ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

Analytical Study on Flexural Behaviour of Glued Laminated Timber

Umaima Muhammed. C.K [1], Arya.R.[2]

P.G. Student, Department of Civil Engineering, AWH Engineering College, Calicut, Kerala, India[1]

Assistant Professor, Department of Civil Engineering, AWH Engineering College, Calicut, Kerala, India[2]

ABSTRACT: This study determines analytically the flexural properties of glued laminated timber beam (glulam) with different thickness of lamina and jointed lamina; it was compared to solid beam. This research used Rubber wood (Hevea brasiliensis). Glulam beam was divided into three groups based on the thickness of lamina, 20 mm, 15 mm and 10 mm respectively. Solid beam was also modelled besides glulam beam. Jointed wood with finger outside maximum moment zone in the bottom lamina was also modelled. Solid wood and laminated wood of rubber wood species was modelled and analysed in ANSYS 14.5.Then modelling of finger joint was done in Computer Aided Three-dimensional Interactive Application (CATIA) and analysed in ANSYS. The result was compared with the available experimental result. The results obtained show that the comparison of flexural properties between solid wood and horizontally glulam wood have no significant difference. Lamina thickness does not make any statistically significant difference in the flexural properties.

KEYWORDS: Glued laminated timber, Analytical study, ANSYS, Flexural behaviour, Hevea brasiliensis

I. INTRODUCTION

Wood has long been in demand as an important building material. Glued laminated lumber (Glulam) is made by joining individual pieces of lumber, laminated together with industrial adhesives under pressure to form large lumber elements. Rubber wood is the species of wood used in this study. An important characteristic of glulam manufacturing is that the bonding of laminations can result in beams of higher strength than the strength of single laminations from which they are constructed. Laminating also allows the dispersion of timber defects throughout the length of the glulam member. Efficient use of glulam in construction requires an understanding of the structural behaviour of numerous species.

Glued laminated timber members can be applied as primary or secondary load-carrying components in structures. Glued laminated timber members are used for transportation structures, highway bridges, marine structures and dome structures. Although adhesive bond lines often represent only a small part of a structural component, they are often crucial parts for the strength and the reliability of the structural component. A typical adhesive bond line in timber engineering has a thickness in the range of 0.1 mm to 1mm.

The early glues were all natural substances. Nowadays we use synthetic resins and polymers The wood adhesives most commonly employed in structural applications today are phenol resorcinol based adhesives (P), (melamine) urea formaldehyde ((M)UF), poly urethanes (PUR) and epoxies (EPX) [1]. Polyvinyl acetate (PVAc), which is used in this study, is an environmentally friendly adhesive, which is often prepared from vinyl acetate (VAc) monomer in the presence of protective colloid, non-ion emulsifier, initiator, and water. It is non-poisonous, not harmful, easily produced, low cost, easy to apply, economical on resources, etc., and has been used widely in porous materials.[2]

When we bond components together, the adhesive first thoroughly wets the surface and fills the gap between. Then, it solidifies. When solidification is completed, the bond can withstand the stresses of use. The strongest adhesives solidify through chemical reaction and have a pronounced affinity for the joint surfaces. Adhesive bonding is sometimes called

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

chemical joining to contrast it with mechanical joining. Rubber wood, a by-product of a crop grown for latex production is being used and marketed in many applications, substituting higher value and less available traditional hardwoods such as teak in Asian countries. India is the fourth largest producer of natural rubber in the world, 89% of which is produced in Kerala.[3]Computational investigation using ANSYS version 14.5 finite element software would be considered a good technique to assess the flexural behaviour of glued-laminated timber.

A finger joint, is a woodworking joint made by cutting a set of complementary rectangular cuts in two pieces of wood, which are then glued. To visualize a finger joint simply interlock the fingers of your hands at a ninety degree angle; hence the name finger joint. It is stronger than a butt or lap joint, and often contributes to the aesthetics of the piece. Finger jointed wood in this study are modelled using CATIA and later analysed in ANSYS workbench platform.

II. MATERIALS AND METHOD

Finite element analysis was carried out for this analytical study. For this ANSYS version 14.5 program was used for the numerical analysis. The geometry of beam models selected for the study is from the experimental study [3]. The solid wood and laminated unjointed wood are modeled using ANSYS, whereas jointed laminated beam was modeled by using advanced mechanical software CATIA and later imported to ANSYS for analyzing. The obtained analytical result was compared with experimental result[3].

ANSYS is an engineering simulation software (computer-aided engineering, or CAE).ANSYS develops, markets and supports engineering simulation software .The ANSYS Workbench platform is the framework unifying our industry-leading suite of advanced engineering simulation technology. In this study workbench platform was used.
CATIA is a multi-platform commercial software which enables the creation of 3D parts, from 3D sketches.CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify, and validate complex innovative shapes

III. BACKGROUND OR RELATED WORK

A simplified finite element modeling approach is presented for the design analysis of structural adhesive joints in the study conducted by Gaofeng Wu and Crocombet on the topic simplified finite element modeling of structural adhesive joints, in which either all the substrates or most of the substrates are modeled by beam elements and the adhesive is modeled by using four-nodded isoparametric elements. Finite element analyses for all the joints is made by using the commercial engineering analysis system ANSYS. [4]. The role of geometry on the mechanical performance of scarf joints in laminated veneer lumber (LVL) bonded with adhesives was investigated by Ayhan Ozcifci. It was observed that the highest bending strength and modulus of elasticity were obtained in control (solid wood) samples having three layered LVL. As a result of the effects scarf joints on bending strength and modulus elasticity test, if the scarf angle decreases, the properties of LVL increase.[5] The research based on a specific finite element model using ANSYS software simulates timber beams with defects and predicts its maximum load in bending. [6]. Yashida Nadir and Praveen Nagarajan conducted study on the behaviour of horizontally glued laminated beams using rubber wood and found that the comparison of flexural properties between solid wood and horizontally glued laminated wood have no significant difference. Lamina thickness does not make any statistically significant difference in the flexural properties. Laminated beam and jointed laminated beam with the same lamina thickness have no significant difference in the flexural properties. The wood adhesive bond strength and the wood failure percentage obtained are appreciable. The experimental results obtained and a comparison with code provisions verifies the suitability of the wood species for composite products.Modulus of rupture (MOR) were calculated by the formula:, MOR = $\frac{\text{PmaxL}}{bh^2}$
L is the span of beam between the supports (mm),), Pmax is the maximum or the ultimate load (N), b is the width of the beam (mm) and h is the depth of the beam (mm). [3]

Themistoklis Tsalkatidis [7] ,in his paper on Numerical simulation and analytical study of glulam timber beams explained the mathematical description of the contact conditions that apply at the interfaces of glulam beams and the development of finite element models by the use of the ANSYS software package. He studies the flexural properties of

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

unreinforced and reinforced glulam beams. The multi-layered glulam beams can be considered as composite members. The composite behaviour of glulam beams is achieved through various contact bonds at the interface of the laminations. When an unreinforced glulam beam is loaded, the interaction between wood layers and the adhesive material forms a shear bond at the wood-adhesive interface. When the loading exceeds the tensile strength of the adhesive, the shear bond is broken and this leads to failure of the glulam beam. The failure mode of the unreinforced glulam beam, as described above, is brittle.The samples with minimum layer specimens displayed the highest MOR and MOE [8]

IV. PRESENTATION OF MAIN CONTRIBUTION OF PAPER

This study focuses to determine the flexural properties of glued laminated timber beams and to compare the flexural properties between solid wood and horizontally glued laminated wood. Here whether laminated wood could be suggested as a replacement to the solid wood was analytically determined. The effect of thickness of lamina, number of layers of lamina on the flexural properties of glued laminated timber was analysed here. Flexural properties of solid rubber wood and laminated rubber wood were analyzed using finite element software ANSYS Workbench platform. Compared laminated wood flexural properties with finger jointed lamina which was modeled using CATIA. The jointing technique favors laminated beam of any size and is particularly useful for rubber wood, where lengthy plies on seasoning gets warped.

V. FINITE ELEMENT MODELLING AND ANALYSIS

5.1. Material models

The multi-layered glulam beams can be considered as composite members. The composite behaviour of glulam beams is achieved through various contact bonds at the interface of the laminations. The finite element method is essentially an approximation of the original real problem. The ANSYS version 14.5 Finite Element Method (FEM) program was used for the numerical analysis. Selected simply supported Beam specimens. The dimension of the beam specimen for modeling was 900X60 X40 mm. All the models in this study are of same dimension. The span to depth (l/d) ratio of the adopted specimen size corresponds to 14. All the models are with third-point loading. .A third-point loading static bending test was carried out, where the distance between the two loading points and the distance between the right and the left fulcrums was the same (Fig.5.1.1).
The entire model in this study has been assumed as simply supported. The support and loading conditions coincide with those of the experimental work [3]. The preparation plan of the test specimens for the study is as below:

1. Solid wood. (S)
2. Laminated wood
    a. Three layer laminated wood with 20 mm lamina (A)
    b. Four layer laminated wood with 15mm lamina (B)
    c. Six layer laminated wood with 10mm lamina(C)
3. Jointed laminated wood with four layer having each lamina 15 mm thick (J)

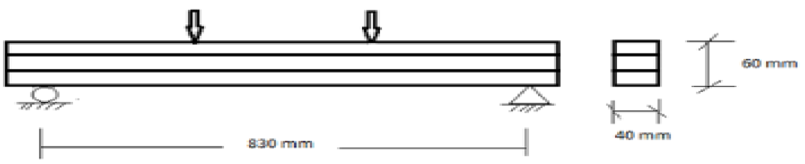


Fig. 5.1.1 Geometry of the model

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

Solid wood model and all the unjointed laminated wood of Rubber wood species was modeled and analyzed in ANSYS software workbench. Jointed laminated wood with four layer lamina was modeled in CATIA version 12 and analyzed in ANSYS after importing it. The ANSYS program is best defined as an iterative process. The ANSYS line commands code was written in order to find the desired stresses and deflection at any location along the timber beam by running the program simply as many times as needed.

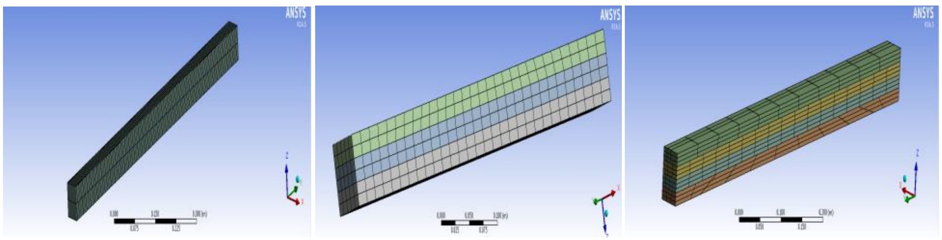
In this study, the experimental investigation of Yashida Nadir and Praveen Nagarajan [3] has been taken to simulate the model in ANSYS. A comparison study was conducted between analytical results obtained from ANSYS and experimental results. Rubber wood (Hevea brasiliensis) having an average density of 605 kg/m3 was chosen as per experiment.

.

ELASTIC CONSTANT	VALUE
EL	8,174.6 Mpa
ER	2,324.6 Mpa
ET	793.4 Mpa
GLT	1,008. 0 Mpa
GLR	1,070.33 Mpa
GRT	256.33 Mpa
V_{LT}	0.771
V_{RT}	0.808
V_{TR}	0.318
V_{LR}	0.489
V_{TL}	0.097
V_{RL}	0.139

Table 5.1.1. Elastic constants of rubber wood

The orthotropic property of rubber wood (Table 5.1.1) were taken from data published by Yashida Nadir et.al.[9]. Three main directions were taken into account: longitudinal (L), tangential (T), and radial (R). The orthotropy of wood is represented by the three moduli of elasticity *EL*, *ER* and *ET*, three moduli of rigidity *GLR*, *GRT* and *GLT* and six Poisson's ratiosUltimate tensile strength of rubber wood was obtained as 50.91 Mpa from a study based on rubber wood [10].



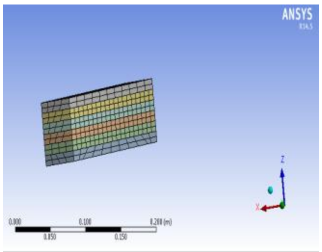
(a) (b) (c)

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

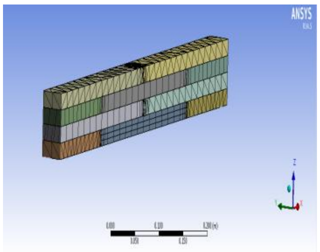
International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015



(d)



(e)

Fig.5.1.2 Meshed model (a) Solid wood(S) (b) Three layer laminated beam(A) (c) Four layer laminated beam (B) (d) Six layer laminated beam(C) (e) Jointed laminated wood with four layer having each lamina 15 mm thick(J)

The first finite element model (Fig.5.1.2 (a))(S) describes the case of a solid wood which was modeled in ANSYS 14.5. Different mesh sizes have been tested in order to get better accuracy in the numerical simulation.. Static structural analysis is done. Engineering data has been entered which include density, orthotropic elastic properties and strength properties. Geometry is created using sketching tool and extruding tool of ANSYS. In new plane, create projection using projection tool for applying loading and support condition at top and bottom face of the wood.

Meshing is done after several iteration to get better accuracy in the numerical simulation. Sweep method of meshing with sweep number of division equal to 250 has been chosen. Loading and support condition is given as per experiments. Each loading point is subjected to 0.5F kN, where F is the total force. For applying loading and support condition, in new plane create projection using projection tool at top and bottom of beam.

For the wood laminations and the adhesive layers of the glulam beam, a non-linear material law (ANSYS feature) has been used. In the case of laminated beam, after extruding slicing is done. Slicing is an ANSYS feature which helps to slice timber beams into many layers. At the interface between two laminas type of glue used in the experiment was poly vinyl acetate having thickness less than 1mm. Since the thickness of glue is very low when compared to thickness of lamina, at the interface of laminas bonded contact connection which is an ANSYS feature is applied. It will give the same effect of glue. However, it is not easy to obtain accurate results using ANSYS when contact connection is there.
In 20mm thick laminated beam (Fig.5.1.2 (b)) (A), mesh method used was sweep meshing with number of division equal to 30. Edge sizing with number of division equal to five along width and edge sizing with element sizing equal to 0.04m was chosen. In 15mm thick laminated beam (B), mesh method used was sweep meshing with number of divisions equal to 17. Edge sizing with number of division equal to five along width and edge sizing with element sizing equal to 0.005m was chosen. In 10mm thick laminated beam (C), mesh method used was sweep meshing. Edge sizing with number of division equal to five along width and edge sizing along depth with element sizing equal to 0.009m was chosen. In the case of jointed laminated beam as there are finger joints, it is difficult to model in ANSYS. So it was modelled in CATIA. Using sketcher and pad option of CATIA, it is very easy to model jointed laminated beam. Edge sizing with element size equal to 0.006m was given at the joints for the jointed model

5.2. Finite Element Analysis

The analysis performed is geometrically nonlinear. ANSYS uses the Newton-Raphson method as an incremental-iterative solution process. For the wood laminations and the adhesive layers of the glulam beam, a non-linear material law, ANSYS feature has been used. Static structural analysis was carried out.

VI. RESULTS AND DISCUSSION

6.1. Computational Results

The following figures present the computational results. These figures depict the total deformation and equivalent von-mises stress diagram of the glulam beam under load for finite element models included in the study.

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

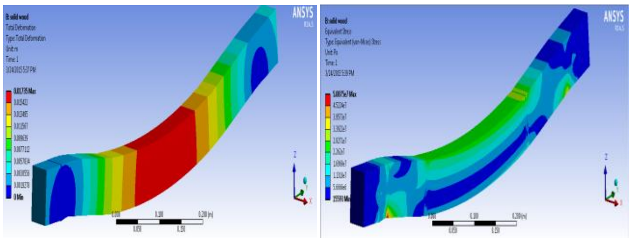


Fig.6.1.1 Total deformation and von-mises stress diagram of solid wood

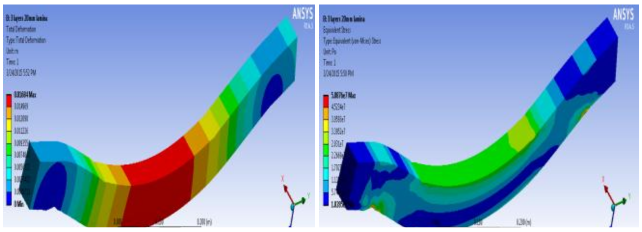


Fig.6.1.2 Total deformation and von-mises stress diagram of 20mm thick laminated wood

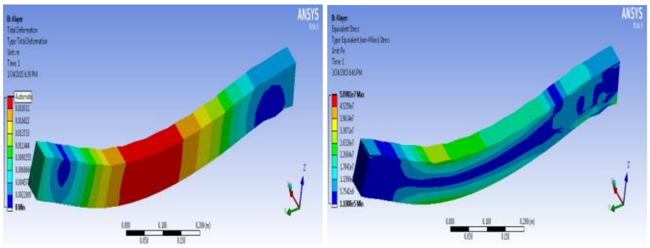


Fig.6.1.3 Total deformation and von-mises stress diagram of 15mm thick unjointed laminated wood

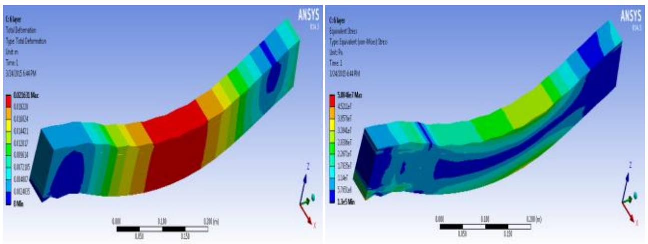


Fig.6.1.4 Total deformation and von-mises stress diagram of 10mm thick laminated wood

Solid wood and laminated wood after modelling in ANSYS are subjected to static structural analysis. After analysing equivalent von- mises stress diagram and corresponding deformed diagram will be obtained(Fig.6.1.1- Fig.6.1.4). The red colour indicates the maximum value and blue colour indicates the least value.

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

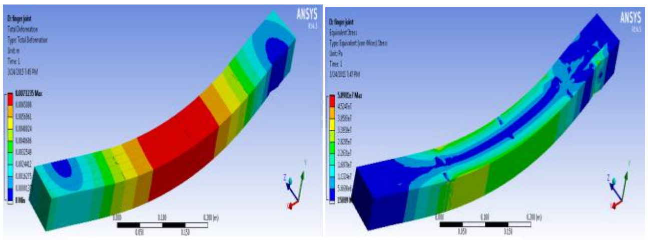


Fig.6.1.5 Total deform laminated wood.

In the case of jointed laminated beam, after modeling in CATIA, it was analyzed using ANSYS which will give the equivalent von mises stress diagram and total deformation diagram corresponding to ultimate breaking load.

6.2. Load-deflection curves

The load- deflection graph was plotted from the values obtained. After analyzing all the models, load deflection graph was plotted. Load–deflection graph of each laminated model and jointed laminated model was compared with load-deflection graph of solid wood model(Fig.6.2.1).

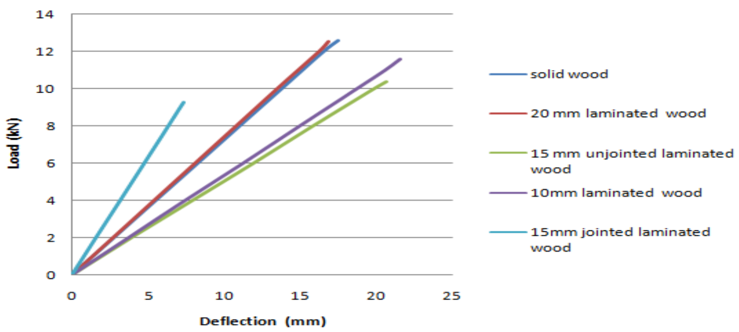


Fig.6.2.1.Load deflection graph

From the load-deflection graph (Fig.6.2.1), it is clear that failure load for both solid wood and 20mm laminated beam are very close to each other. There is no statistically significant difference existed between laminated jointed 15mm thick lamina and laminated un-jointed 15mm thick lamina.

	Samples	Mean value obtained from experiment (Mpa)	Value obtained after analysing in ANSYS (Mpa)	Percentage error (%)	Group S-solid wood A-20mm thick lamina B-15mm thick lamina C-10mm thick lamina J-15 mm thick jointed lamina
MOR	Group S	69.14	72.625	4.7	
	Group A	70.35	72.163	2.5	
	Group B	62.94	59.77	5	
	Group C	67.08	66.86	<1	
	Group J	55.10	53.523	2.8	

Table6.2.1Comparison of MOR obtained from experimental study and from ANSYS

The values obtained for the flexural properties of solid wood, laminated wood having different lamina thickness, jointed laminated wood from the experimental study are given in Table 6.2.1 Comparisons of the MOR of various groups showed that the highest mean was exhibited by 20 mm thick laminated beam followed by solid wood. The experimental results of this study show no effect for lamina thickness and no significant difference in the flexural properties between solid wood and laminated wood. The mean MORs of solid wood and laminated wood (unjointed) having different lamina thickness showed no statistically significant difference.

The analytical result of this study does not show much effect for lamina thickness and no significant difference in the MOR between solid wood and laminated wood. Highest MOR is exhibited by solid wood followed by 20mm thick laminated beam. MOR of 15mm thick jointed laminated beam and 15mm thick unjointed laminated beam does not show much variation.

Specimen	Failure load (kN) using experimental(average)	Failure load (kN) using ANSYS (average)	Percentage error (%)
Solid wood	11.99	12.6	4.8
Laminated beam	12.02	11.49	4.4
Jointed laminated beam	9.91	9.28	6.2

Table 6.2.2Comparison of Failure Load obtained from experimental study and from ANSYS

From the analytical study, for solid wood failure load was 12.6kN (Table6.2.2) which is slightly higher than the failure load exhibited by 20mm laminated beam. In the case of four layer laminated beam, failure load is equal to 10.37kN for unjointed and 9.286kN for finger jointed wood. Whereas for six layer laminated wood, failure load is equal to 11.6kN. So this study does not show much effect for lamina thickness and no significant difference in the failure load between solid wood and laminated wood.

VII. CONCLUSION

The results of the proposed finite element simulation have been compared with experimental ones from the international literature [3]. The failure modes of the both the computational and the experimental glulam beam were brittle. A finite element analysis of glulam beams and solid wood beam was done. The small difference of 5% of the MOR obtained from the FE model and the tests MOR values reported by experimental study confirms the strength of the finite element model as an analysis tool for glued laminated beam.By conducting this study**,** it was helpful to understand the potential usage of rubber wood in laminated products. Furthermore, it would be beneficial to carry out new research studies related to the same topic with different loading condition contributing to the literature on this subject, opening a new area of research.

REFERENCES

1. Erik Serrano, and Per Johan Gustafsso, "Influence of Bondline Brittleness and Defects on the Strength of Timber Finger-joints", International Journal of Adhesion and Adhesives, Vol.19(1), pp. 9-17, 1999.
2. Hui-Wang Cui, Qun Fang, and Guan-Ben Du, "Exfoliated Nanocomposites of Polyvinyl Acetate-NHydroxymethyl Acrylamide and Intercalated Montmorillonite from an Octadecyl Trimethyl Ammonium Bromide Surfactant", Polymer-Plastics Technology and Engineering, Vol.53, pp. 961–968, 2014.
3. Yashida Nadir, and Praveen Nagarajan, " The behavior of horizontally glued laminated beams using rubber wood", Construction and Building Materials, Vol.55,pp.398–405, 2014.
4. Gaofeng Wu and A. D. Crocombet , "Simplified finite element modelling of structural adhesive joints", Journal of Computers & Structures, Vol. 61 (2), pp. 383-391, 1996.
5. Ayhan Ozcifci, "Effects of scarf joints on bending strength and modulus of elasticity to laminated veneer lumber (LVL)", Building and Environment ,Vol.42 , pp.1510–1514, 2005.

ISSN(Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

6. Vanessa Bano, Francisco Arriaga, Azahara Soilan and Manuel Guaita, "Finite element model analysis of the strength loss in timber due to the presence of knots", Science Journal,,Vol.114, pp .214-222, 2010.
7. Themistoklis Tsalkatidis," Numerical simulation and analytical study of glulam timber beams", international journal of engineering & Technology, Vol. 3(2) ,pp.129-136, 2014.
8. Homeira Asgari, Amir Lashgari and Mehran Roohnia , "Effects of layer lengths and arrangements on bending strength properties (MOE and MOR) of laminated lumber made of Pinus sylvestris", Bulletin of Environment, Pharmacology and Life Sciences, Vol .3 [12], pp. 8-10, 2014.
9. Yashida Nadir, Praveen Nagarajan,, and A.J.Midhun, "Measuring elastic constants of Hevea brasiliensis using compression and Iosipescu shear test", European Journal of Wood and Wood products, Vol.72(6), pp.749-758, 2014.
10. Somjot Chirasatitsin, Suteera Prasertsan, Worawut, Wisutmethangoon and Buhnnum Kyokong,m, "Mechanical properties of rubberwood oriented strand lumber (OSL): The effect of strand length", Songklanakarins, Journal of Science and Technology, Vol.27(5) ,pp. 1047-1055, 2005.