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RESEARCH ARTICLE

Numerical Analyses of Timber Columns Reinforced by Particulate Composite Material

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Abstract: Beams are structural elements commonly used in structure for construction designs. Usually wood is applied as structural elements and its use is very important because it is a material of renewable source, low density and satisfactory mechanical performance. When the wood surface is not properly treated, the structure can be destroyed not only by environmental conditions but also the attack of insects, compromising the structural design. This research presents the use of a particulate composite material of epoxy resin reinforced with white Portland cement in order to be applied as repair in timber columns. The mechanical performance of this material is essentially numerical, based on the Finite Element Method. The wood used in the simulation was the *Eucalyptus grandis*. The elastic properties were obtained from the specialist literature in the field of timber structures. The results of numerical simulations in terms of tension and buckling loads, the inclusion of the composite in the damaged regions (for all dimensions of the defects studied) provided buckling load results significantly higher than the buckling load values for the conditions without composite, and near to the values of the buckling loads without defect, highlighting the good performance of the particulate composite material in the repair of timber columns.

Keywords: Cement, Column, Composite material, Finite element method, Reinforcement, Repair, Resin, Structural reinforcement, Timber.

INTRODUCTION

Columns and beams are fundamental elements in the majority of structures. In a building, we highlight the use of wood for being a renewable source material, presenting excellent relationship between strength and density, according to [1] this gets to be four times higher when compared to steel. The wood, which until the early twentieth century represented one of the main structural materials in construction [2].

The buildings constructed with wood require appropriate maintenance and use. According to [3], structural elements of wood are susceptible to variations in their mechanical properties due to natural factors, such as growing conditions

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and genetic species. Moreover, according to [4], many structural components of wood have been experiencing a significant deterioration due to moisture, damages caused by insects, fungi, and others.

According to [5], problems related to the low efficiency of structural elements, increase of overload and degradation by aging has motivated the development of researches involving the study of reinforcements and recovery to the structures.

Recently, alternative materials have been used to recover and reinforce structures, highlighting the use of composite materials, mainly reinforced by fibers and polymers, flexible materials that are highly resistant and can replace with advantages, in some instances, conventional techniques of reinforcement, as the employment and repairs with steel screws [6].

In this context, this research aims to review the use of a particulate composite based on epoxy resin and white Portland cement as reinforcement in structural wood columns (*Eucalyptus grandis*), subjected to axial compressive loads.

The idea to reinforce timber structures is not new and with time it has been developed and improved.

According to [7], among the mostly employed methods in recovery of timber structures, the *Traditional* is highlighted in which the structure is restored with new elements, with dimensions and properties similar to the originals that replace the degraded, the *Mechanics*, in which the structural repairs are made using metal connectors and the *Adhesive Method*, in which resin variations are used in combination with structural reinforcements [8, 9].

Regarding the mechanical methods, [10] evaluated the use of steel as reinforcement in historical buildings is evaluated (timber structures). It was concluded that the use of steel in these structures does not have restrictions or limitations, demonstrating that it is ideal to the used. However, due to corrosion, the steel shows changes in their mechanical properties, being able to compromise the structure.

Many studies using the adhesive method have been done in recovery and reinforcement structures, mainly with regard to the materials used in reinforcement and interaction reinforcement/column.

According to [11], the most efficient technique for recovering timber structures is the one that uses epoxy resin. The epoxy can be manually injected into the damaged elements, which increases the mechanical strength of the structural piece. This material is used to fill the superficial cracks (attacked by insects) and voids. Besides sealing the damaged area and reducing the appearance of cracks, the epoxy can increase the structure's load capacity.

Recently, aiming to evaluate the repair and reinforcement in timber structures, many studies are being developed, emphasizing the use of reinforced fiber with polymers (RFP). According to [12], the application of RFP as reinforcement is a promising technique, especially to increase the load and stiffness of the timber structure [13]. Experimentally investigated the strengthening of timber structures with approximately 100 years of use, reinforced with RFP strips. Satisfactory results led the authors to conclude that this technique has great values in restorations. However, they pointed out that the reinforcement effectiveness depends on the quality of the tie between timber and RFP. It means that a preparation of the adhesive surface plays an important role.

Evaluated the use of laminate composite in damaged timber columns with presence of cracks in order to fix them. The obtained results showed that in some conditions, the columns recovered 20% the load capacity after repair [14].

Experimentally investigated the behavior of timber columns reinforced by RFP [15]. The columns received the composite application through the surface and then were subjected to axial compression test. It was observed that the columns reinforced with composite, when compared to non-reinforced columns, obtained a small variation in the values of maximum compressive strength, resulting in greater reliability.

Thinking on alternative efficient and practical applications, in this research, a particulate composite was injected into the cavity face of the column, created to represent a defect in the timber, such as a node in part or some other natural failure. This condition implies that the composite will be confined in wood by compressive forces, making its efficiency less dependent on the adhesion between resin and wood [16]. Still, in the case of design consideration, provided small displacements (geometric linearity) and physical linear behavior for the materials, has greater security in the integrity of the interface between the wood and the composite, allowing the consideration of perfect adhesion between the materials.

MATERIAL AND METHODS

The mechanical properties of the composite material and wood used in the numerical simulations of axial compression tests were obtained from the research developed by Panzera *et al.* [17] and the Brazilian standard ABNT NBR 7190 [18], as well as done in the research of Braz *et al.* [19], that evaluate numerically the mechanical behavior of timber beams with the same composite material.

The selected material for the simulation from the research of Panzera *et al.* [18] was the composite C3, that present modulus of elasticity and strength modulus in compression equals to 33.98 GPa and 98.80 MPa, respectively, consisting of 50% polymeric phase and 50% cementitious phase. The relationship between bulk density and mechanical strength presented by this composite is very promising, exhibiting high mechanical performance, low density, and high tenacity. According to [18], the analysis by FTIR (Infrared by Fourier Transform) showed that there is hydration of the cement grains for the epoxy resin even without adding water. The elastic-plastic behavior of the composite C3 may result from an interaction (hydrogen bridges) between resin and formed portlandite, combined with a low porosity that prevents the initiation of cracks and prolongs the elasticity.

The Poisson ratio value used for the composite material was equal to 0.35, like the epoxy resin value presented by Daniel e Ishai [20].

The wood adopted for simulations was *Eucalyptus grandis*. For the numerical evaluation of wood it is necessary to know the modulus of elasticity in parallel compression to the grain ($E_{c,}$), however, these variables ($E_{c,0}$ = 12 813 MPa) were obtained from the Brazilian standard [18].

Still about the wood, it is treated as isotropic material. This consideration is commonly used in structural projects, since the Brazilian standard makes no references to calculate the longitudinal modulus elasticity in the three directions, longitudinal, radial and tangential, neither for the shear modulus of elasticity (G) and their respective Poisson ratio (ν) of the material. In the simulations, the Poisson ratio of the wood was considered equal to zero, as well as assumed by [19].

As previously mentioned, the numerical simulations were developed in order to verify the efficiency of the use of composite material in timber columns of structural dimensions, and evaluated the axial compression model, (see Fig. **1**).

Fig. (1). Compression test model.

The dimensions of the timber column, length, width and height were respectively equal to 3000 mm, 200 mm and 200 mm. Once selected these dimensions were defined as the dimensions A and B of the cavity, removed from the central part of the column (Fig. **2**). The values of dimensions A and B (combined) used in the simulations are shown in Table **1**.

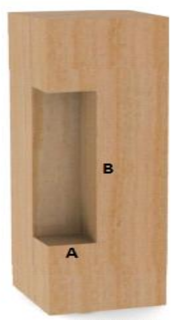

Fig. (2). Dimensions to be varied.

Table 1. Conditions used in the simulations.

		Dimensions B (mm)		
		200	320	400
Dimensions A (mm)	40×40	D1	D2	D3
	60×60	D4	D5	D6
	80×80	D7	D8	D9

The simulations consist of evaluating nineteen experimental conditions, one with the piece without the presence of defects, and eighteen others pieces with defects, being nine without the presence of the composite material and nine with the composite. The numerical tests were named as D1, D2, D3, D4, D5, D6, D7, D8, D9, according to the cavity dimensions (Table **1**). The presence of defects and the use of the composite as reinforcement are illustrated in Fig. (**3**).

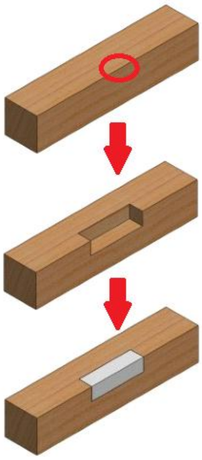

Fig. (3). Representation of columns without defect, with defect and without the composite and with defect and with the composite.

The numerical simulations of the timber columns with and without reinforcements were evaluated with the aid of the software Altair HyperWorks®, based on the Finite Element Method. The finite element meshes were constructed with hexahedral elements (20×20×20mm), with six degrees of freedom per node and linear interpolation, as illustrated in Fig. (**4**).

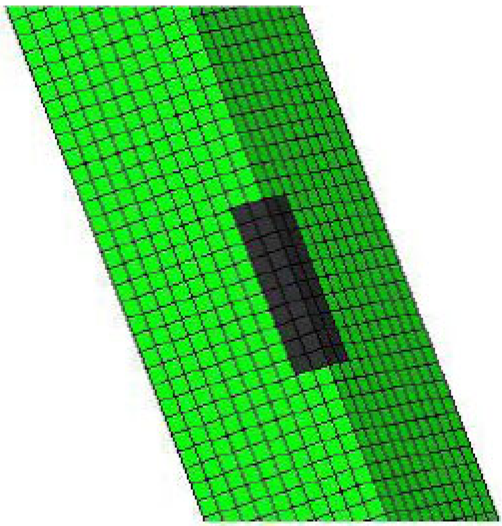

Fig. (4). Used Mesh's geometry.

The value of the added load to the simulation was unit. This served to analyze the value of the normal stress and the critical buckling load.

RESULTS AND DISCUSSION

The simulations of timber columns were analyzed in two ways, the first consisted of evaluating the critical buckling load and the second the maxim compressive stress. Fig. (**5**) shows the first buckling mode of the beams (natural and with reinforcement). Also it should be noted that as the elastic modulus was considered in the parallel direction to the grain, the direction of the axial load is the same of the fiber orientation.

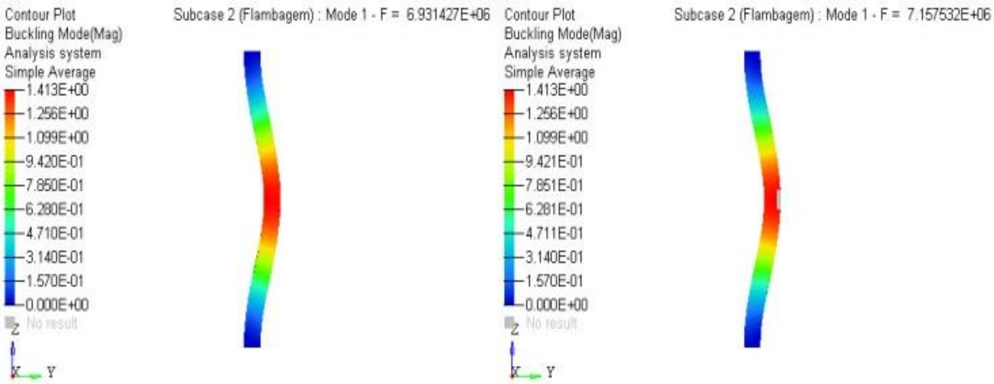

Fig. (5). Graphic of the critical state of stress in a column.

The value of the critical load buckling obtained through the intact column and without defects was 7259.9kN. From this value the dimensions of the defects and the application of the composite in this defect were analyzed. The values of critical load obtained in the simulations are shown in Table **2**.

Table 2. Analysis of the critical load buckling.

Dimensions of the defects	**Critical Loads (kN)**	
	With composite	Without composite
D1	7157.5	6931.4
D2	7158.7	6846.3
D3	7159.5	6796.4
D4	7166.2	6641.2
D5	7173.3	6480.1
D6	7177.8	6390.5
D7	7187.3	6234.4
D8	7209.6	6000.7
D9	7223.7	5878.7

The results shown in Fig. (**6**) demonstrated that the application of composite in the analyzed structure are presented as a high efficiency compared to the defective column without this material.

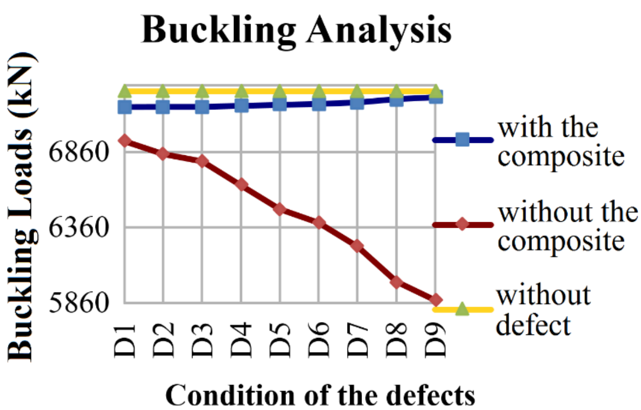

Fig. (6). Critical buckling load× dimensions of defects.

Using the same criterion used in the analysis of the critical buckling, the compressive stresses were evaluated. Fig. (**7**) indicates the presence of stress in the region of the defected part.

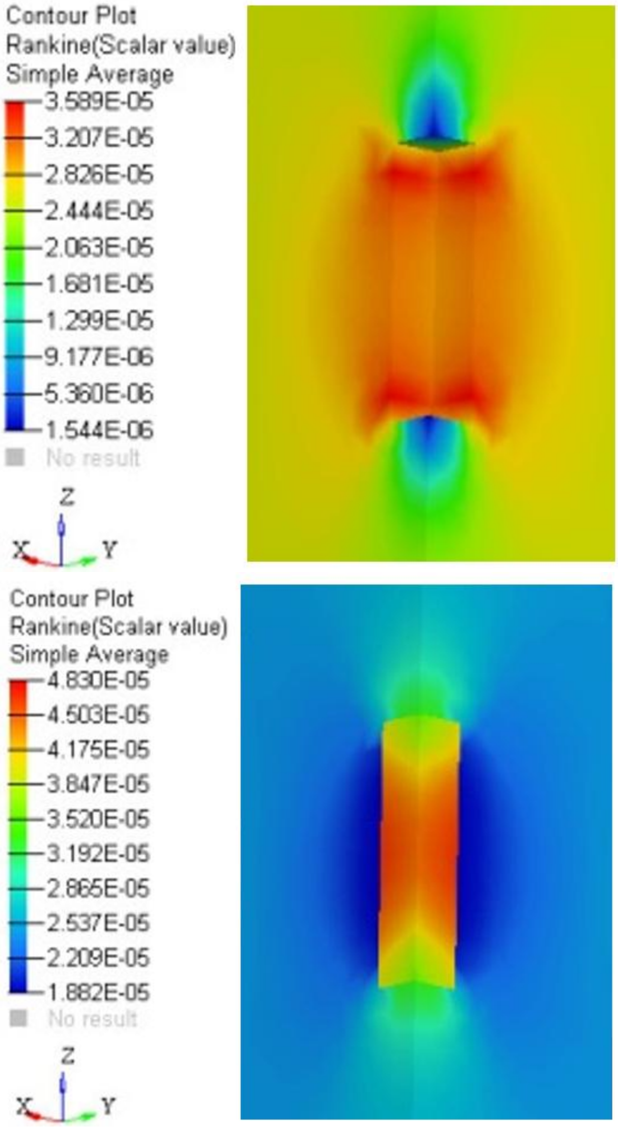

Fig. (7). Graphic of the maxim stress on defects.

Table **3** indicates the maximum stress obtained. The observed values are proportional to unit load applied in the simulation, therefore, with a compressive load of 1kN, the maximum stress in the column without defect is 25Pa.

Table 3. Analysis of the maximum stress.

Dimensions of the defects	**Maximum Stress (Pa)**	
	With composite	Without composite
D1	48.3	35.89
D2	50.82	35.60
D3	51.74	35.43
D4	45.01	43.89
D5	46.45	43.15
D6	47.08	42.73
D7	44.08	54.61
D8	45.7	53.06
D9	46.2	52.18

As shown in Table **3**, the sizes of defects represented by their conditions are significant factors to evaluate the maximum stress, because there is an increase in regions where tensions are concentrated.

Fig. (**8**) represents the value of the maximum stress according to the increase of the conditions with defects.

Analyzing Fig. (**8**) it is observed that the application of composite in the column is not always effective, both defective columns, with and without composite, do not present a state of stress close to that provide by the wood column without defect, justified by the geometry of the defect present points of stress concentration.

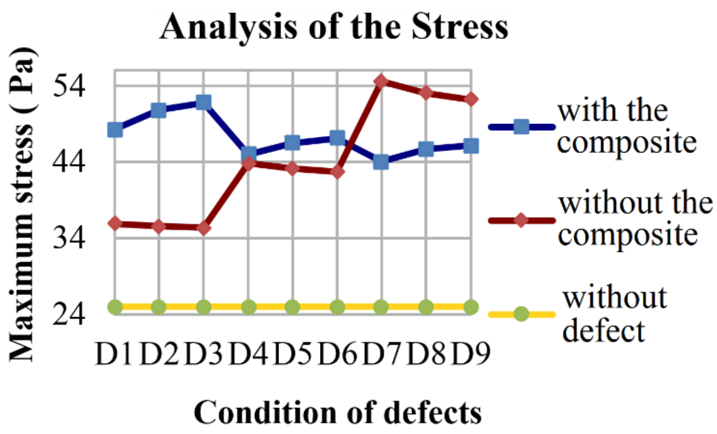

Fig. (8). Maximum stress applied × dimensions of defects.

CONCLUSION

The composite material developed by Panzera *et al.* [18] used was developed to withstand compressive forces. This material differs from the others after investigating the effect of adding a Thermoset polymer with high mechanical strength in cement pastes containing without water.

With the aim of verifying the application of this composite material as repair in timber columns, the computational analysis based on the Finite Elements Method, in case of axial compression, demonstrated that the column with repair resists a higher critical load of buckling when compared to the piece without repair.

When compared with the element without defect, the composite material inserted presents a similar strength. Although, this strength is not higher or equal, with the repair being considered viable, not being necessary for the substitution of the defective piece for another element without defects. It indicates that the used composite can be very efficient when used for these purposes.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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