NUMERICAL ANALYSIS OF MECHANICAL PERFORMANCE OF A PARTICULATE COMPOSITE MATERIALS OF EPOXY REINFORCEMENT WITH CEMENT INSERTS IN WOODEN BEAMS HOW A WAY TO REPAIR OR STRENGTHENING: THE INFLUENCE OF DIMENSIONS IN SEMICIRCULAR GEOMETRIES

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Abstract. *Beams Structural elements are commonly used in construction for structure designs. The use of the structural wood elements is very important because it is a renewable source of material, low density and mechanical satisfactory performance. When the wood surface is not properly treated, the structure not only destroyed can be by environmental conditions but also the attack of insects compromising the design. This paper presents the development of a particulate composite material of epoxy reinforced with white Portland cement in order to be applied to repair of wooden beams. The mechanical performance of this material into wood beams essentially is numerical, based on the Finite Element Method. The wood used in the simulation is the Jatoba (Hymenaea spp.)The elastic properties were obtained from the specialist literature in the field of timber structures. The numerical results Indicates that the developed composite material can be used the repair of wooden beams of Jatoba.*

Keywords: *Composite Material, Wooden Beams, Finite Element Method.*

1. INTRODUCTION

Beam elements are present in most structures. On dealing with construction, there is the use of wood, being a renewable source of material, with one of its main features the excellent relationship between strength and density, according Calil *et al*. (2003), it reaches to be four times higher when compared to steel.

According Christoforo (2007), in Brazil, the use of wood in construction is intended in part to higher temporary works, such as anchors, forms for concrete structures and others having as one of possible explanations, the lack of knowledge about their physical and mechanical properties by construction professionals.

The buildings made with wood require maintenance and use appropriately. According Fiorelli (2002), problems related to low efficiency of structural elements, the increased overhead and degradation by aging are very frequently in building, motivating the development of research involving the study of structural reinforcements and recovery.

Recently, alternative materials have been used to restore and strengthen structures, emphasizing the use of composite materials, particularly fiber-reinforced polymers, flexible materials that are highly resistant and may replace with advantages in some cases, conventional techniques of reinforcements as the use of repair with steel and screws Miotto and Dias (2006).

In this context, this work aims at the development and use of a polymer-ceramic blend consisting of epoxy resin and white Portland cement as reinforcement in beams of wood. This material differs from the other since it investigates the effect of adding a thermoset polymer with high mechanical resistance in cement pastes with no added water.

The verification of the mechanical performance of the set (wooden block with the addition of the composite) was performed with the aid of the Finite Element Method (FEM) simulation of the mechanical model of a four-point bending in a piece of wood Jatoba with structural dimensions. For that, the particulate composite is applied into cavities created in the semicircular upper surface of the beam so as to reproduce the faults in the wood material.

2. REPAIRS ON WOOD BEAMS

The idea of reinforcing wood structure is not new and over time they have been developed and perfected. According to Mette and Robinson (1991), among the methods employed in the recovery of wooden structures stand out Traditional, where the structure is restored with new parts that replace the degraded, with dimensions and properties similar to the originals, the Mechanics where structural repairs are made using metal connectors and Adhesive Method, which are variations of resin used in combination with structural reinforcements.

Many studies using the patch method have been conducted in the field of rehabilitation and strengthening, especially with regard to materials used in strengthening and enhancing interaction / beam.

According to Ritter (1990), the most efficient technique to recover pieces of wood is that it uses epoxy resin. The epoxy putty is a gel, easily malleable, and can be manually injected into damaged parts which increases the mechanical strength of structural part. This material is used to fill surface cracks (attacked by insects) and empty spaces. The epoxy, and seal the damaged area, reducing the appearance of future cracks, further increase the load capacity of the structure.

Recently, in order to study the repair and reinforcement of wooden beams, many jobs are being developed, emphasizing the use of fiber reinforced polymers. Fiorelli (2002) examined experimentally the mechanical performance of the employment of fiber-reinforced polymer (FRP) glued along the bottom of a wooden beam of the species Pinus Elliott (*Pinus elliotii*) and Eucalípitos Grandis (*Eucalyptus Grandis*).The technique proved to be the simple application and presents an interesting feature, the presence of a large deformation before rupture, justified by the lowering of the neutral line, causing crushing of a large quantity of wood in the compressed part.

Miotto and Dias (2006) discuss the use of natural fibers (sisal fiber) as reinforcement in the form of Glued Laminated Wood Beams (MLC), showing itself as a favorable alternative for a better utilization of forest resources in Brazil. The authors conclude, among others, that the addition of fibers pulled on the face of the wood provide excellent mechanical performance in bending, however, being a modest contribution in terms of stiffness. Still argue that the strength of the MLC can be improved with the addition of fibers (glass or carbon) in the region pulled, resulting in increased reliability of the material and a reduction of 30% to 40% in volume of wood used. It is further intended that the enhancement applied to a rate of 2% to 3% may increase the flexural strength of beams of MLC in more than 100%.

In this context, Campilho *et al*. (2010) experimentally evaluated the influence of the use of laminated composite with carbon fibers added to the upper surface of a wooden beam of *Pinus* pinaster, according to the scheme of four-point bending, with a semicircular hole created in the mid-span beam and its top surface, as well as show the Fig.(1). This reproduces a semicircular notch defect in the wood, created for the employment of the composite as a form of reinforcement. The results of the experimental analysis shows that the composite laminate, designed for tension, even inserted in the region requested by compressive stresses, but still was able to increase the mechanical strength of the set.

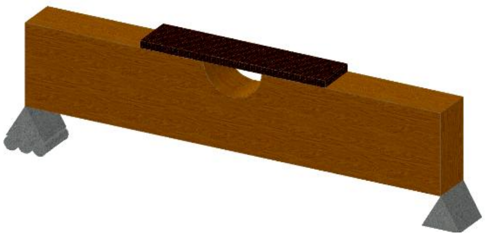

Figure 1. Mechanical model used to study the use of composite laminate.

Thinking of alternative and efficient practical applications, this paper proposes the use of a polymer-ceramic blend, designed to withstand compressive forces to be inserted into cavities of semicircular geometry, rented the upper face of the beams, where the wood is subjected to compressive stresses.

Some peculiar features justify the interest in studying the use of particulate composite materials, requested by compressive forces, as reinforcement in wooden beams.

Where the use of laminated composites, the repair efficiency is highly dependent on the effectiveness of the adhesive used. By definition, a bond is "a substance capable of joining materials by contact between their surfaces."But the ability to join materials is not an intrinsic property of the substance, but depends on the context in which the substance is used (Fiorelli, 2002).

Balseiro (2008) conducted collage tests on of bodies -of-proof composite carbon fiber pieces of wood using epoxy resin Sikadur ®, in order to verify the influence of the size of the collage and hygrothermal conditions. In proof-of-bodies that were bonded with a high water content The resistance was very low or absent, indicating that the presence of moisture in wood parts for your collage is very harmful. Since the specimens used in evidence which showed the influence of the length of glue in the binding values were higher than expected, and the greater length and area showed a higher bonding shear strength.

In this work, the blend polymer-ceramic developed is injected into the cavity of the upper semicircular cross section, designed to represent a defect in the wood, such as a knot in the piece or some other kind of natural defect. This condition implies that the blend is contained in the timber by compressive forces, making their effectiveness less dependent on the adhesion between resin and wood. Still, as regards the design consideration, subject to small displacements (geometric linearity) and linear behavior for the physical materials, has increased security in the integrity of the interface between wood and composite, allowing the consideration of perfect adhesion This hypothesis is used in the simulations.

3. DEVELOPMENT OF POLYMER-CERAMIC BLEND

The polymer-ceramic blend designed to withstand compression forces consisted of a thermosetting polymer of high strength Portland cement added to CP-V without adding water. Only a reference formulation, ie, pure cement paste was prepared with water for comparison. The cementitious composites studied were fabricated with the following proportions of the polymer phase: 100% (0% cement), 75%, 50%, 25% and 0% (100% cement). The experimental conditions analyzed in this research can be seen from Tab.(1) it, and illustrated by Fig.(2).

Table 1. Experimental conditions.

	Polymer	Cemen	H_2O
C1	100%	*	*
C2	75%	25%	*
C3	50%	50%	*
C4	25%	75%	*
C5	*	100%	30%

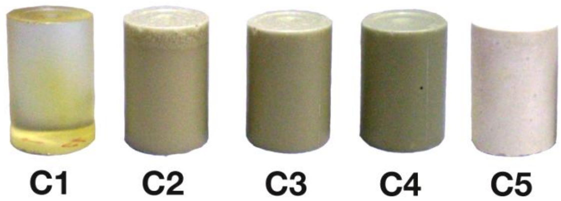

Figure 2. Photo of the composites investigated in the experiment.

Portland cement used in the experiment was the CPI-40, the manufacturer Cauê - Brazilian industry. Since the epoxy resin consists of two parts, one called the other Araldite hardener. The Araldite LY was used 1564BR plowing and hardener 2954. The mix ratio by weight used was 74% to 26% araldite hardener.

The test of mechanical strength was based on the recommendations of British Standard (BS-12390, 2002).Seven bodies of the test piece were made for each experimental condition. The tests were conducted randomly. The composites were measured for a cure period of 28 days. The elastic modulus and compressive strength were determined according to the stress-strain graphs obtained from compression tests. The volume density of the composites was calculated by dividing the dry mass of the composite (after 24 hours at 105 ° C) by the volume of samples (28 mm diameter and 56 mm height).

Table 2 displays the means and standard deviations (SD) of results of compressive strength (Rc), modulus of elasticity (E) and volume density (Dv) to the experimental conditions investigated.

Table 2. Experimental results mean and standard deviations.

	Rc (MPa)	DP	E (GPa)	DP	Dv (g/cm^3)	DP
C1	64.33	0.23	23.76	1.43	1.17	0.01
C2	67.07	0.56	25.29	1.52	1.34	0.02
C3	98.80	2.11	33.98	4.69	1.64	0.01
C4	81.73	2.55	46.27	4.65	1.84	0.02
C5	28.93	1.90	47.88	1.63	1.92	0.03

The material related to the simulation was the composite C3, consisting of 50% and 50% polymeric cementitious phase. The relationship between strength and volume density by this composite is promising, exhibiting high strength, low density, and high toughness, compared with composite C4 and C5. According Panzera *et al*. (2009) analysis by FTIR (Fourier Transform Infra-Red) proved that there is grain hydration of cement by epoxy resin without adding water. The elastic-plastic behavior of the composite C3 may be the result of an interaction (hydrogen bonding) between the resin and portlandite formed, combined with a low porosity that prevents the initiation of cracks and prolongs the elasticity.

4. METHODOLOGY

Wood adopted for the simulations was the Jatoba (Hymenaea spp), to be among the wood cataloged by the NBR 7190 (1997), the highest modulus. The mechanical performance of satisfactory employment in the blend developed Jatoba wood beams, allows the extrapolation to use this material as reinforcement in other woods of least resistance and stiffness.

For the numerical evaluation of the wood becomes necessary to understand the elastic modulus in bending (E_m), compressive strength parallel ($f_{c,0}$) and tensile strength parallel ($f_{t,0}$), for both these variables were obtained from the Brazilian normative document (NBR 7190:1997).The tensile strength of wood parallel compression and Jatoba are respectively equal to $f_{c,0}$ = 93.30 MPa and $f_{t,0}$ = 157.70 MPa. Mechanical properties item in this normative code, it presents a relationship between the modulus of elasticity in bending with the modulus of elasticity in compression parallel ($E_{c,0}$) that for hardwoods, such as the Jatoba, is expressed by $E_m = 0.90 * E_{c,0}$. The value of the modulus of elasticity in compression parallel Jatoba is equal to $E_{c,0}$ = 23.61 MPa, resulting in the bending modulus of 21.25 MPa.

Assuming the partial modification $k_{mod,1} = 0.6$ $k_{mod,2}$ = 1.0 and $k_{mod,3} = 1.0$ comes to the value of the coefficient modification $k_{mod} = 0.6$. The effective value of the bending modulus ($E_{m,f}$) is expressed as $k_{m,f} = k_{mod} * E_m$ = 12.75 MPa, the values of resistance to compression and tension parallel calculation respectively equal to $f_{c0,d}$ = 40 MPa and $f_{t0,d}$ = 52.50 MPa.

Still on the wood, it can be treated as isotropic material. This account is commonly used in structural projects, as the NBR 7190 (1997) makes no references on the calculation procedures for determining the longitudinal modulus of elasticity (E) in the three directions, longitudinal, radial and tangential, not for modules transversal elasticity (G) and their coefficients of Poisson (v) Of the material. Empirically, this policy document, the transverse modulus of wood is obtained from the equation $G = E/20$.This relationship when substituted in the equation that establishes equality between modulus of elasticity and transverse isotropic ($G = E / [2 \cdot (1 + v)]$) exceeds the limits for the Poisson ratio, and can extrapolate the maximum value of 0.50 in eighteen times. Thus, here the value was null Poisson wood in the simulations, also known its limited influence in the design of beams subjected to bending.

For the blend of the condition C3, see Tab.(2), the modulus used in the simulations along with the value of compressive strength is respectively equal to 33.98 MPa and 98.80 MPa. The value of Poisson's ratio for the composite material was used as the epoxy resin which, according to Daniel and Ishai (1994), this value is approximately equal to 0.35.

As previously mentioned, the numerical simulations are developed in order to verify the efficiency of the use of composite material in wood beams, structural, and evaluated the model of a four-point bending, Fig.(3), which is the model proposed by ASTM D198-97 which deals with the determination of modulus of elasticity of structural parts.

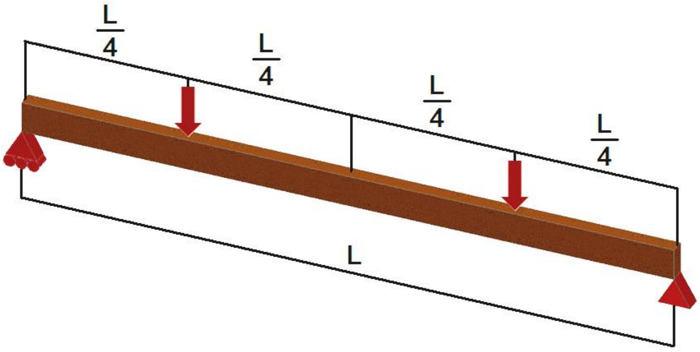

Figure 3. Bending test of four points

The dimensions of the wood, length (L), height (h) and width of the cross section (b) are respectively equal to 2100mm, 100mm and 50mm.The ratio L / h for the measures set concerning the relationship presented in the work of Lahr (1983), neglecting the effects of shear forces in the calculation of deflections of beams.

Once selected the dimensions of the pieces were defined dimensions of the semicircular cavities to be "removed" from the top of the cross section located at the midpoint of the beam (region of occurrence of a greater compressive normal stress) for subsequent use of the material repair. The radii of the semicircular cavities adopted are equal to 10, 20 and 30 mm.

For the beam initially without blemish, it was discovered through the inverse analysis, the approximate value of the strength in bending is responsible for causing a maximum displacement about to 10.50 mm, respecting the condition of small displacements (L/200) suggested by the Brazilian standard NBR 7190 (1997), to guarantee a linear geometry for the beam. This strength value was divided into ten increments. For each increment of force used in part without consideration of other defects were carried out two numerical tests, in order to verify the displacement calculated at the midpoint for their other conditions, defective and faulty unreinforced and reinforced. This methodology allows us to evaluate the mechanical efficiency of the whole.

Thus, the simulations are to assess seven conditions, with a full part, without the presence of "defects", and for each of the three dimensions of cavity radius semicircular two conditions were analyzed with and without the presence of composite material.The numerical simulations were named R1, R2 and R3 to the grooves of 10mm, 20mm and 30 mm radius, and the extensions SS, CC and SC are used to identify respectively the condition without the presence of defects and the job or not composite reinforcement, as illustrated in Figure 4 and presented in Tab.(3).

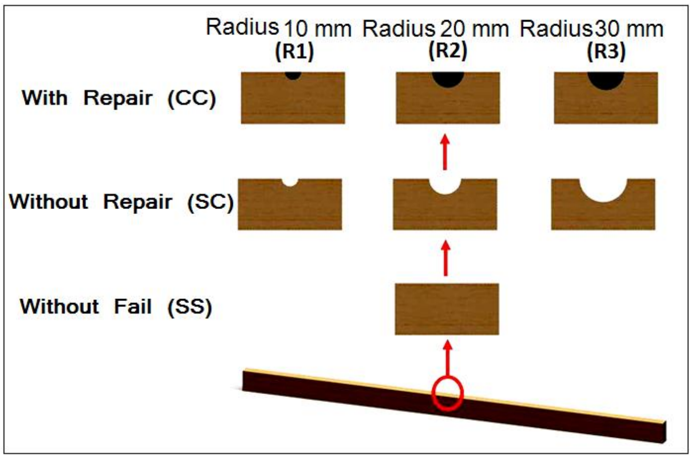

Figure 4. Diagram of semicircular sections.

Table 3. Designation of test conditions.

Experiment	Radius Notch (mm)	Application reinforcement
SS	without	without
R1-SC	10	without
R1-CC	10	with
R2-SC	20	without
R2-CC	20	with
R3-SC	30	without
R3-CC	30	with

The numerical simulations of the wooden beams with and without reinforcement were developed with the use of finite element, with the use of Abaqus software version 6.8.2, installed on a workstation with Intel ® CoreTM 2 Quad Q9550 with 3 GB of memory RAM and Windows ™ operating system XP 32-Bit, Sustainable Manufacturing Group at the Universidade Federal de São João del-Rei.

The strength criterion adopted was the maximum stress for materials, timber and blend, resulting in check and direct comparison between the values of strength of materials with the stresses calculated by the software.

The boundary conditions were applied to fix an end with restricted horizontal and vertical and the other end with vertical restraint (support fixed and mobile respectively).We used a finite element mesh of hexagonal geometry with a size of 5 mm for wood and 2mm for the blend, as illustrated in Fig.(5).

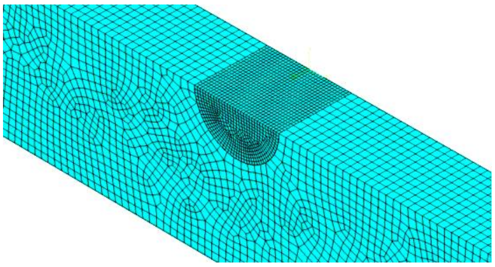

Figure 5. Geometry of the mesh used.

The value of the force responsible for causing a displacement value at the midpoint of the beam approximately equal to 10.5 mm is 1000 N. Therefore, this value was divided into ten equal parts, applying the fold structure, increases in strength equal to 100 N.

5. ANALYSIS OF RESULTS

Table 4 displays the values of the displacements obtained for each condition by the use of force increments of ten.

Table 4. Displacements obtained at the midpoint of the beam to the seven conditions.

Beam	Force (N)									
	100	200	300	400	500	600	700	800	900	1000
SS	1.004	2.007	3.011	4.015	5.019	6.022	7.026	8.030	9.034	10.037
R1-SC	1.017	2.034	3.051	4.068	5.085	6.102	7.119	8.136	9.153	10.170
R1-CC	1.000	2.000	2.999	3.999	4.999	5.999	6.998	7.998	8.998	9.998
R2-SC	1.060	2.119	3.179	4.238	5.298	6.358	7.417	8.477	9.536	10.596
R2-CC	0.993	1.986	2.979	3.972	4.965	5.958	6.951	7.944	8.937	9.930
R3-SC	1.143	2.285	3.428	4.570	5.712	6.855	7.997	9.140	10.283	11.425

Figure 6 displays the values of the increments of force along with the displacements obtained for the number seven conditions studied.

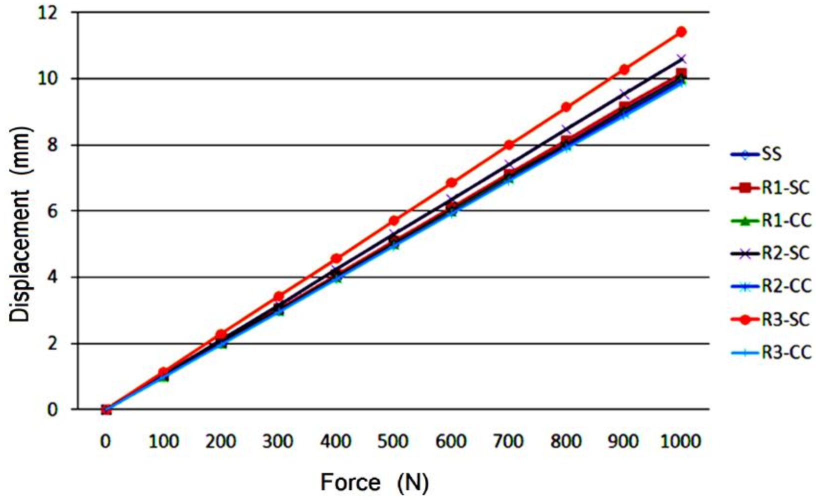

Figure 6. Force × Displacement.

As expected, the behavior between force and displacement for the increments of force in the seven conditions evaluated numeric displays a linear regime. Thus, use, or is the linear regression model for adjustment of each of the seven curves shown in Figure 6, in order to estimate with greater precision, the value of force responsible for causing, in seven cases, a shift at mid-span of the beam equal to 10.5 mm. The values of these forces are presented in Tab.(5).

Table 5. Force applied to obtain the deflection of 10.5 mm.

Beam	Force (N)
Interiça (SS)	1046.0
R1-SC	1046.0
R1-CC	1050.0
R2-SC	1057.4
R2-CC	1064.7
R3-SC	919.0
R3-CC	990.9

Based on the strength values shown in Tab.(5), there were seven new simulations, in order to verify and compare the magnitude of the field of tension displayed by the software, valued at the section located at the midpoint of the beam, allowing to compare the values of stresses found for the limits of strength of materials. It is noteworthy, as previously reviewed and justified market, the condition was taken as a perfect interface, avoiding the concern of stress analysis of normal and shear at the interface of contact between the materials.

The numerical simulations involving the analysis of normal stress in a direction parallel to fibers (S11) are shown in Figure 7, which emphasized their distribution in cross sections located at the midpoint of the beams.

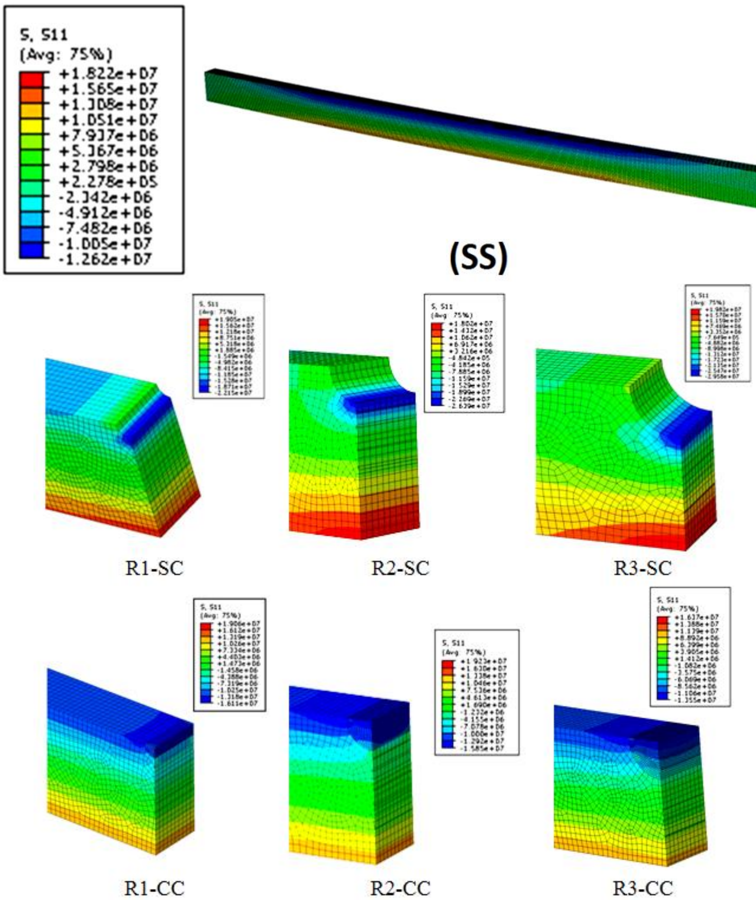

Figure 7. Distribution of normal stress.

The findings of the simulations illustrated in Fig.(7) are presented in Tab.(6).

Table 6. Values of normal stress condition for the deflection equal to 10.5 mm.

Experiment	Force (10,5 mm)	Maximum Compression Stress of on Beam (MPa)	Maximum Traction Stress of on Beam (MPa)	Maximum Compression Stress of on Repair (MPa)
SS	1046.0	12.62	18.22	X
R1-SC	1046.0	22.1	19.05	X
R2-SC	1057.4	28.16	19.23	X
R3-SC	919.0	29.58	19.82	X
R1-CC	1050.0	10.25	13.19	16.11
R2-CC	1064.7	7.13	13.47	15.96
R3-CC	990.9	3.57	11.39	13.55

The results presented in Tab.(4) show the gain in terms of mechanical efficiency of the use of composites as reinforcement in the beam of wood, as part of the displacement at the midpoint with the addition of reinforcement is less than the displacement of the piece of wood without blemish.

The results presented in Fig.(6) confirmed the proportionality between forces and displacements for the seven conditions studied.

4. CONCLUSIONS

By the values of maximum stresses in tension and compression acting on the timber and compressive stresses acting on the repair it can be seen, the values of strength of materials, projected that the number surely resist the action of charging tax.

The strategy of using the polymer-ceramic blend in the compressed region the number showed up as a promising alternative for the strengthening of beams, avoiding to the previous study of the interface conditions between the materials, since the set is designed for small displacements and composite material being confined in the timber.

It is believed, by the results of the use of composite wood beamed Jatoba, as for other timber with a lower modulus of elasticity, which developed the composite material can also be employed.

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5. RESPONSIBILITY NOTICE

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