Novel and Non-Conventional Materials and Technologies for Sustainability

Edited by
Yan Xiao, Zhi Li, Rui Wang,
Bo Shan and Khosrow Ghavami

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Selected, peer reviewed papers from the
13th International Conference on
Non-Conventional Materials and Technologies
(13NOCMAT 2011),
22nd-24th September 2011, Changsha, Hunan, China

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Fax: +41 (44) 922 10 33
e-mail: sales@ttp.net

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Trans Tech Publications Inc.
PO Box 699, May Street
Enfield, NH 03748
USA

Phone: +1 (603) 632-7377
Fax: +1 (603) 632-5611
e-mail: sales-usa@ttp.net

13th International Conference on
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(13thNOCMAT 2011)
22nd-24th September 2011
Changsha, Hunan, China

Foreword

The 13th NOCMAT Conference was continuing the events which provide a forum for researchers, governmental and non-governmental agencies and introduce the research results on innovations in the field of low cost, energy saving materials and technologies which are renewable and locally available like bamboo, soil fibers, alternative cement technologies, new materials and technologies making use of the non-conventional materials like natural fibers, agricultural and industrial residues in a more cost-effective, durable, environment-friendly, energy efficient and sustainable construction. It is hoped that the NOCMAT to contribute in solving the existing need for housing and by creating jobs in the progress and help to eradicate extreme poverty which still afflicts a large percentage of the population around the globe. Further by using NOCMAT our world will become healthier and fairer. Another objective is the formation of global partnership for economic progress and social stability.

The 13th NOCMAT Conference was successfully held in Changsha, Hunan Province, China, following previous events in Cairo, Egypt (2010), Bath, England(2009), Hanoi, Vietnam(2002), Bhubaneswar, India (1097) and the first one in Rio de Janeiro, Brazil (1984). In NOCMAT conferences were also held also in João Pessoa, (2003), Pirassununga (2004), Rio de Janeiro (2005), Salvador (2006) and Maceio (2007) and in Colombia (2008). The 13th conference was very informative and interesting for all participants. Over 220 papers were received from all over the world. Innovations and sustainable use of novel technologies were presented and exhibited. Many non-conventional materials in the 21st century are rooted in traditional vernacular construction, including soil, lime and natural plant based materials, such as bamboo, straw and reeds. In order that non-conventional materials and technologies meet the demand of sustainable construction, significant research effort is under way. Industrial materials such as steel and concrete are being examined newly for sustainable solutions. Because of the different cultural backgrounds the wide range of research results presented might only stand for a regional approach but might easily transferred, copied and adapted to another regions. If we could fuse this new approach with the ancient ways of using for example bamboo, Kah-Gel (Soil- fibers) we could truly reach a superb material which could benefit many people around the globe and perhaps give the term "globalization" a new meaning.

With great pleasure, we present the selected papers in the proceedings of the 13NOCMAT.

Khosrow GHAVAMI, Ph.D.
Chairman of IC-NOCMAT
Full Professor, PUC-Rio

Yan XIAO, Dr. Eng, PE.
Co-Chairman, 13NOCMAT
Professor and Dean, College of Civil Engineering, Hunan University
Professor, University of Southern California

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Limits States Analysis for Bamboo Pin Connections

Luis Eustáquio Moreira[1,a]; and Khosrow Ghavami[2,b]

[1]Universidade Federal da Minas Gerais

[2]Pontifícia Universidade Católica do Rio de Janeiro

[a]luis@dees.ufmg.br, [b]ghavami@puc-rio.br

Keywords: Bamboo, pin joint, finite element, functionally graded material

Abstract. In this paper the result of an investigation using finite element model (FEM) of a simple bamboo pin joint as commonly used in many types of structures especially in plane and space structures is presented. The nonlinear pressure distributions at the contact area of a steel pin in a bamboo circular hole were analyzed considering the anisotropy and heterogeneity of the functionally graded material. In turn the obtained results of the analysis are compared with those based on simplified constitutive models assuming isotropic and homogeneous representations for bamboo. The experimental results are compared with the results obtained from both methods. The assumption of the bamboo as an orthotropic material presented more reliable design method of bamboo structures Although the different maximum forces applied in each case, local stress are relatively high on both cases, showing that this type of connection depends on local reinforcements to be a safe connection. Finally the suggestion that bamboo joints at the hole can be improved by reducing the stress concentration factors, through applying reinforcing elements such as natural fiber straps composites close to the hole.

Introduction

Pin or bolted bamboo structures are constructed in many countries all over the world in different form. In some cases bamboos are filled by cement mortar at the joint. To reinforce the splitting of bamboo at the contact zone with the steel bar a metallic sheet is fixed at these points. To establish the reinforcement at the contact zone the local stress distribution in bamboo wall thickness must be established. The studied bamboos are having relatively small wall thickness. Besides bamboo tissue anatomy is functionally graded material with longitudinal fibers being as slender columns immersed in a porous tissue, cells used as nutrients deposits, the parenchyma. Parenchyma cells are easily failed by a crack caused by shear stress parallel to fibers. The crack at the contact zone of bamboo propagates at the pin contact in a linear form between lateral fibers bundle.

In pin bamboo connections three failure modes are established based on test results, Figure 1. a)-squashing of the fibers by normal contact stress between pin and hole b)-shear of the wall by shear stress along the fibers c)- the longitudinal splitting of bamboo wall at the center of the pin created by tensile stress normal to fibers. However the failure mechanism, for air dry bamboo, is a combination of shear and split modes. Wet bamboo principally fails due to squash mode at the hole before splitting-shearing of the wall. To predict the failure mode the local geometry of bamboo (thickness of the wall and exact transversal section form); the size of the pin at the contact zone of the wall thickness; the bamboo moisture content; the species; the micro structural of the transversal section must be considered The shear stress failure, split failure or split-shear failure, has the same occurrence probability on dry bamboos. Otherwise, squashing of the fibers has high probability to occur on moist or green bamboos. This paper presents the results of rigorous research program considering bamboo pin connections tests and finite element analysis (FEA). In the analysis an elastic- plastic model is proposed for the contact stress between pin and bamboo wall. Based on rigid body diagram parallel to fibers shear stresses are estimated and approximate equations are proposed.

Materials and Methods

In this investigation the results of the research considering only one pin hole is considered and discussed. The mechanical properties of the bamboo were established using the ISO recommendations. The compression, tensile and shear strengths of whole bamboo were determined. The shear strength of the bamboo along the fibers also was found a bamboo segments. Figure 1 presents the test in the hole of bamboo. Six bamboo of the specie, *Phyllostachys pubescens* culms were randomly chosen from a homogeneous lot. From each bamboo culms two test specimens for tensile, compression and shear were executed Moreira et.al [2011]. The modules of elasticity of the studied bamboo is $E_0 = 11360$ *MPa*; and Syz= 10 *MPa* The results for the bamboo species *Dendrocalamus giganteus* is Szz = 4,5 *MPa* Moreira [1998]. These data were used in finite analyses of the joint using SAP 2000 v14 structural analysis software.

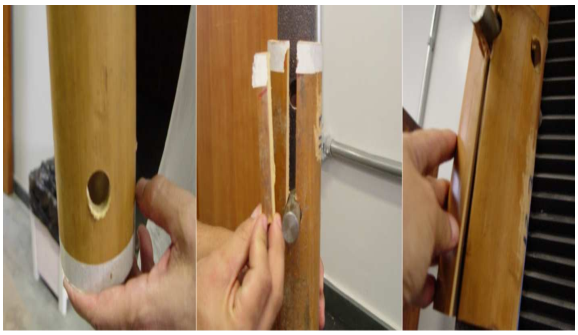
MODELING OF THE JOINT

According to Figure 2, from Murtha [2010], pin displacement has a maximum mean value 1,45 *mm* at the failure instant. Bamboo wall hole was partially squashed before the failure. Figure 3 shows the displacements of the steel pin deformation. It can be easily deduced that the vertical displacement $\delta_v(\theta)$ on each point localized by θ_j is described by Eq. (1). In Figure 3, the variables are

θ = angle with center in the center of the hole

δ = maximum pin displacement below contact pin-hole at failure, or maximum fibers deformations below pin, despising deformations on steel pin.

R_h = hole radius



Squashing *Shear* *Splitting*

Fig.1. Failure Modes

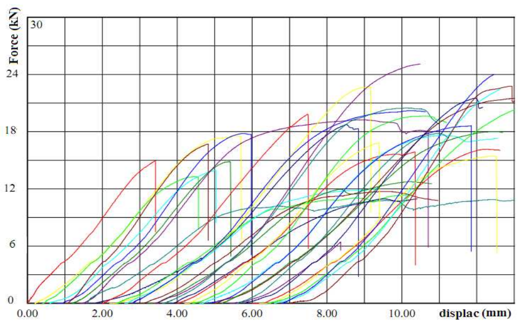


Fig.2. Displacements of two opposite holes

R_p = pin ray

$i = (R_h - R_p)$ = gap between pin and hole

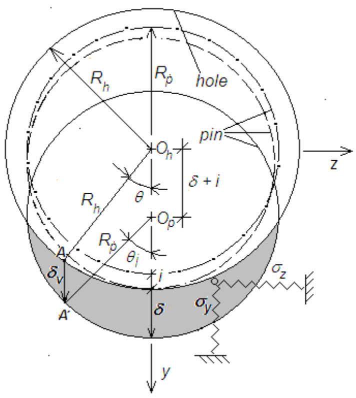


Fig.3. Steel pin displacements and hole deformation at failure

then

$$\delta_v(\theta) = R_p \cos\theta_j + \delta + i - R_h \cos\theta \tag{1}$$

Or

$$\delta_v(\theta) = R_p \sqrt{1 - sen^2\theta_j} + \delta + i - R_h \cos(\theta\ ) \tag{2}$$

But it is also evident that

$$sen\theta_j = \frac{R_h sen\theta}{R_p} \tag{3}$$

Where θ_j is the angle with center to the center of the pin at deformed configuration Equation 4 presents the vertical displacements of the fibers underneath the pin.

$$\delta_v(\theta) = R_p \sqrt{1 - \frac{R_h^2}{R_p^2} sen^2\theta} + \delta + i - R_h \cos(\theta\ ) \tag{4}$$

Figure (4a) presents vertical elastic plastic contact stress proposed in this paper. The elastic interval was considered linearly because an elliptical form, as suggested by contact stress theory has not a closed integral. The difference is small and this linear hypothesis increases in negligible quantity as compared with the plastic interval.

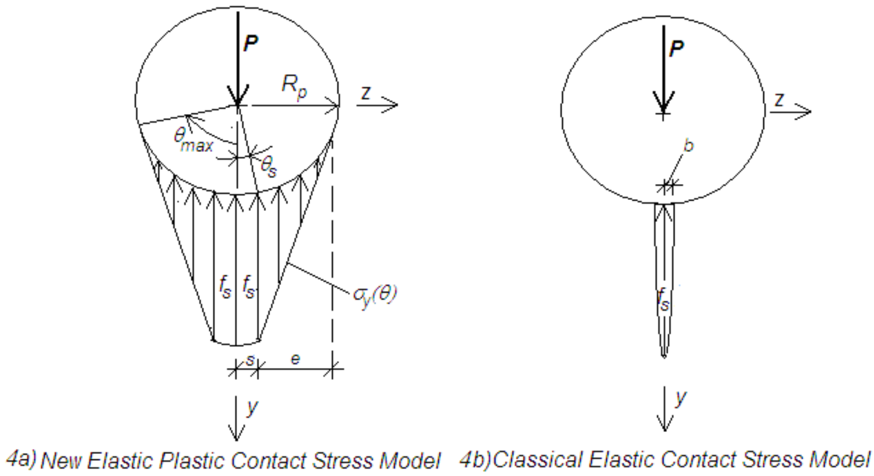


Fig.4. Elastic Plastic and Elastic Contact Stress Models

The elastic plastic contact stress model has to be in equilibrium with the applied force P, Figure 4a. The angle $\theta_{\max}$ corresponds to the point where $\delta_v(\theta)$ displacement is zero in Eq. 4. At the squashed or plastic interval *s*, the vertical normal stress σ_y is equal to the limit resistance f_s, corresponding to the bamboo fibers squashing strength in compression. The result of tested specimens, with the following characteristics was taken analyzed using SAP 2000. P = 7500N; $D_h = 20\ mm$; $D_p = 19\ mm$; bamboo external diameter $D = 90\ mm$; bamboo thickness wall $t = 7{,}5\ mm$. Considering these data it can be written that; $i = 0{,}5\ mm$; and Eq.4 gives $\delta_j(69{,}7^\circ) = 0$ and Eq.5 gives $\theta_j = \theta_{\max} = 80{,}8^\circ$.

Besides, the component σ_y at the elastic interval *e* can be deduced as

$$\sigma_y(\theta_j) = \frac{f_s(sen\theta_j - sen\theta_{\max})}{sen\theta_s - sen\theta_{\max}} \tag{5}$$

Where θ_s is the angle which positions plastic region into half. The angles θ_s , θ_j and $\theta_{\max}$ shown in Eq. 5 have their centers at the center of the pin. However, from now on, the general angle θ_j will be renamed as θ avoiding excess of the indices. So, the pin free body equilibrium diagram, Figure 4a gives Eq. (6).

$$P = 2\int_0^{\theta_s} f_s R_p t d\theta + 2\int_{\theta_s}^{\theta_{\max}} \frac{f_s(sen\theta - sen\theta_{\max})}{sen\theta_s - sen\theta_{\max}} R_p t d\theta \tag{6}$$

Or, after integration,

$$P = 2 f_s \theta_s R_p t + \frac{2 f_s R_p t}{sen\theta_s - sen\theta_{\max}}\left[-\cos\theta_{\max} + \cos\theta_s - (\theta_{\max} - \theta_s)\times sen\theta_{\max}\right] \tag{7}$$

Through Eq. 7 any unknown variable can be determined if the other variables are known. For example if P is the total failure force, then the position of the plastic interval θ_s can be found. In Eq.7 the first expression is plastic resistance and second one presents the elastic resistance. Considering the previous data and $f_s = 80\ MPa$, then $\theta_s = 10^o$.

The local lateral normal stress around the pin, will occur only because material has resistance in this direction. Each pin base point has only displacements in Y positive direction. After considering different models, evaluating σ_x stress, the best solution was the consideration of a local plain strain state. Here the axisymmetric geometry in the pin neighborhood restrains ε_z strain was assumed according to 3D generalized Hooke's law given by Eq.8.

$$\varepsilon_z = \frac{1}{E_z}(\sigma_z - \nu_{zy}(\sigma_y + \sigma_z)) \tag{8}$$

At $\varepsilon_z = 0$, the normal to fibers stresses, responsible for the splitting of bamboo wall the tensile stress are estimated by Eq.9.

$$\sigma_z = \nu_{zy}\sigma_y \tag{9}$$

where ν_{yx} is the Poisson Coefficient which correlations strains $\nu_{zy} = \left|\frac{\varepsilon_z}{\varepsilon_y}\right|$.

The forces $P_y(\theta)$, ca be calculated using Eq. (10) from θ_s until θ , in the elastic interval at one side of the pin through a simple change of the integration limits in the elastic portion of Eq. (7).

$$P_y(\theta) = \frac{f_s R_p t}{sen\theta_s - sen\theta_{\max}}\left[-\cos\theta + \cos\theta_s - (\theta - \theta_s)\times sen\theta_{\max}\right] \tag{10}$$

For a small plastic interval $0 \le \theta \le \theta_s$, the forces are given by Eq.11.

$$P_y(\theta) = f_s \theta\ R_p t \tag{11}$$

And the horizontal resultant force at one side of the pin, $0 \le \theta \le \theta_{\max}$ is given by Eq.12.

$$H_z(\theta\ ) = \nu_{zy} P(\theta) \tag{12}$$

Equations (10) to (12) were used to calculate the concentrated forces over the contact surface of the pin hole using SAP 2000 structural analysis software shown in Figure 4. The modulus of elasticity parallel and normal to fibers $E_y = 11360\ MPa$; and $E_z = 1336\ MPa = \frac{E_y}{8,5}$ respectively taken from Acha 2011. The Poisson coefficient was taken as $\nu_{zy} = \nu_{zx} = \nu_{yx} = 0,2$. From Tung [2010], the shear modulus was taken equal $G = 996\ MPa = \frac{E_y}{11,4}$. It is important to note that different values for these elastic orthotropic constants change significantly the stress in bamboo wall near the pin. For example, the bigger G, the bigger shear stress parallel to fibers.

In this paper, G was estimated by timber properties analogy. It was supposed that the modulus E changes with θ according to *Hankinsson* equation for stress in timber; Eq. 13,

$$E(\theta) = \frac{E_y E_z}{E_y sen^2\theta + E_z \cos^2\theta} \tag{13}$$

But, the classical deduction of the relationship between G and E is done observing the diagonal elongation of an infinitesimal square. So, we have to calculate E_{45°, and substitute this value in Eq. (14).

$$G = \frac{E_{45}}{2(1+\nu_{yz})} \tag{14}$$

In this case, Eq. (13) gives $E_{45} = \frac{E}{4,75}$ and Eq. (14) gives $G = \frac{E}{11,4}$.

The linear analysis through SAP 2000, v14 was done as a first study, with orthotropic material and thin shell elements and pin hole load was applied as shown in Figure 5.

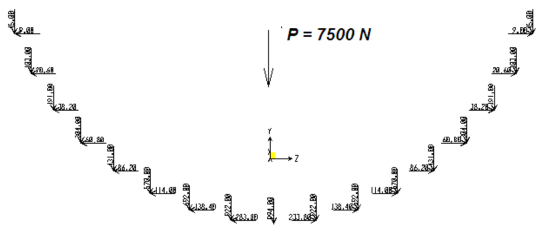


Fig.5. Pin Hole Contact Forces

Figures 6 show lateral deformed shape of bamboo segment with a scale factor 30.

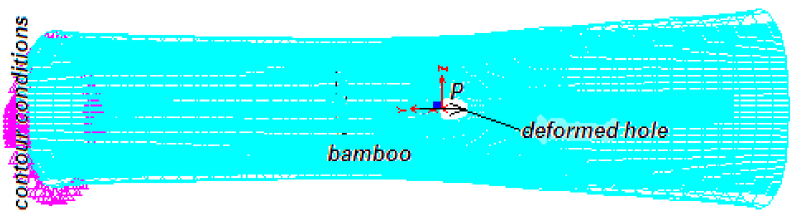


Fig.6. Longitudinal Deformed shape (scale factor 1:30)

Figures 7 to 18 show shear and normal stress on the hole surrounding wall. Top is the visible surface of bamboo wall and Base is the opposite or inner surface of bamboo wall which are different due to bending of the shell as seen in Figures 6.

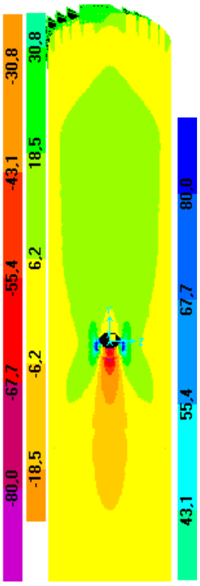


Fig.7. Syy Top

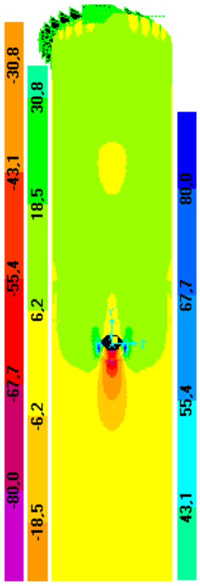


Fig.8. Syy Base

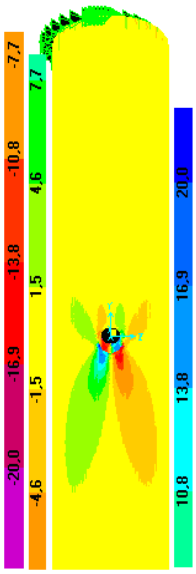


Fig.9. Syz Top

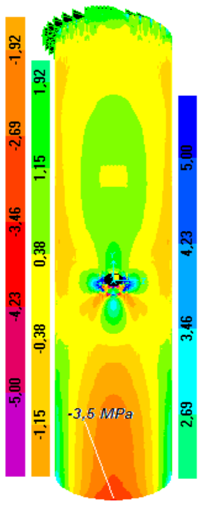


Fig.10. Szz Top

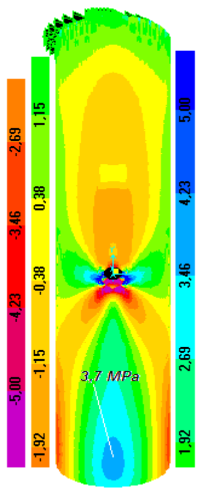


Fig.11. Szz Base

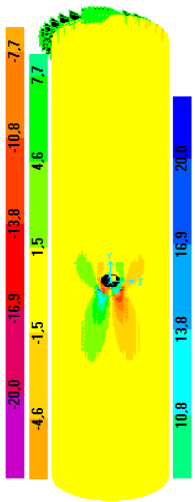


Fig.12. Syz Base

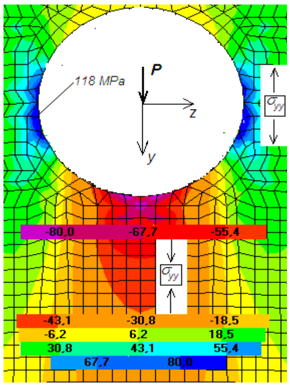


Fig.13. Syy Top

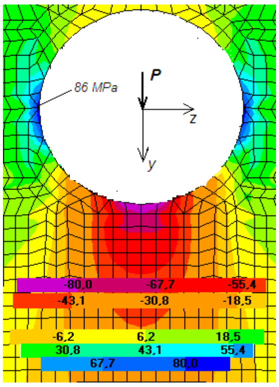


Fig.14. Syy Base

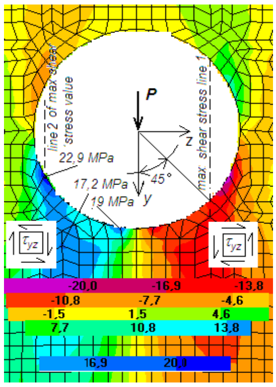


Fig.15. Syz top

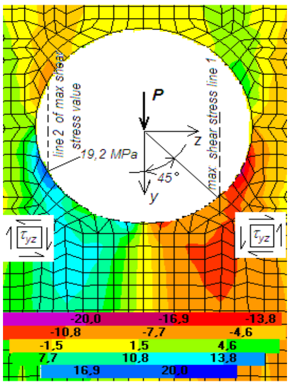


Fig.16. Syz Base

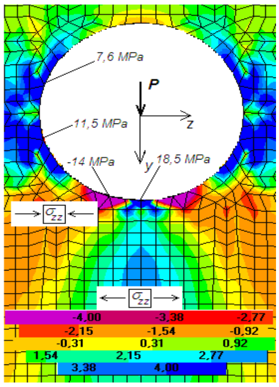


Fig.17. Szz Top

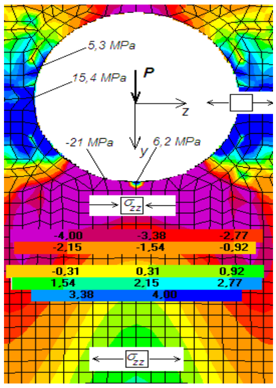


Fig.18. Szz Base

Maximum Shear Stress at Failure

Figure 19 presents the stress distribution according to SAP 2000 results of the Figures 15 and 16, over the line of maximum shear stress. Plotting the results and adjusting data it were obtained the exponential functions for Top, Mean and Base surfaces, as seen in Figure 19.

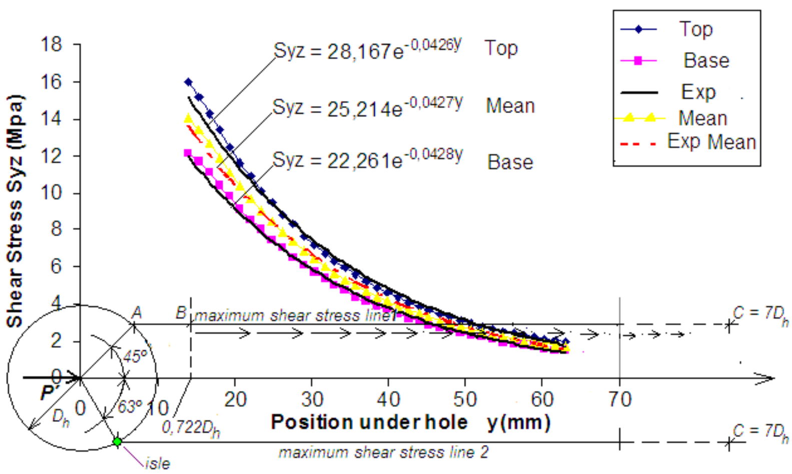


Fig.19. Exponential distribution of the shear stress

The stresses in AB interval have a very different distribution from the BC interval. So, despising the AB resistance, and considering that the double interval BC resist to a fraction *P´*, of the total force *P*, and integrating over the maximum shear stress line *1*, it can be obtained, by equilibrium, the equations for *Syz* and C_M, Eq. 16 and Eq.17, respectively. It is also supposed that the resistance occur from B up to a point C, distant *n*D from B. The value $n = 7$ was used because shear stress are relatively negligible at this distance. Until 45° double angle, *P´* is exactly 86 % of the total failure load *P*.

The shear stress on the mean surface, in line *1*, after some manipulations and considering $P' = 0{,}86P$ leads to Rq.15.

$$S_{yz} = C_M e^{-0,0427(y-0,722D_h)} \tag{15}$$

Where,

$$C_M = \frac{0{,}01836P}{(1-e^{-0,0427(nD_h-0,722D_h)})t} \tag{16}$$

Normally the difference *i* between pin and hole rays is no more than 1 *mm*. In the studied case *i =0,5 mm*. So there are reasons to think these equations can be generalized to estimate maximum shear stress to another situations corresponding to the failure load. The shear stress values are slightly greater than the real values due the AB neglected interval resistance, what is a conservative result. So, through Eq. 15 and 16, the maximum shear stress value on line *1* will be 18,45 *MPa* on $y = 0{,}722D_h$, *n*=7;15 % greater than the SAP 2000 result, *16 MPa* at Top Face.

Analysis of The Results

To get a good connection safety understanding it is important to observe the shear stress Syz (Mode II Fracture) and normal stress Szz (Mode I Fracture) simultaneously; both on Top and Base. Figures 15 and 16 shows that the bigger shear stress occur symmetrically in a line positioned by an angle $\theta = 45°$ although the contact presents isle with the highest values. Now we have to see the normal stress Syy in these locals of high shear stress values. The Figures 17 and 18 shown that line 1 has an interval subjected to high values of compression to fibers normal stress. This situation allows high values of shear stress, bigger than the shear stress resistance parallel to fibers, without start a crack in these positions, because compressive σ_{zz} enclosure that point. The isles, $\theta = 63^{o}$ (relative to D_h) is near the point where $\delta_v = 0$, where $\theta = 69{,}7^{o}$ (relative to D_h), with highest shear stress values of 22,9 *MPa* (Top) and 19,2 *MPa* (Base) , Figures 15 and 16, are subjected to high values of tensile stress, 11,5 *MPa* and 15,4 *MPa*,(Figures 17 and 18) where the crack can be initiated. The crack propagation path depends on the pattern of stress distributions along the way. Compression stress (enclosure stress) normal to crack way tends to counteract the propagation and tension stress increases the crack propagation. Both situations occur up and down the pin. Besides, these biggest values of shear and tension stress in the pin contact are being influenced by concentrated forces. So, on these specific points it can be considered that real stresses are probably smaller than that. Out of the contact the shear stress values in line 2, fall rapidly to values smaller than that on line *1*. Anyway, it can be used Eq. (15) to estimate the biggest stress along line *1*, and multiply this value by 1,24 which is the rate between the maximum value 22,9 (contact on line *2*) *and* 18,45 *MPa* (maximum value for line *1*), estimating so the maximum value in contact in line *2*.

At the same time, we have to see the maximum values of tension stress Szz (Mode I Fracture). The Figures 10, 11, 17 and 18 shows these maximum values. They can split bamboo before the shear of the wall. The tension stress value 18,5 *MPa* at Top and 6,2 *MPa* at Base will certainly start a crack in this contact point. But the propagation, again, depends of the stresses neighbourhood. The stresses Szz under pin have a fast change from tension to compression, which tend to enclosure the crack propagation. Observing Figures 10 and 11, we can see that Top and Base have inversed Szz stress along the longitudinal way. Near and down the pin, Top tends to propagate the crack and Base tends to enclosure it. Far way down the pin, Top tends to enclosure the crack and Base tends to propagate the crack. Above the pin, again, Top and Base have opposite influence on crack propagation. At the local of maximum tension stress Syy, shear stress Syz is zero. But, Figure 15 shows a shear stress of 19 *MPa* near the maximum Syy tension value. This is a critical superposition of Modes I and II to start here a crack. The mechanical tests show that failure can start on all these critical points numerically identified. As seen, the maximum values of shear and tension stress normal to fibers, are very higher than the resistance of the material itself. This is because the normal to fibers compression stress enclosure crack propagation. It is relatively difficult foresee the crack type or its exact position before failure. And certainly not only the local geometry but also the test machine speed has influence on the type of failure mode. All they, split, shear or shear-split crack dispute the first place. And the split can occur up or down the pin and, as seen in Figure 11 it can start at the border of bamboo.

Is there safety for bolted connections without reinforcements?

To answer this question a modeling based on classical elastic contact stress was done, Figure 4. Through these equations the maximum axial force *P* and contact width *b* are given respectively by Eq. (17).

$$P = \frac{(f_s)^2\, tCR_pR_h}{0{,}564^2(R_h - R_p)} \tag{17}$$

Where,

$$b = 1{,}13\left[\frac{PC}{t\left(\dfrac{1}{R_p} - \dfrac{1}{R_f}\right)}\right]^{1/2} \tag{18}$$

And

$$C = \frac{1-\nu_{bb}^2}{E_{bb}} + \frac{1-\nu_s^2}{E_s} \tag{19}$$

Considering the same f_s previously used and another bamboo properties, Eq. 18 gives $P = 2500\ N$ and the correspondent stress distributions are presented in Figures 20 to 25.

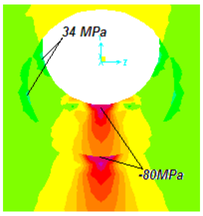


Fig.20. Syy Top

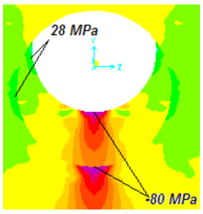


Fig.21. Syy Base

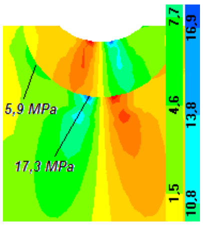


Fig.22. Syz Top

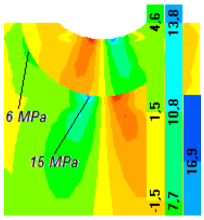


Fig.23. Syz base

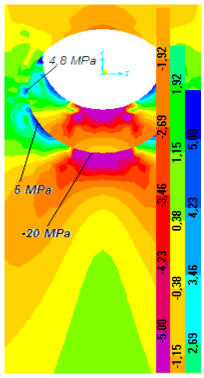


Fig.24. Szz Top

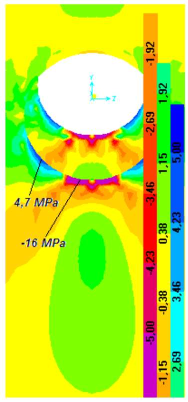


Fig.25. Szz Base

Conclusion

Different from shear failure, splitting failure has an additional geometrical resistance. It is shown that shear stress has a free path to propagate through parenchyma cells. The compression stress normal to fibers restrains the crack initiation under relatively high shear stress parallel to fibers. The presence of bamboo diaphragm under the pin hole reduces the risk of splitting failure. The reinforcement of the bamboo under the steel pin hole would improve the splitting failure of bamboo.

The results of this investigation have shown that the shear Syz and normal stress Syy respectively are considerably lower (Figures 22 to 25) as compared with those obtained using elastic plastic model (Figures 15 to 18). In both cases the shear stress Syz reaches again relatively high values. In the analysis lateral contact isles where both the shear and tensile stresses contribute to initiate a crack. The presence of the compression stress along the crack propagation tends to stabilize and diminish the risk of failure. The resultant stress field in cases of two or more steel pins would crack faster between the holes each due to stress superposition at these regions. The safe distance between sequential pins supporting bamboo axial forces has to be better investigated on futures works with the objective of establishing the minimum distance between the holes. Tensile tests of the pin joints conjugated with FEM analysis are being investigated with the objective of establishing more reliable methods. Future works have to consider Fracture Mechanics Theory for better understanding of the crack propagating behaviour.

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Projects Selection and Evaluation Tools for the of Non-Conventional Materials and Technologies (NOCMATS)

Ohayon, P.[1,a], Ghavami, K.[2,b]

[1]Universidade Federal do Rio de Janeiro (UFRJ)

[2]Pontifícia Universidade Católica do Rio de Janeiro (PUC - Rio)

[a]pohayon@facc.ufrj.br,[b]ghavami@puc-rio.br

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Abstract. The results of many successfully realized Research and Development (R&D) concerned with non-conventional materials and technologies (NOCMAT) in developing countries including Brazil have not been used in large scale in practice. This is due to the lack of selection and evaluation criteria and concepts from planning and designing to implementation programs by governmental agencies and private organizations concerned with the newly developed sustainable materials and technologies. The problems of selecting and evaluating R&D innovation outputs and impacts for construction are complex and need scientific and systematic studies in order to avoid the social and environmental mistakes occurred in industrialized countries after the Second World War. This paper presents a "logical framework" for the implementation of pertinent indicators to be used as a tool in R&D of NOCMAT projects selection and evaluation concerned with materials, structural elements and technologies of bamboo and composites reinforced with vegetable fibers. Indicators, related to the efficiency, effectiveness, impact, relevance and sustainability of such projects are considered and discussed.

Introduction

Since the 70ties local energy saving materials such as rice husk ash, soil-vegetable fibers, cement composites reinforced with vegetable fibers, bamboo as well as renovated ancient technologies started to be investigated by scientists and researchers in order to substitute industrialized materials which are highly polluting and high energy demanding in their production. Although proved technically and scientifically that the newly developed *non-conventional materials and technologies* (NOCMAT) were superior to the conventional industrialized materials they have not been used in large-scale projects. The NOCMAT findings could contribute immensely to the pursuit of sustainable development, which is a major global issue especially in developing countries including Brazil. These countries are in urgent demand for adequate housing for an ever-increasing population.

The present energy crisis in the world due to the extreme low level of water available over the last decades besides the indiscriminate industrial growth based on the program from industrialized nations' interferences has caused increasing concern about managing the energy resources still available besides the environmental degradation. There is an intense on-going search for non-polluting materials, which consume little energy in their production and/or utilization. Attention of researchers has turned to materials such as vegetable fibers including bamboo, soil, mining, industrial and agricultural wastes for engineering applications. New cements using all types of wastes are being developed and used for the production of composites reinforced with vegetable fibers around the world in a global effort to find a substitute for health hazardous asbestos cement which is prohibited by law in industrialized countries and used in most of developing countries with low cost.

To overcome the serious construction problem in Brazil and other developing countries in the world, several successful research programs have been carried out since 1979 at PUC-Rio. The results are being propagated through the ABMTENC (Brazilian Association of the Science of Non-Conventional Materials and Technologies) and implemented in other universities using indigenously available local materials such as bamboo, vegetables fibers, soil, quick lime, and cement mortars in the production of new structural elements such as bamboo space structures, corrugated sheets made of cement mortar composites reinforced with bamboo pulp, sisal and coconut fibers, soil-fibers composite for load bearing walls and concrete elements reinforced with bamboo [1].

Although with the accumulation of technical data concerning the developed materials and structural elements obtained from the research programs, they are not systematically used in large scale in civil construction. To reduce this barrier, a systematic and methodological selection and evaluation framework including a pertinent set of indicators is needed. In this paper a short description of the materials and structural elements using bamboo and vegetable fibers are given. Then the methodology for the selection and evaluation framework for the successful implementation of the results in large NOCMAT projects is discussed.

Bamboo and composites reinforced with vegetable fibers

In civil engineering the development and application of materials, with low cost and reduced energy consumption has turned into an actual basic requirement. The industrialized materials, so called conventional, mobilize vast financial resources, consume an enormous amount of energy and require centralized processing. In consequence of this, among other effects, activities are suppressed in rural areas or even in small towns, and non-renewable materials are wasted and causing permanent pollution. In this sense, it becomes obvious that ecological materials satisfy some fundamental requirements such as minimization of energy consumption, conservation of non-renewable natural resources, reduction of pollution and maintaining a healthy environment.

Bamboo presents a tremendous economical potential, as it reaches its full growth in only a few months and its maximum mechanical resistance in a few years, besides the fact that it occurs in abundance in tropical and sub tropical regions of the globe. The energy necessary to produce $1m^3$ per unit of stress projected in practice for materials commonly used in civil construction has been compared with that of bamboo. It was found that for steel it is necessary to spend 50 times more energy than for bamboo. The use of bamboo is attractive as a substitute for steel, especially when considering the relation between tensile strength and specific weight of bamboo, which is six times greater than that for steel. Although used intensively in South America by the natives for centuries, European colonizers did not know the potentials of bamboo. Systematic studies have been carried out on bamboo for more than two decades in order to develop methodologies for its application in space structures and as reinforcement in concrete considering their safety and durability. Bamboo to be used in a large scale as an economically viable material in engineering and with the possibility of its industrialization requires, at R&D of NOCMAT projects level, a systematic and logical framework for planning and evaluation in view of a sustainable technological development.

Selection and evaluation functions

Science and technology have contributed largely in the last three decades to the economic development without considering adequately different social classes. The intensive R&D activities in the rapidly growing areas of ST&I (Science, Technology and Innovation) such as new high resistance cements, steel, petrochemical derived materials, among others have not given the opportunity to less developed nations to cut the vicious circle which maintained them technologically dependent on industrialized countries. The *Science, Technology & Innovation Green Book* of the Brazilian Ministry of S&T, presented for discussion on July 2001, brings new challenges for the next ten years with its priorities notably related to low cost energy materials and technologies which are ecologically acceptable. It indicates that one of the main “bottle-necks” in terms of information, which restricts seriously the proper ST&I planning and decision making process, is the production of pertinent indicators [2].

In order to overcome these difficulties, six new interrelated key functions of technological resources management, characterizing the *what*, *why*, *when*, *where*, *how* and *who* for strategic and operational applications, should be considered. They have not been systematically regarded for the assessment of innovative projects related to the use of locally available materials in abundance and appropriate technologies, in developing countries [3]. These strategic functions are: *to carry out an inventory* of technological resources (available technologies, expertise and skills); *to select and evaluate* technological resources, their strengths and weaknesses, and their economic potential; *to* o*ptimize* (make the best use of technological resources); *to* e*nrich* technological resources through investigation, acquisition, alliance, research, development, improvement, innovation, renewal and replacement, as well as to further develop human technological expertise and skills by recruiting, training and team building; *to* w*atch* developments in the scientific, technological and competitive environment employing an appropriate *technological vigilance and intelligence system*; *to* p*rotect* technological resources by safeguarding intellectual property, and by preserving human expertise and skills.

The accelerated rhythm in which the results of the research on NOCMAT are being introduced into a society, principally used to conventional materials and technologies imported from industrialized countries and not sufficiently prepared to receive them, create new economic, financial, administrative, organizational and human resources problems. Specifically NOCMAT projects which benefited from an unconditional enthusiasm by researchers are seen by the community as suspicious not because of their "few" results but of their "any" results obtained. To show the reliability and durability of the newly developed materials and technologies, in addition to the results obtained in the laboratories, large scale constructions should be built and permanently monitored, requiring higher and continued investments from sponsoring agencies and private organizations. Therefore, interest to establish rational framework integrating scientific institutions and sponsoring agencies for research programs, which are directed to social, economic and technological advancement is increasing [4].

R&D of NOCMAT Projects Selection and Evaluation Capacity. Project is understood as a set of actions, performed in a coordinated way by a temporary organization, in which necessary inputs are allocated for, in a given period, achieving a specific goal [5]. There are over the last decades numerous conceptualizations for research project and technology development - R&D [6, 7, 8, 9, 10, 11, 12, 13, 14, 15].

Several relevant aspects are considered in the management of R&D projects, namely: (i) project team; (ii) project life cycle; (iii) organizational climate project and environmental conditions.

Selection and Evaluation in most developing countries is becoming as an important tool for the management of technology, as a necessary link between R&D and society needs. A key feature of a successful S&T organization is the ability to learn from past experience and react to market or client responses. Selection and Evaluation capacities can play an important role in influencing policy analysis and formulation; improving resource allocation and budgetary process; improving investment programs and projects, examining fundamental missions. However, in these countries the adequate use of feedback in formulating projects, programs and policies and allocating resources is only incipient. Sensitivity to public criticism and the fear of political fallout from selection and evaluation findings are inhibiting factors. Many social appropriate technologies still lack the essential requirements of effective selection and evaluation. The quality of information and access to it is often insufficient, mechanisms for feedback into the decision making process are weak and a culture of accountability by using pertinent indicators is not firmly applied.

The barriers in the selection and evaluation of NOCMAT are mainly high cost of their procedures and lack of interest and commitment to the selection and evaluation functions at the political level; feedback mechanisms for applying selection and evaluation findings; more attention given to preparing and appraising programs and projects than to evaluating their performance on completion; involvement of institutional and national staff in selecting and evaluating externally financed programs and projects; attention to the quality of information; objectivity and independence in conducting selection and evaluation; access to the research result on low-cost energy materials and technologies; trained staff [16]. In addition, most experts receive their education in industrialized countries and are not necessarily aware of local conditions and local solutions for a sustainable program. These experts could even damage or hinder the development of the project. In state and federal sponsoring agencies, selection and evaluation does not have high priority for major reasons such as: little effective methods for selection and evaluation; lack of incentive for future productivity and limited freedom of action.

The R&D of NOCMAT Project Framework Matrix. The R&D of NOCMAT project framework is being recommended by IAEA - International Atomic Energy Agency based on models provided by World Bank and UNIDO - United Nations Industrial Development Organization among other technical assistance agencies [17]. It is a tool which helps to think through all aspects of a project and analyzes its "logic" in order to ensure a good quality proposal which: (i) responds to a real need; (ii) produces significant economic or social impact; and (iii) demonstrates high potential for sustainability through strong commitment of the government and social groups concerned.

The project framework matrix presented in Table 1 points out the most important aspects of the project. The first column constitutes the *project design* and work plan; the second column *project's performance indicators* outlines the objectively verifiable performance indicators used to judge "success"; the third column indicates the *means of verification* of the indicators and the fourth column notes the *main assumptions* that may influence the course of the project [18].

The *project's design* contains the five specific elements (input; activities; project outputs; specific objective; development/overall objective) linked to each other by logical cause-effect relationships. The *overall objective* is the highest level result to which the project should contribute directly or indirectly. It explains why it would be necessary to carry out the project. The *specific project objective* explains what is expected to be achieved through the use of project outputs, and for whom (end user or target group), if successfully completed in a given time.

Project outputs are the immediate results that can be guaranteed as a consequence of project activities carried out during implementation. *Project activities* are the actions taken or planned to transform the inputs into outputs: how the project intends to produce the outputs. *Project inputs* are the products, services, or resources (financial, human, materials etc.) needed (necessary and sufficient) to carry out activities of the project.

The *project's performance indicators* are the signals that allow the measurement of achievement of the main design elements and must provide quantifiable and verifiable evidence of the progress made towards the objective. Performance indicators describe and specify what is expected to be obtained through the use of the outputs by the direct recipients, in terms of: quantity (how much, how many); quality (how good or how well); target group (for whom); time and location (by when and where).

Means of verification indicate the sources of information necessary to verify the accomplishment of the indicators and should include the information which is to be made available, in what form, by whom and when. Baseline data, implementation records and progress reports are necessary to monitor and evaluate the achievement of the project's objective.

Table 1 Project Framework Matrix for NOCMAT

	Project Design Elements	**Verifiable Indicators**	**Means of Verification**	**Main Assumptions**
To contribute	**Development/overall objective:** National capacities are established for low cost housing.	Number of new local housing with cost-effectiveness.	National and international documents.	Environmental and safety regulations are assumed
To Achieve	**Specific objective:** Capabilities to enable NOCMAT participation in housing programs.	% of effective cost reduction in implemented housing using NOCMAT.	Surveys related to the implementation of housing and low cost energy programs using NOCMAT.	Social/economic adherence to the housing program implementation is assured.
	Project outputs: Servicing facilities and training for local use of appropriate materials and technologies.	New techniques adopted for local uses, time required for program implementation, % of NOCMAT used.	Follow-up of the reports, comparing different programs results and laboratory results.	Technical patterns and costs are maintained; contract negotiations are successful.

To Produce	**Activities:** Construction of laboratories, training events, technical tests and evaluations; expertise on NOCMAT.	Education of human resources specializing in appropriate materials and technologies.	Project schedule and costs accomplishment.	Human/financial resources are available, effective training are provided.
Provided	**Inputs:** Experts advice, laboratories equipments and space.	Time, quantity, quality of specific resources.	Progress reports and national/international comparisons for NOCMAT projects.	Inputs are provided just in scheduled chronogram.

Source (adapted): [17, p. 6].

M*ain assumptions* should point out conditions that ought to exist for the project to succeed but which are outside the direct control of the project management. They are positive conditions that are logically necessary, for example, for the activities to lead to the outputs. The likelihood/probabilities of these assumptions should be analyzed at the formulation stage and monitored throughout implementation, as it is a decisive factor for taking corrective actions or modifying the work plan.

The Main Dimensions of Selection and Evaluation Framework. For the elaboration of a NOCMAT project different proposal should be examined. Selection and Evaluation should take into account five important dimensions, reflected into the NOCMAT project framework matrix: efficiency, effectiveness, impact, relevance and sustainability. *Efficiency* considers how well inputs are converted into outputs for example: the percentage of non-conventional materials included in products/objects and economic efficiency measured by energy and costs reductions, safety and life-cycle improvements. *Effectiveness* defines the extent to which the innovative project is likely to achieve its main objectives. It should reveal the effective changes observed by government action and relative advantages of the innovation to the users, improvements in warranty, reduction in complaints, new norms created or adopted for constructions, reduction of construction deficit.

I*mpact* is related to the longer-term effects on the problem situation or need which relates to the Development/Overall Objective. It should present the economic and social advantages pointing out changes in local culture, increased applications for constructions, pollution reduction, waste reduction, number of inhabitants benefited by the project implementation, increased Human Development Index by NOCMAT utilization, improved dissemination of technical information.

Relevant projects are those, which are necessary to solve the problems/needs, and their outputs are necessary to achieve the objective through direct and verifiable cause-effect relationships. *Relevance* should indicate: the degree of urgency and rate of growth of private and public funds allocated for housing programs using non-conventional materials and technologies; improved state of art in selected scientific disciplines and contributions to solve technical problems; professional learning; adaptability of NOCMAT application for construction in specific environmental and socioeconomic conditions.

Sustainability refers to the extent to which the improved situation (as resulted from the achieved objective) can be maintained by users in their own way. It is linked to the local availability of funds for continued operation, maintenance of equipment and re-training of staff, and to the institutional and managerial capabilities. It should stand out the scientific and technological prestige using appropriate indicators, local/regional and international cooperation, financial saving and new contracts with state sponsoring agencies.

Selected Indicators for R&D NOCMAT Project. Indicators should be applied consistently throughout the selection and evaluation processes, such as: proposal application and selection stage; ongoing evaluation and monitoring stage; final evaluation stage. The last stage is probably the most important element of the overall continuous evaluation and monitoring process in terms of assessing the achievement of objectives of NOCMAT projects and thus encompasses aspects of networking, dissemination and outputs. The final set of measurement indicators should include: (i) *additionality* (improvement of R&D to main objective); (ii) outcomes and achievements; (iii) quality; (iv) benefits; (v) continuity and; (vi) gaps (areas of research competence not covered or not represented by representatives) [19].Strategic objectives which express the specific ones with NOCMAT refer to: reduction of pollution shown by the increased use of NOCMAT; biodiversity protection through the number of families adopting NOCMAT; improvement of the quality of life of the population given by the number of dwellings using NOCMAT and the increased *per capita* of local revenue; organization/community and institutional participation reflected by the number of Non Governmental Organizations, NGO, and public institutions and by the number of NOCMAT courses promoted [20].

Sustainable Development is aimed at meeting the material needs of the present generations without compromising the ability of the future generations to meet their needs [21]. At the upstream stage of the sustainable technological development, indicators of *prevention* are pointed out such as: less energy inputs for raw materials measured by: (i) reduce use of natural resources not renewable; (ii) reduce ecological disturbances; (iii) reduce noise and vibration and emissions. At the process stage, *containment* is considered, still pollution is being generated and has to be controlled. At the downstream stage, *utilization* of NOCMAT is focused, assuring less wastes generation, energy savings and financial resources savings for needy populations [22].

Final remarks

The understanding of NOCMAT and its sustainability in constructions has undergone changes over the years. First attention was given to the issue of non-renewable resources and how to reduce their impact on the environment. Now emphasis is placed on more technical issues such as bamboo and composites reinforced with vegetable fibers for the construction components and technologies with energy related design concepts. In this paper, it is shown that the implementation of NOCMAT could be well succeeded by applying the selection and evaluation framework for R&D projects, which should be seen by all concerned parties as a way to learn and improve their integrated action in a systematic form. This is possible when the efforts are made to build social, political, economic, environmental, cultural and technical indicators for innovative projects, which are designed to serve the real needs of decision makers at local, state and federal level.

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Application of Non-Conventional Materials: Evaluation Criteria for Environmental Conservation in Brazil

Moraes, L. A. F. de [1a], Ohayon, P.[2b], Ghavami, K.[3c]

[1]Universidade Federal do Estado do Rio de Janeiro (UNIRIO), Instituto de Biociências. Av. Pasteur 458, Urca, Brasil

[2]Universidade Federal do Rio de Janeiro

[3]Pontificia Universidade Católica do Rio de Janeiro, (PUC-Rio)

[a] luziademoraes@gmail.com,[b]pohayon@facc.ufrj.br,[c] ghavami@puc-rio.br

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Abstract. The present worldwide socio economical system created the actual situation where almost two third of world population lives under the minimum living conditions which have been established by the United Nations criteria. To overcome these deficiencies, there is an urgent need to establish a new paradigm for promoting conservation and environmental sustainability. This paper presents the evaluation criteria for this major concern. The main variables considered are: sufficient availability, renewability, adequate physical-mechanical characteristics, cost efficiency, easy access, simple production, local technology adapted to local conditions, and durability. The non-conventional materials and technologies (NOCMAT) minimize adverse impacts into the environment and also provide adequate products for a market increasingly competitive. Thus, very strict norms and clean technologies should be implemented. Positive results in Brazilian research institutions have been developed on the use of NOCMAT (bamboo, vegetable fibers, bio-composites, recycled conventional materials, etc.) since 1979 at the Pontifical Catholic University of Rio de Janeiro (PUC-Rio, Department of Civil Engineering). Nevertheless, these NOCMAT are not yet sufficiently disseminated and employed in the country due to the lack of sufficient investments. Thus, government incentives and private initiatives must be increased substantially to change this panorama in Brazil.

Introduction

In our society, we are concerned by serious issues such as demand and depletion of natural resources. Population growth in the world has caused an increased demand for resources, energy, food and water. The few native forests that exist in the world are being decimated. The Amazon is losing its forests due to deforestation for the use of wood and forest fire. Given these problems, one of theses issues discussed is the use of non-conventional materials in civil construction and in furniture and paper industries for the replacement of native wood that has run out in the world, in addition to the legislation banning the use of illegal timber. Among the impacts related to the use of wood one can point out deforestation, forest fires, environmental degradation, and destruction of trophic chains, altering biodiversity and pollution. Brazil is emerging as one of the biggest polluters due to activities such as burning and soil use. For these reasons, different alternatives are being suggested which minimize substantially adverse impacts in the environment and at the same time can provide effective and efficient products for a market increasingly strict and competitive, but also lacking of solutions and of new and clean technologies.

For being considered as sustainable products some characteristics should be satisfied, including: physical and mechanical properties, cost/benefit, ease for production and availability in the environment, technology used in the production, minimization of adverse impacts. Among the alternatives discussed in this study, the use of bamboo is one of them. There is a great biodiversity of species of bamboo over the world [1, 2]. In countries such as China and India, bamboo is being used for thousands of years [3, 4] and currently for various purposes, including civil construction [5, 6, 7]. The scaffolding of many modern buildings in these countries are built exclusively with bamboo, due to its low cost, and to efficiency provided by mechanical physical and geometrical characteristics.

Brazil has a great biodiversity of bamboo species adapted to tropical conditions, with about 135 species [8]. In Brazil, the species most cultivated is the *Bambusa vulgaris* with twisted stems [9] and little application for furniture, handicrafts and construction, and its principal use is oriented to the manufacture of pulp and paper [10]. Different species of bamboo have sizes ranging from ornamental plants, even the giants of 30 cm in diameter and height of over 20 meters [1, 11]. In the southwest of the Amazon rain forests exist in opened areas arboreal bamboos, thorny gender *Guadua* covering about 180,000 km^2 [12]. The *Guadua* species also appear in the Serra dos Órgãos, State of Rio de Janeiro [13]. Many researches in Brazil have been conducted in relation to bamboo by renowned institutions and laboratories such as PUC-Rio and EMBRAPA agro biology located in Rio de Janeiro, ESALQ and UNESP in the State of São Paulo, UFMG and UFV in the State of Minas Gerais, UnB in Brasília/Federal District and, UNIDERP in the State of Mato Grosso do Sul.
The use of bamboo generates income for communities in southeastern and northeastern regions of Brazil [14], and provides other projects such as "Eco House" for popular housing made with bamboo, coordinated by the Institute for Amazon Research (INPA).

Issues

Native forests are being depleted in Brazil, especially those belonging to the Atlantic Forest Biome, and now the focus is on Amazon. The importance of forests is critical because they play very important ecosystem roles such as the release of oxygen and carbon capture, maintenance of water and biodiversity, protection against erosion. And still, they provide a growing business opportunities from activities related to ecotourism. It is not any more conceivable nowadays the unsustainable exploitation of the forest, although this activity remains illegal, despite all available technologies such as remote sensing and active and passive sensors with very high resolution.

Brazil presents a successful competitive production of bleached pulp and paper (such as newsprint, paper towel, packaging paper) from the use of *Eucalyptus*, considered a short fiber length, with exceptional quality and low cost. However, there are many heated discussions about the adverse impacts of *Eucalyptus* plantations. These impacts depend on the preconditions for the implementation of the forest, on the biome where it will be inserted as well as on the handling techniques employed.

Concerning the international market for long fibers, Brazil is still unknown and the substitution of *Araucaria angustifolia* fiber by *Pinus* fiber is less successful because the *Punus taeda*, a species cultivated in Brazil, has different characteristics due to the soil and climatic conditions which restrict their cultivation in the three Southern states of the country.

According to different authors, the bamboo's fiber is considered a medium size's one (2.2 to 3.0 mm) and for this reason it should provide a business opportunity for various purposes and substitute traditional long fibers with a greater or lower percentage in its composition. Another very serious problem, in addition to deforestation and extinction of native forests by the disorderly use of the land, and by the illegal and unsustainable plundering of nature, is the trash in all its forms.
In fact, what is poured today in aquatic and ground environments is not waste but green businesses opportunities. The plastic generated in the world as plastic bottles and other metals, glass and paper are not trash but can be fully recycled and reused. The benefits are immense for both nature and man himself. In this way, what is also being discussed in this study is the use of plastic materials discharged that should be transformed into products used for different purposes.

Objectives

The main objective of this study is to discuss few non-conventional alternatives for civil construction as well as for uses in products and processes inherent to our modern society. These alternatives are discussed in relation to different criteria and goals.

Theoretical basis

Among the alternatives for replacing the use of wood, are being investigated, biocomposites, eco plated materials, recycled plastic and bamboo, among other alternatives, aiming at sustainability for a world increasingly crowded with lacking solutions for current and future demands. Some specific criteria for the use of non-conventional materials should be considered, such as:
- Reduce deforestation;
- Avoid more environmental degradation;
- Use of sustainable technologies;
- Get a higher yield;
- Applicability for various purposes;
- Avoid further pollution and contamination;
- Reuse, reduce and recycle industrial residue;
- Increase cost / benefits relation;
- Improve efficiency / effectiveness.

Bamboo. Bamboo is used for various purposes [15] although its production technology of existing species is still little known and underutilized in Brazil. It is recognized as an environmentally ecological product because its cultivation avoids the use of fertilizers, pesticides and heavy equipment and the constant routine of replanting in the same area and also the stem of few species has good growth rate [16]. It is used by indigenous peoples and also by different people from Asia. Among bamboo's applications, few should be cited, such as:

A) Agriculture: it is used for irrigation of soils and crops; its tubular structure facilitates the water transport from the source to local irrigation [17].

B) Biomass production [18, 19]: bamboo is efficient for obtaining hydrogen. There are a number of researches from energy companies for creating fuel cells for power generation [20, 21].

C) Coal: the bamboo's charcoal is also produced by pyrolysis, in the same way of the conventional coal [22]. In Brazil, the bamboo's charcoal is being produced on a pilot scale, in the State of Alagoas [23], and the feasibility of bamboo's charcoal filter has been tested as a post-treatment in sewage treatment plant [24].

D) Culinary: the bamboo shoots are rich in nutrients such as vegetable protein, fibers, amino acids, calcium, phosphorus, B1, B2 and C vitamins. However in Brazil, the most used species in order to obtain shoots belong to the Pyllostachys and Dendrocalamus genders and whose sprouting in the State of São Paulo respectively occurs in September-November and January-March [25].

E) Bamboo plywood: bamboo laminate is produced on a larger scale in Asia for the manufacture of walls and floors. Nevertheless, Brazilian companies that typically use bamboo plywood import them from China [7, 26].

F) Civil construction [5, 27, 28, 29]: in housing, the technology developed enables cost reduction and time for building affordable housing [30, 31].

H) Paper [10, 32]: The bamboo fiber is also an excellent raw material for pulp and paper, despite fleeing from the standard in many ways. Its forest yield is considered competitive, such as Eucalyptus. But its growth is very fast, allowing harvest every year (with selective logging), or at least every two years (with cut down to ground level), against a waiting period of six to seven years for eucalyptus and fifteen to twenty years for Pinus.

Table 1 shows the distribution of bamboo species in the main Brazilian biomes [33]. It can be observed that bamboo is used more in the Atlantic Forest biome, followed by the Amazon.

Table 1 Distribution of bamboo species in Brazil (Source: Filgueiras & Gonçalves, 1988 [33].)

BIOMES	SPÉCIES	%
Atlantic Forest	151	65
Amazon region	60	26
Cerrado region (low vegetation)	21	9
Total	232	100

The areas where it can be found bamboo forests in Brazil are not yet clearly determined. **Figure 1** shows the main Brazilian states where there it is possible to find woody bamboo. According to *Guadua Bamboo Nurseries and Plantation Management Consultancy of Costa Rica*, Brazil is the country with the highest diversity of species of bamboo, with the highest percentage of endemic species of woody bamboo in Latin America totaling 137 species and 17 genders (**Figure 2**).

The states of São Paulo, Minas Gerais, Santa Catarina, Bahia and Paraná are those which have the highest diversity of woody bamboos. The states of Acre and Amazon include a great area of woody bamboo, and being the *Guadua* gender more dominant.In southern Brazil, mainly in the States of Paraná and Rio Grande do Sul, the production of bamboo is not developed due to the lack of technical knowledge more appropriated to regions prone to frost and cold.

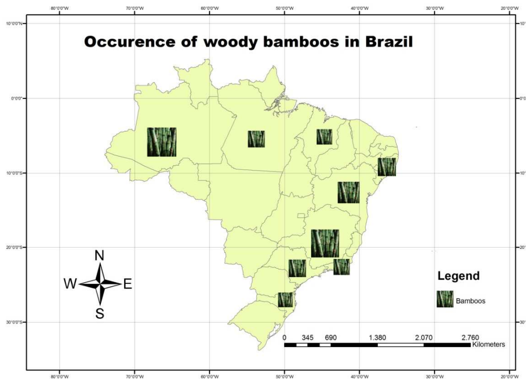

Fig.1. Key Brazilian states including woody bamboo

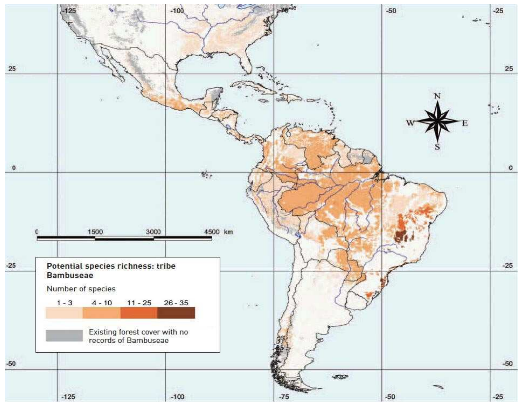

Fig.2. Diversity of bamboo forests in Latin America(Source:http://www.guaduabamboo.com/bamboo-species-of-latin-america.html)

Plastics. Plastic materials are increasingly being studied and requested to substitute wood and other materials, which are considered natural resources. An example of sustainable and ecological use of plastic is the EcoARK, a building with 1.5 million plastic bottles. It has three floors, theater, exhibition hall and uses collected rainwater for its cooling system. It is located in Taipei (Taiwan). Rugged and designed to withstand earthquakes, the structure resembles a honeycomb, with polli-made bricks (bricks of plastic bottles).

An interesting aspect of the paradigm shift of modern societies is that we are increasingly observing nature and trying to imitate it. One example is the conformation of bottles used in ecoARK, taking the shape of beehive, and if well adapted they result at the same time into a solid, sturdy and ecological structure.Table 2 shows some positives and negatives aspects for using non-conventional materials like bamboo and plastic.

Table 2 Positive and negative aspects of the use of bamboo and plastic materials

Alternatives	Positive Aspects	Vulnerabilities
Bamboo	- It is used for different purposes: agriculture, biomass, culinary, plywood, pulp and paper, civil construction, laminates, among others. - Its growth is rapid; reduce the time for being used. - The forest yield reaches 40 ton/ha/year, similar to *Eucalyptus*. - Propagation is spontaneous, through new shoots and does not require planting for over 100 years in the same area. - The stems' cellulose and lignin contents are similar to those of other woods. - It exempts the use of fertilizers and pesticides. - It reduces pollution. - It reduced deforestation. - It reduces carbon and methane release into the environment. - It is resistant to tension; it can be used as a substitute for steel aiming at the reinforcement of concrete structures, according to studies developed at Concordia University in Montreal, Canada.	- It is susceptible to degradation by fungus. It should take shelter from sun and rain. - It is intolerant to land which have some of the following characteristics: waterlogged, compacted, clayey, very acidic and very alkaline. - The dampness of newly harvested stems is greater than any kind of wood species. This affects the cost of handling and transport. - It has high contents of silica and starch. - It is vulnerable to termites.
Eco plated materials	- They are crafted from recyclable thermoplastic and waste from vegetable sponges. - They can substitute the wood and prevent further degradation; - They are waterproof and resistant to heat and rain.	
Ecological wood	- It doesn't degrade the environment. - It recycles materials which otherwise would be thrown out into the environment. - It doesn't absorb dampness. - It is resistance to heavy people traffic. - It doesn't warp. - It is resistant to ultraviolet ray and fires. - It doesn't crack and prick. - It is immune against pests such as termites and fungus. - Its durability is up to fifty years. - It needs low maintenance. - It is available in a variety of colors.	

Discussion

Studies show that these non-conventional materials can and may need to be used in substitution to those conventional, mainly because they meet the required criteria for uses in different activities, despite the supply chain still remains informal and dispersed and the technology is not yet very widespread. Thus, strong investments and government incentives are required for scientific and technological research and for production of non-conventional materials in Brazil. This will be possible from a paradigm shift aiming at the conservation and environmental sustainability, through reuse, recycling industrial residue, land reclamation, respect to each ecosystem vulnerabilities and potentiality, investments in research and development for the use of new materials. Otherwise, there will be no resources to meet this growing demand. The wood is getting increasingly difficult to find, not to mention the forest damage that it causes.

The United Nations Conference on Environment and Development (UNCED), known as Rio Conference Earth Summit (Eco 92) involved 172 governments where 2400 representatives participated. Earth summit 2002 (Rio + 10) held in Johannesburg/South Africa. Now, Stakeholder Forum for a Sustainable Future, also called Earth Summit 2012 will be realized in Rio de Janeiro/Brazil (Rio +20). New challenges are expected, trying to shape a strategic, global, multi-stakeholder movement to influence and implement the outcomes from the sustainable development agreements and the Millennium Development Goals. One of the main challenges not yet resolved is the effective engagement for more democratic, ethical and effective governance processes, and educational organizations engaged effectively in these processes. Too much money is spent within international organizations and governments for establishing policies which are not applied in practice over the world.

In this way, faced with the current energy crisis, global warming and socio-environmental stresses, the use of non-conventional sustainable materials and technologies becomes a great ally for minimizing the impact of those conventional, and encourage changes in attitudes of professionals involved more specifically in the environmental conservation in Brazil. With the deepening of studies on the potential and advantages of using bamboo, eco plates materials or ecological wood, into the Brazilian civil construction and the increased use of methods for environmental conservation assessment, in a very few years, these NOCMAT will appear as fundamental ones to be specified in different civil construction projects by architects, engineers and managers interested to meet these methods and its criteria.

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Impregnation of Bambusa Vulgaris with Polymeric Resins

Antonio Sobrinho Jr[1], Sandro Marden Torres[1], Normando Perazzo Barbosa[1], Sandra Reyes Ortiz[2], Khosrow Ghavami[3]

[1]Federal University of Paraiba, Brasil

[2]PhD Student National University of Colombia, Bogotá

[3]Catholic University of Rio de Janeiro

Keywords: bambusa vulgaris, polymeric resins, macrostructure

Abstract. There are more than one thousand of bamboo species around the world, but in some areas the most common is the *Bambusa vulgaris*. Comparing with other species used in construction, it is more susceptible to insect attack and its strength is slower. This work shows some studies made using culms of this bamboo with the aim to improve its durability and mechanical properties by impregnation of polymeric resins into their vases. Some information about *Bambusa vulgaris* microstructure is done. The percentage of vases, fibers and parenchyma was measured using an optical microscope. The absorption of this species in liquids with different viscosities was determined. Using an equipment to force the liquid into the vases, time of penetration of fluids with different viscosity was measured. Results show that the fluids penetrate most easily in the internal vases, where the diameter is greater than that close to external face of the culms and confirm that it is possible to fill the bamboo vases with viscous fluid as oil or polymeric resins. The attack of insect was eliminated when a impregnation with a resin made by 80 % de styrene + 20 % de metilmetacriyate was applied to *Bambusa vulgaris* culms.

Introduction

The interest in the use of Bamboo in the field of construction is growing everywhere this plant is being known by the architects and engineers. This can be attributable to its good engineering properties as well as the fact that it grows fast and comes from a renewable source. There have been several proposals for the use of bamboo as reinforcement of structures such as concrete beams, floors, panels and trusses [Sobrinho Jr. (2006); Dalcanal et al. (2000); Lima Jr. et al. (1995); Moreira (1988); Barbosa et al. (1993)], Achá (2002), Lopes (2003)]. Durability is very important for all the uses of bamboo.

For architectural and engineering purpose, the part of the plant of major interest is the culms. There are much more than one thousand of bamboo species: some with few centimeters high others are attaining more than 30 meters.In the Brazilian North-eastern, Bambusa vulgaris is the most spread. However, its durability and mechanical properties are usually inferior to others species such as Dendrocalamus giganteus and Guadua angustifolia. The idea in this paper is the impregnation of the vases of Bambusa vulgaris culms with polymeric resins to improve its properties of durability.

Macrostructure of the culms

Microscospically the bamboo culms is a tube in a truncated cone with bumps where there are the nodes (Figure 1). The diameter and the wall thickness are bigger in the bottom than in the top. Nature knows that it is in the inferior part of the culms where the solicitations dues self weight and wind are more important, being necessary there higher inertia. Internally, at the nodes exists a diaphragm, also seen in Figure 1 that gives strength against buckling to the culms wall.

As it will be shown, bamboo is not an homogenous material, so its properties change with the direction in the one which they are being measured. So it is convenient to consider in the bamboo culms the directions longitudinal, radial (or transversal) and circumferential, as indicated in Figure 2.

Fig.1. Bamboo culms showing its tonc-conic form

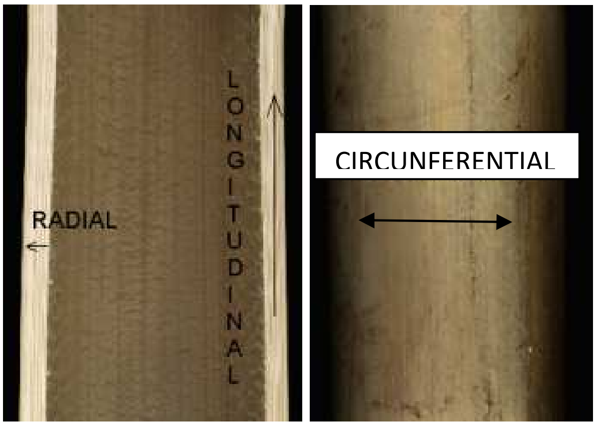

Fig.2. Directions considered in the bamboo culms

Meso and microstructure of the culms

Bamboo can be said to be a composite material made by fibers strongly bonded to a lignin matrix as shown in Figure 3.

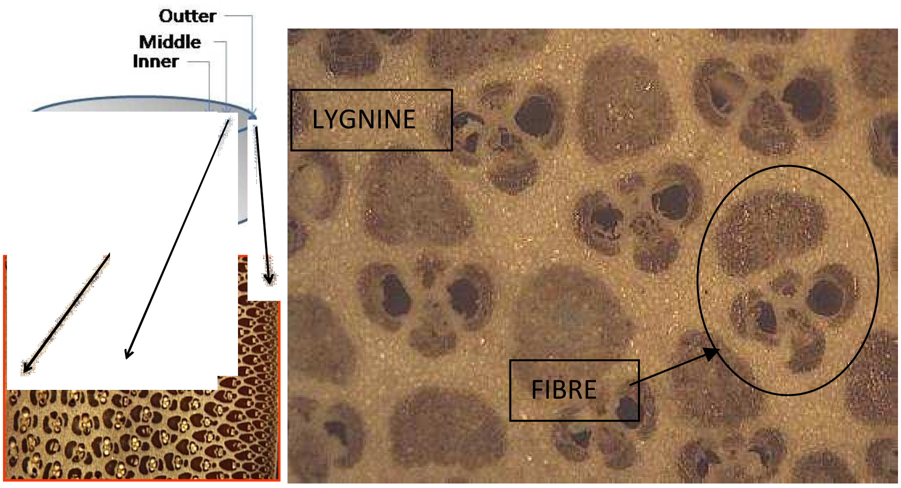

Fig.3. View of transversal secition of bamboo culms

Fibers are the resistant component of the bamboo. In the radial direction, as can be seen on the left in Figure 3, the distribution of the fibers is not homogeneous. They are concentrated in the external face of the culms where stresses are higher by wind load.

In the longitudinal direction, they are distributed almost homogeneously, the fibers are parallels suffering some deviation in the node region (Figure 4, left). In the circunferential direction, the distribution of the fibers can be considered uniform (Figure 4).

Examining the fibers in Figure 5, it can be seen "tubes" that forms the vascular system of the plant. They are divided in metaxylem, phloem and protoxylem. The stiffer part of the fiber is called sclerenchyma. It is responsible by the strength of bamboo culms.

Fig.4. View of bamboo culms cut longitudinally an transversally and distribution of fibers

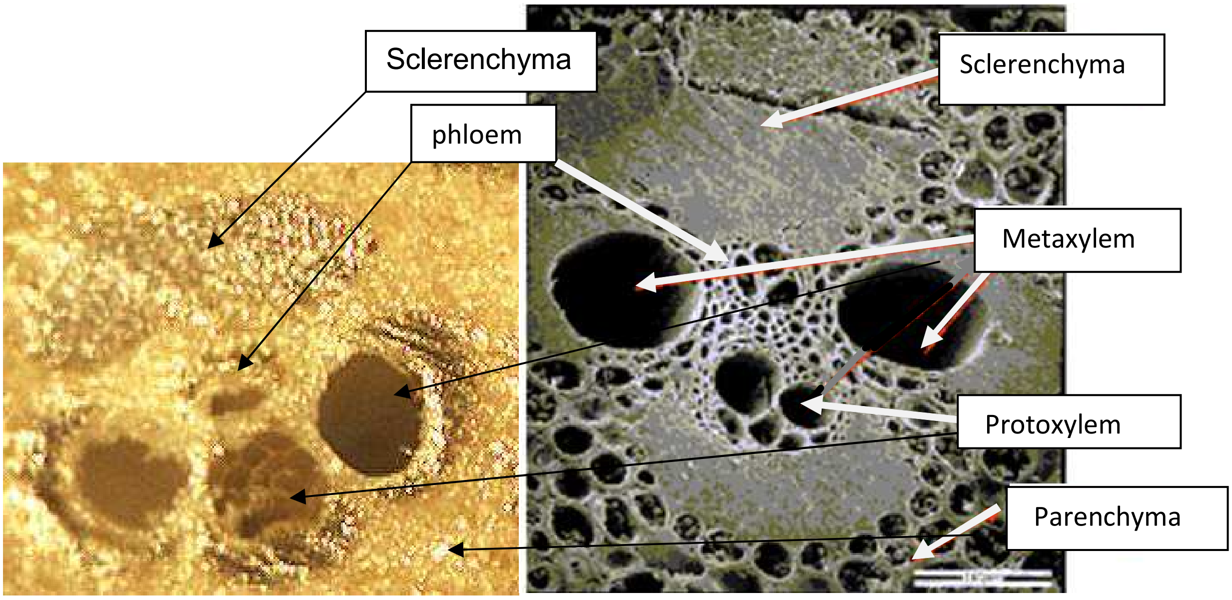

Fig.5. Vascular system of bamboo

The metaxylem diameter changes in the radial direction. In Figure 6 it can be seen the distribution frequency of the diameter of the metaxylem in the parts: outer, middle and inner, of the culms wall for *Bambusa vulgares*. It is clear that it is bigger in the internal part.

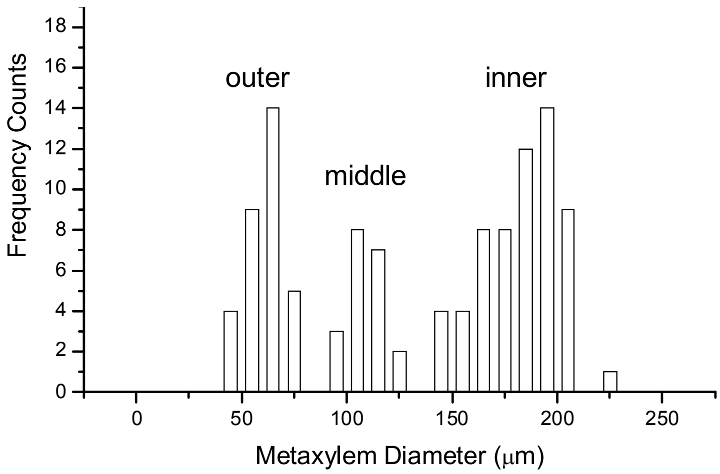

Fig.6. Distribution of metaxylem diameter in the radial direction of *Bambusa vulgaris*

As the vases are voids, they can be filled by a fluid that harden with time. Polymeric resins can be employed for this. To arrive at the impregnation, some experiments were made, to determine some properties that can have influence in this process.

The distribution of parenchyma, fibers and vases was obtained and indicated in Figure 7 in different parts of the culms Sobrinho Jr (2010). The percentage of vases can be considered about 10%.

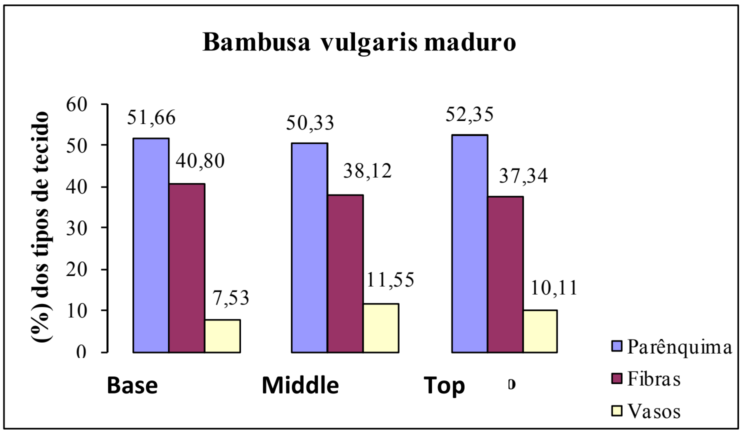

Fig.7. Distribution of different components of bamboo measured in the transversal section

PH of bamboo

Sobrinho Jr (2010) find that the pH of *Bambusa vulgaris* culms varies from 5.5 to 6.8, so it is slightly acid.

Absorption of bamboo. In Figure 8 indicates the absorption of Bambusa vulgaris different liquids. It can be seen that the absorption of water is the most important.

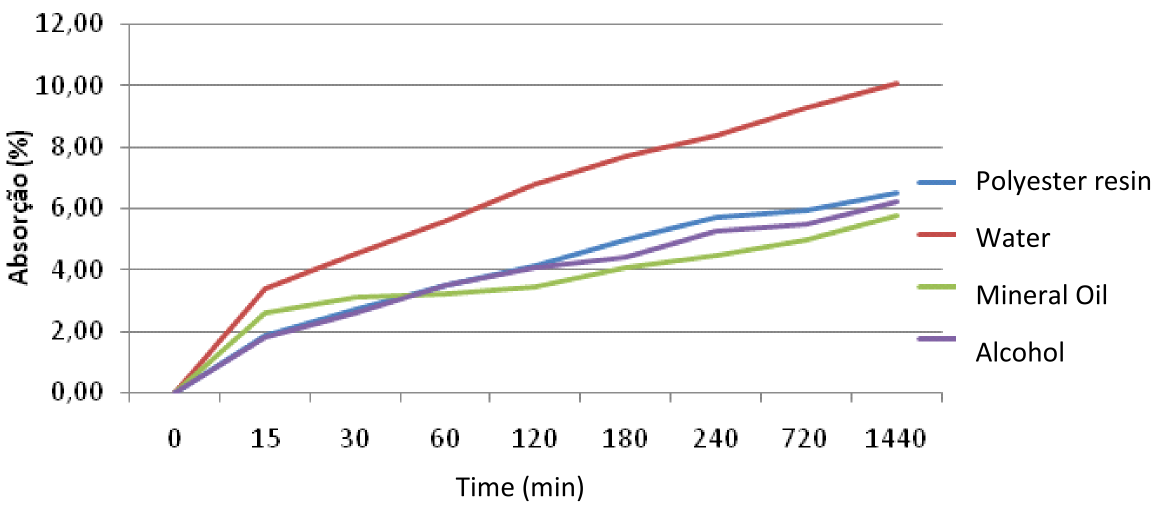

Fig.8. Absorption of different liquids by the bamboo

Figure 8 shows the absorption rate with time for different fluids in young bamboo. It can be observed that the maximum absorption rate is at around 12 to 18 hours of immersion. How denser is the fluid slower the absorption rate.

Parameters for impregnation

A machine to impregnate the bamboo culms was developed, as showed in Figure 9 on the left. Pressure on the liquid can be controlled. For small quantities, another dispositive was created.

To study the behavior of the bamboo culms during the impregnation process, before use polymeric resins, distilled water, motor car oil 20 W and 40 W were utilized. The oil 20 W used has viscosity 1.97 higher then water and the oil 40 W, 2.35 higher, as obtained by a viscometer Brookfield, model LD DVII.

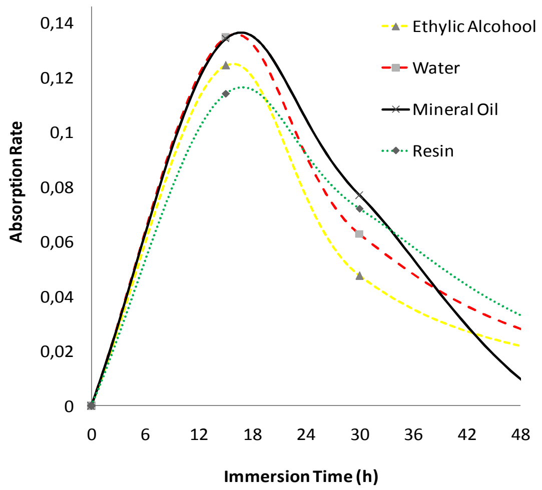

Fig.8. Absorption rate of bamboo in different liquids

Fig.9. Machine to impregnate bamboo

Using a pressure of about 0.5 bar, the time spent by 20 g of the liquids to pass through a piece of bamboo culms 40 cm long was measured. In Figure 10 it is possible to see that the liquid starts to pass though the vases of major diameter that are in the internal parts of the radial direction of the transversal section of the bamboo. Figure 11 indicates that the more viscous the fluid, higher the transit time.

Impregnation of resin

The fist impregnation with resin was made using 80% of styrene and 20 % of metil methacrylate. This resin has low viscosity and it penetrates well in the bamboo culms, as can be seen in Figure 12.

Fig.10. Oil crossing a piece of Bambusa vulgaris

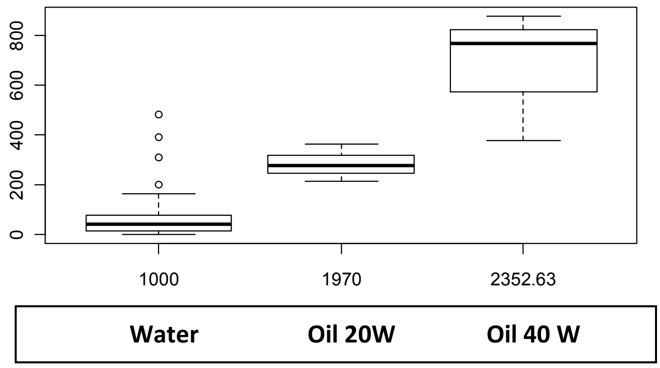

Fig.11. Time in seconds for 20 g of liquid cross the 40 cm of bamboo culms

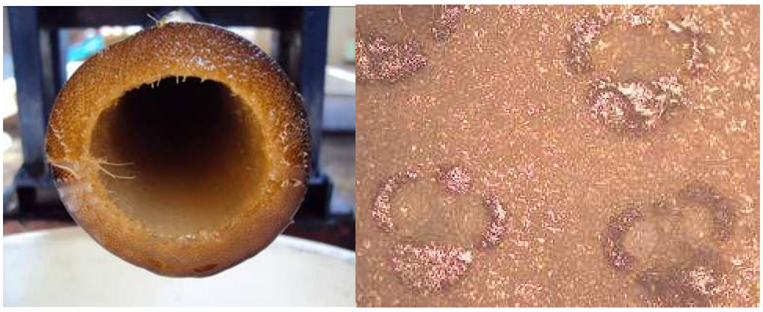

Fig.12. Piece of bamboo culms impregnated with styrene metil methacrylate resin

Some compression samples were extracted from the impregnated culms. Before testing, they were dried in a oven at 50°C. The strength was compared with that obtained with the culms in the natural state, air dried. Results are in the Figure 13.

Sample	Condiction	Compr. Strentgh (MPa)
1	Natural (air dried)	43.0
2		49.4
3		42.0
4		59.0
5		44.5
6		43.7
media		**47.0**
7	Impregnated (dried oven 50°C)	64.4
8		69.3
9		74.8
10		77.0
11		67.3
12		66.3
media		**69.9**

Fig.13. Compression strength test and results of bamboo samples

Fig.14. Bamboo culms full of insect and pieces of impregnated bamboo without any attack

Concerning durability, pieces of impregnated bamboo were put together a culms that was being attacked by the insects *Dinoderus minutes,* as showed in Figure 14. For more than two months any insect penetrated in the impregnated bamboo.

Final remarks

The meso and microstructure of bamboo shows it is an intelligent composite material. The fibers are the resistant component. They have real tubes that go from bottom to top of culms. The biggest "tubes" are called metaxylem and its diameter can reach even more than 500 micrometers in the *Bambusa vulgaris*.

Some experiments were made with the intention of impregnate bamboo vases. A machine was developed for this. Even liquids two times and half more viscous than water cross the bamboo vascular system. Pressure about half bar is enough.

To impregnate resins some difficulties needs to be supplanted. The resin set time is low, in general. So it is necessary to control impregnation time and take care that the equipment is not damaged by hardening of the resin in it.

Others kinds of resins need to be tested in this process.

The impregnation of bamboo culms can be a good solution to protect them against insects and to transform them in a durable material.

Acknowledgments

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Experimental Study of Glubam Single-bolted Joint Loaded by Tension

R.Z. Yang[1, a], Y. Xiao[1, 2, 3, b]*

[1]Modern Bamboo, Timber and Composite Structures, Hunan University, China

[2]Dept. of Civil and Environmental Engineering, University of Southern California, USA

[3]MOE Key Laboratory of Building Safety and Energy Efficiency, Hunan University, Changsha 410082, Hunan

[4]Advanced Bamboo and Timber Technologies, Changsha, Hunan, China

[a]swijane@gmail.com, [b]yanxiao@usc.edu

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Abstract. Glubam is a new construction material and glubam bolted joints have been developed in modern bamboo structures. To observe the performance of bolted joint, two major groups of glubam-single-bolted-joint specimens with double steel side plates are tested. Bearing strength and failure mode are analyzed and discussed. It is shown that specimens with tension parallel to bamboo fiber always yield by shearing out and showed higher bearing strength as well as better ductility, while specimens with tension perpendicular to bamboo fiber will fail by net tension. Results of bearing strength are evaluated by the 5% off-set method. At the end, equations obtained from test data and analysis about yielding strength of glubam bolted joint was obtained for following study and project design.

Introduction

With the development of society, conventional construction materials such as steel and concrete are getting more anti-environmental and finding new eco-friendly materials in civil engineering are becoming increasingly crucial. Though has been used in buildings and bridges long years ago, bamboo has always been used in original form. Modern structure using bamboo as basic material has found a new way to standardize bamboo materials and form industrialized construction method, which well become a new breakthrough in the civil engineering field [1].

The dowel-type joints are very common in timber structures mainly in combination with Glulam members [2]. Glubam as a similar structural material, its connection between members is mainly trough bolts or dowels. The bearing capacity of bolted joint is crucial in element or even whole structure. Modern bamboo structure first promoted by XIAO et al.[3] also adopt bolted joint as an important connection method. However, properties of glubam are quite different from both timber and steel. So is the property of bolted connection made of glubam. In this paper, the author designed and conducted a series of experiments to show the characteristics of glubam bolted connection. To simplify the experiment and put emphasis on the single bolt hole in the glubam board, the authors selected steel side plate. In the history of bolted connection research, single-bolt connection's property is very important to the following studies.

Up to now, wood or composite bolted connection has been studied by many researchers, some of whom have done a lot of studies on property of wood single bolted connections [4-10]. As for laminated composites, mechanical bolted joint is studied by some researchers including Dano et al.

[11], Schulz et al. [12], Xiao and Ishikawa [13], Park [14] and so on. All these researches mentioned above contribute a lot to the bolted connection and can supply some methods and ways to solve the glubam-bolted-joint problems. However, it should be noted that because of the different structures and properties of materials, the properties and failure modes will differ a lot.

The mechanical properties and the composite structure of glubam is different from wood composites. Glubam has more good tension, and bending property than wood. This can be seen in the experiment of glubam trusses, which got its failure by the twisting of top chord rather than the split of bolted joint. Up to now, there is no relative paper about research on bamboo-based product bolted joints.

In this paper, glubam bolted connection with different end distance and side distance are considered. Fig. 1 shows the representative characters of some distances in specimens.

The rest of the paper is organized as follows. Firstly, the Glubam material used in the test is introduced in Section 2; In section 3, experimental set-up is shown and the tests are carried out; results and discussion is presented in Section 4; at last, some conclusions are listed in Section 5.

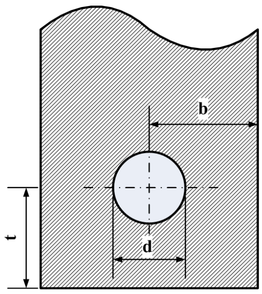

Fig.1. Geometric notation for bolted glubam board

Material

GluBam, trademarked by Xiao et al., are similar to plywood except using bamboo as basic materials, and are well established industrial products in China. There are two typical types of bamboo veneer sheets, which the authors categorize as the thin layer lamination and thick layer lamination [3]. The thin layer laminated bamboo sheets are much cheaper and more suitable for house and bridge use, typically have a thickness of about 10 to 15 mm, and are made by laminating approximately 2 mm thick bamboo strip mats. Xiao et al. made the modifications of the configuration of thickness and orientation. In this study, 30 mm thick bamboo veneer sheets are used, which were manufactured at a facility in Hunan Province, China.

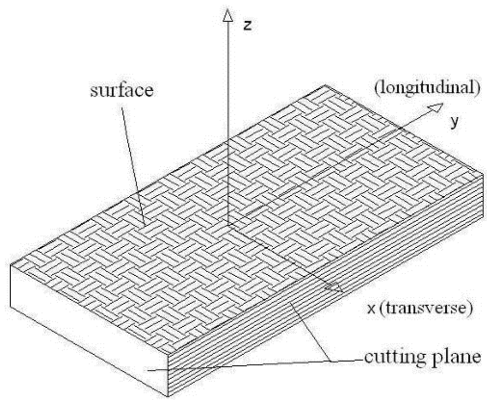

Fig.2. General view of planes of glubam board

As construction material, Glubam's mechanical properties haven't yet been standardized. A schematic diagram in Fig. 2 shows Glubam board's three different planes. As is depicted, planes perpendicular to axis Z is surface, including top surface and bottom surface; planes parallel to axis Z is cutting planes. However, cutting planes in two directions differ from each other in that the amount of fiber in longitudinal direction is two times that of transverse direction. In this test, ratio of fiber in longitudinal and transverse direction is 4:1. The properties of glubam have been tested and the results are listed in table 1.

Table 1 Summery of test results

Test type		N*	MV† [MPa]	SD‡	VC§	VC§ in GB	AI ǁ
Tension	Strength	16	82	16	20%	20%	10%
	Modulus	16	10400	16	20%		
Compression strength	without cold glue-line	26	51	2.6	5%	13%	2.0%
Static bending	Strength	32	99	11	10%	11%	4%
	Modulus	32	9400	927	10%	20%	3%
Shear strength		25	16	2	12%	20%	5%

*Number of specimens; †Mean value; ‡Standard deviation; §Variation coefficient; ǁ Accuracy index.

Experiment

Specimen. One end of specimen is holding end and other is for testing, as shown in Fig. 3. The end distance and edge distance of the tested end is designed.

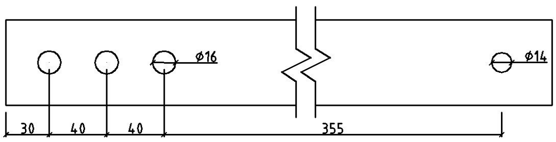

Fig.3. Dimension of specimens

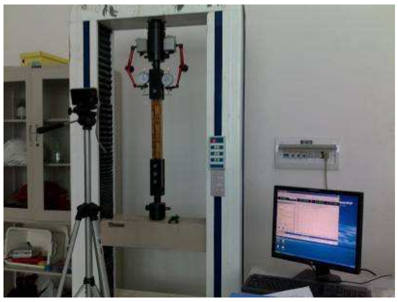

Fig.4. Test system

The experiment involved two major groups of specimens, in each of which there are nine groups of specimens with different end distance and edge distance. Table 2 shows the groups of specimens. The thickness of all glubam specimens is 28mm. There are nine kinds of sizes for specimen, and each size has ten specimens both in longitudinal and transverse direction. So there are 90 specimens in total in this test.

Table 2 Dimension of specimens

V1/H1 groups		V2/H2 groups		V3/H3 groups	
	t=24		t=24		t=24
b=24	t=36	b=36	t=36	b=48	t=36
	t=48		t=48		t=48

Test setup. Testing procedures outlined in ASTM D 5652–95 (R2000) were followed. Each specimen was subjected to a displacement-control rate of 3mm/min until the end of the test, to make sure specimens reach maximum load in not less than 5min and no more than 20min [17]. A universal loading machine was used to apply the load. Bolts were not fastened with nuts and their diameters are 12mm. In Fig. 4, test system is showed. Universal testing machine is used to control and apply force, as well as record data. And camera is used to take pictures and videos of crucial phenomenon.

Results and discussion

Failure mode. Most design standards use the Johansen's Yield Model. It is a mechanics-based model to determine the resistance of bolt for various ductile failure modes. In Johansen Yield Theory, it is hypothesized that wood or composite wood and bolt will reach total ductility under dowel bearing stress and moment of bolt, as shown in Fig. 5. And this kind of failure mode have been considered as the best condition, on which the bolt, side board and middle board will arrive failure at the some time, so all the material energy can be used.

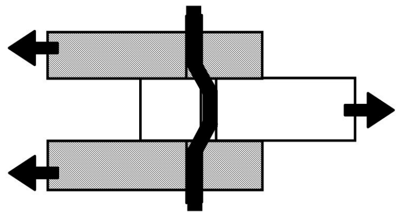

Fig.5. Ideal failure mode in Johansen Yield Theory

In the test of this paper, there are two main kind of failure mode, shearing out and net tension, as shown in Fig. 6 and Fig. 7 Shearing out occurred in V group and net tension in H group. For single bolted joint, the predominant failure modes include bearing, shearing out, cleavage and net tension. The governing mode and failure load of a joint depend on factors such as orientation of fibers in the members, the joint geometry, and clamping force [18-21]. For bearing strength, it is the ideal failure mode in Johansen Yield Theory and is most desirable. But for specimens in the test, they were clamped by the same prefabricated fixture and no tension was loaded on the bolt, so the specimens tended to fail by glubam breaking, and bolt diameter may be the other reason.

Fig.6. Failure mode of V group-shearing out

Fig.7. Failure mode of H group-net tension

Bearing strength. The results of the test show great regularity that has been expected, while some phenomenon is unexpected. As shown in Fig. 8, in V1 group, V2 group and V3 group, ultimate strength increase with the growth of edge distance. H group in Fig. 10 showed the same regularity except H1 group. On the other hand, when the end distance is the same, H group in Fig. 10 showed discipline that ultimate strength increase with the growth of side distance, while V group in Fig. 8 doesn't show any regularity.

The reason why these disciplines are showed can be found in the totally different failure mode of V group and H group. As discussed in section 4.1, V group specimen tends to fail by shearing out and H group specimen tends to fail by net tension. So it is reasonable that end distance is the first factor for ultimate strength of V group and edge distance for H group.

Comparing Fig. 8 and Fig. 9, it can be found that V group has correspondingly high strength than H group, which means loading parallel to fiber is beneficial to the ultimate strength of specimen.

In Fig. 9, another phenomenon should be noted that although edge distance is the first factor to influence the ultimate load, the end distance do obviously affect the results especially for H2 and H3 groups. Why would this happen? The failure mode can no longer explain this but distribution of stress. Many researchers did studies on the stress distribution both numerically and experimentally. Ce´sar Echavarrı´a and Alexander Salenikovich [22] published a paper about model for predicting brittle failures of bolted timber joints.