in the condition of the total load did not exceed half of the predicted rupture load) the results of modulus of elasticity in the same sample showed minor variation (less than 5%).

It was verified that modulus of elasticity evaluated in tangential and radial direction, in the same sample, showed also similar values.

Table 1 – Results of bending tests with horizontally glued layers

	Rupture load [kN]	**Deflection at rupture [mm]**	**Delay till rupture [s]**	**Strength of rupture, f_m [N/mm²]**
Average	41.05	38.97	7min25s	119.58

Table 2 – Results of bending tests with vertically glued layers

	Rupture load [kN]	**Deflection at rupture [mm]**	**Delay till rupture [s]**	**Strength of rupture, f_m [N/mm²]**
Average	42.8	27.4	5min15s	104.8

The small differences found in repetition tests on the same sample proved that intensity of load were conducted in elastic zone (e.g. proportional deformation) and also that duration of load did not produce plastic deformation. Sample properties being not affected by the test itself allows the study of other bending test parameters as the influence of load speed application, the span.

The exact point of rupture was not easy to find out because it was initiated with micro-ruptures much before the maximum load was reached. Tension rupture happens generally in fibber direction in the traction zone. When angle grain was present it was verified that the maximum load before rupture was much lower and deflection for the same value of load was higher.

In bending test compression rupture happens very often before tension rupture. Compression rupture does not mean a loss of strength. In most of the events it was verified that the sample continued supporting the load applied although at a slower rate and increased maximum load. In some cases the compression rupture was difficult to identify since it may not always appear in the surface.

In general, after the first signals of rupture the intensity of load does not decrease immediately, it can maintain stable with the continuous increase of deformation.

In tests to determine the modulus of elasticity (E) when no more that 50% of predicted rupture stress was applied, residual deformations were insignificant and recovered slowly but totally.

It was verified that there was an indicative correlation between modulus of elasticity and bending load rupture, Figure 6.

Samples showing the higher values of modulus of elasticity when tested with glued layers in horizontal position also presented the higher values when tested with glued layers in vertical position which proves that mechanical behaviour depends more from internal organization and wood itself than from geometric characteristics.

Rupture model

Although eucalyptus revealed to be one of the mechanically strongest species, explained by its fibrous microstructure and high density, it has been a surprise to observe that the compression rupture initiated previous to tension rupture near application load pads, Figure 7. A mixture of horizontal compression stresses and vertical compression stresses occurs in that zone near the surface.

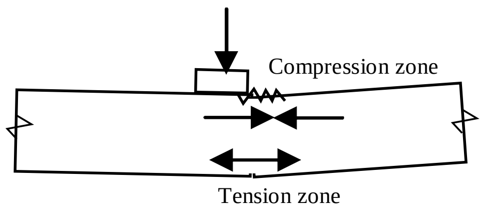

Figure 7 – Location of rupture by compression

Conclusions

The wood of *Eucalyptus globulus* presented very high values for the modulus of elasticity, when compared to other species, mainly the Softwoods such as Maritime Pine, Northern Pines or Spruce

(CARVALHO, 1996). Taking into account the results of these tests it can be said that blue gum has a great potential for its utilization in structural applications.

Gluing techniques and adequate drying process are essential to allow the preparation of long and dimensionally stable components (AITIM *et al.*, 1994). The gluability of this species was absolutely trust worthy, because in none of the present tests did rupture start at the glued layer. From the aesthetic point of view eucalyptus also has a great value by its light colour, good finishing quality and also in the reduced section needed to support flexural loads.

Finally eucalyptus is cheaper than some other structural tropical species and has much fewer knots compared to Softwoods, namely Maritime Pine.

Modulus of elasticity evaluation can be a good indicator to predicted bending strength.

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