

Study on Flexural Behaviour of Glued Laminated Timber

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ABSTRACT: Timber is a heterogeneous, hygroscopic, anisotropic material which composed of fibers of cellulose, used as a building material after stone. It has many advantages as an engineering material. The main disadvantage is that it can easily be affected by fungi and insects which cause decay of wood. These defects can be removed to a great extent by removing the moisture content present in the wood .The lamination of wood causes increase in strength since it is easier to dry wood of smaller thickness without degrade, than that of solid wood of large dimensions. Hence it is efficient to use wood as glued laminated timber. Glued laminated timber is a structural member glued up with durable moisture resistant structural adhesives from suitably selected and prepared pieces of wood either in a straight or curved form with the grain of all pieces essentially parallel to the longitudinal axis of the member. It reduces the overall amount of wood used when compared to solid wood by diminishing the negative impact of knots. Glulam is two third the weight of steel and one sixth the weight of concrete. Rubber wood is selected for the study, since it is very economical and light weight. The present research has developed a specific finite element model using ANSYS software that models solid timber beams with different grain angles and glued laminated timber beams then predicting the flexural behaviour, by finding the ultimate load capacity.

KEYWORDS: Hygroscopic, Glued laminated timber, Glulam

I. INTRODUCTION

Wood is a porous and fibrous structural tissue found in the stems and roots of trees. It has been used for thousands of years for both fuel and as a construction material. It is an organic material, a natural composite of cellulose fibers (which are strong in tension) embedded in a matrix of lignin which resists compression. Wood is a heterogeneous, hygroscopic, cellular and anisotropic material. It consists of cells, and the cell walls are composed of micro-fibrils of cellulose (40% – 50%) and hemi cellulose (15% – 25%) impregnated with lignin (15% – 30%). Wood has complex chemical nature along with its properties. However, it also has some drawbacks of which the user must be aware. Wood has many advantages as an engineering material, it is strong and stiff compared to steel, and it's also light and flexible. Wood is different due to its annual-ring-and-grain structure. But wood is anisotropic, it has different properties in different directions. One of the best things about wood is how long it lasts. Like other natural materials, it is subject to the natural forces of decay through a process known as rotting, in which organisms such as fungi and insects such as termites and beetles gradually nibble away the cellulose and lignin and reduce wood to dust. Although wood is excellent heat insulator, its strength and other properties are affected adversely when exposed to temperatures above 100°F. The combination of high relative humidity and high temperatures, as in unventilated areas, can have serious effects on roof sheathing materials and structural elements.

II. RELATED WORK

The performance of Glulam elements depends on the quality of the individual laminations, the quality of the glue-lines and the integrity of the cross-section which is made up of single lamellae which are stacked and glued to cross-sections. Grain angle is measured relative to the longitudinal axis of the stem of the tree. Although patterns of variation in grain angle within and between trees are highly complex and variable. The typical pattern is a left handed

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

angle in the rings nears the pith; gradually decreasing to straight grain and sometimes changes to a right handed angle towards the bark. The magnitude of the angle is usually greatest in the rings nearest the pith. For sawn timber, the grain angle relative to the longitudinal axis of a sawn batten is determined not only by the inherent grain angle of the tree but also by the taper and straightness of the stem and the sawing pattern used in the saw mill. The interaction between grain angle and out turn is therefore complex. Zobel and Jett (1995) agreed that as grain angle increased there was a significant reduction in the strength and stiffness of timber. Harris (1989) who stated that strength in compression, tension and bending all decreased with increasing grain angle.

T.Juricek *et al.* ^[3] (2009) conducted a study on the analysis of composite beams based on wood and reinforced fibers. It deals with the analysis of glued laminated timber beam and with the effect of the reinforcement of carbon fibers on its characteristics. A three dimensional model of glued laminated timber beam reinforced with carbon fiber was created using the ANSYS 8.1 program. The GLTB consists of basic materials such as timbered laminas and the glue between them. Three types of models are made. GLTB unreinforced, GLTB reinforced with a carbon fiber on lower edge of the beam, GLTB reinforced with a carbon fiber on both edges of the beam. The analysis of the model shows that placement of the reinforcement on the lower and upper edges of the beam achieved a considerably higher effect on the bearing capacity compared to the one with lower edge of the beam is reinforced.

III. GLUED LAMINATED TIMBER

Glued laminated timber, also called glulam, is a type of structural timber product comprising a number of layers bonded together with durable, moisture-resistant structural adhesives. It is a timber product composed of several layers of dimensioned timber glued together. By laminating a number of smaller pieces of timber, a single large, strong, structural member is manufactured from smaller pieces. These structural members are used as vertical columns or horizontal beams, as well as curved, arched shapes. Glulam is readily produced in curved shapes and it is available in a range of species and appearance characteristics to meet varied end-use requirements. Connections are usually made with bolts or plain steel dowels and steel plates. Glulam optimizes the structural values of a renewable resource – wood. Because of their composition, large glulam members can be manufactured from a variety of smaller trees. Compared with other engineered wood products, it reduces the overall amount of wood used when compared to solid sawn timbers by diminishing the negative impact of knots and other small defects in each component. The high strength and stiffness of laminated timbers enable glulam beams and arches to span large distances without intermediate columns, allowing more design flexibility than with traditional timber construction.



Fig.1 Glued laminated beams of different sizes

IV. ADHESIVES USED FOR LAMINATION

Adhesives are used to bond together the pieces of timber to form glulam. The adhesive used in the glulam process must be capable of developing shear strength in excess of the wood capacity and must be “wet-use” adhesive. The adhesive used must also provide bonds of such strength and durability that their integrity is maintained throughout the expected life of the structure. The adhesive used should be in accordance with BS EN 301. The most widely used adhesive is phenol-resorcinol-formaldehyde (PRF). It was developed out of the resorcinol-formaldehyde (RF). It was introduced in 1940s, it produces a distinctive brown glue lines and is suitable for most severe conditions. Both PRF and RF are used for exterior use like timber jointing and lamination. The Urea-formaldehyde (UF) is another type of

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 7, July 2016

adhesive which was developed in 1930s. The UF is used for interior use such as particleboard, plywood and laminating. The rubber board usually uses Poly Vinyl Acetate as adhesive.

V. BENEFITS OF LAMINATION

The main advantage of lamination of wood is improved strength; this is so because it is easier to dry wood of smaller thickness without degrade, in comparison to solid wood of large dimensions. It is possible to reinforce positions where greater strength is required, by selecting and placement of proper species or grades of wood in those positions, and by proper design. Improved strength is also accomplished by removal or redistribution of defects, such as knots. Good strength to weight ratio, glulam is one of the strongest structural materials per unit weight compared with structural steel and concrete it can produce a lighter superstructure with a consequent economy in foundation construction. Production of various sizes and shapes, lamination allows for possibility of production of large beams and timbers of almost any dimension, including shapes impossible to achieve with traditional lumber, particularly curves, including compound and multiple curves that allow for design possibilities that are unavailable when using purely solid sawn timber. Improved durability is due to the possibility of better preservative treatment of lamellae for protection against fungi and insects, or by placement of durable species on exposed surfaces. When wood is sliced into thin plies or pieces, trapped stresses are relieved; when bonded back together the resulting laminate becomes more dimensionally stable, that is, able to resist the swelling, shrinking or warping that a thick one piece component may produce.

VI. OBJECTIVE

1. To study the behaviour of both glued laminated timber and solid timber.
2. To identify the ultimate load carrying capacity of glued laminated timber specimens.
3. To identify the best combination of lamina based on Load-deflection curves.

VII. METHODOLOGY

1. Validation of Finite element analysis of unreinforced glued laminated timber based on the study done by Themistoklis Tsalkatidis (2014) "*Numerical simulation and analytical study of glulam timber beams*"
2. Finite element analysis of Glued laminated timber
3. Interpretation of results.

VIII. SCOPE OF PROJECT

The Scope of Work is as detailed below,

1. Problem study & input data finalization
2. Concept study of glued laminated timber
3. FEM Analysis: Static structural Analysis.

IX. CHARACTERIZATION OF RUBBER WOOD

Characterization, when used in materials science, refers to the broad and general process by which a material's structure and properties are probed and measured. It is a fundamental process in the field of materials science, without which no scientific understanding of engineering materials could be ascertained. In this experiment it is aimed to find out whether there is any layer wise variation in properties of timber. For that the Rubber Wood is divided into three layers of depth 30 mm each. Three layers are named as top layer, middle layer and bottom layer. Bend test was conducted using Universal testing machine. Three points loading was done. Span adopted is 400 mm. Details of tested specimen are given below.

Permissible bending stress = 36.8 N/mm^2

Factor of safety for material of specimen = 6

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Ultimate bending stress for material = $6 \times 36.8 = 220.8 \text{ N/mm}^2$
 Span of the specimen = 400 mm
 Breadth of the specimen = 75.5 mm
 Depth of the specimen = 30 mm
 Moment of resistance, $M = Fz$
 Modulus of the section = $z = \frac{b \times d^2}{6} = \frac{75.5 \times 30^2}{6} = 11325 \text{ N/mm}^2$

Details of Top Layer

Table 1: Test results of top layer

Load (kN)	0	0.5	1	1.5	2	2.5
Dial gauge reading	0	145	258	335	430	540
Actual central deflection	0	1.45	2.58	3.35	4.30	5.40

Load at breaking point = 3.3 kN
 Maximum deflection = 5 mm

Maximum fibre stress = Modulus of rupture = $\frac{WL}{4Z} = \frac{3.3 \times 10^3 \times 400}{4 \times 11325} = 29.13 \text{ N/mm}^2$

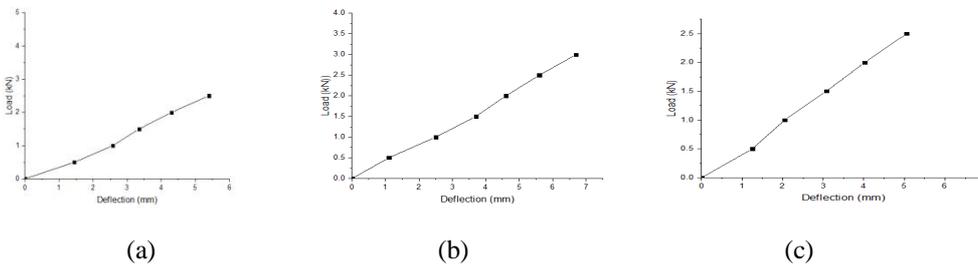


Fig. 5 (a) Load Vs deflection graph of top layer (b) Load Vs deflection graph of bottom layer (c) Load Vs deflection graph of middle layer

From graph [Fig. 5.(a)]

Load = 0.85 kN

Deflection = 1.8 mm

Modulus of elasticity = $\frac{Wl^3}{48\delta l} = \frac{0.85 \times 10^3 \times 400^3}{48 \times \frac{75.5 \times 30^3}{12} \times 1.8} = 3706.42 \text{ N/mm}^2$

Details of Bottom Layer

Table 2: Test results of bottom layer

Load (kN)	0	0.5	1	1.5	2	2.5	3
Dial gauge reading	0	110	250	370	490	560	670
Actual central deflection (mm)	0	1.1	2.5	3.7	4.9	5.6	6.7

Load at breaking point = 3 kN
 Maximum deflection = 9 mm

Maximum fiber stress = modulus of rupture = $\frac{WL}{4Z} = \frac{3 \times 10^3 \times 400}{4 \times 11325} = 26.49 \text{ N/mm}^2$

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From graph [Fig. 5.(b)]

Load W = 1.2 kN

Deflection = 2.7 mm

$$\text{Modulus of elasticity} = \frac{Wl^3}{48\delta l} = \frac{1.2 \times 10^3 \times 400^3}{48 \times \frac{75.5 \times 30^3}{12} \times 2.7} = 3488.4 \text{ N/mm}^2$$

Details of Middle Layer

Table 3: Test results of middle layer

Load (kN)	0	0.5	1	1.5	2	2.5
Dial gauge reading	0	125	205	308	402	605
Actual central deflection (mm)	0	1.25	2.05	3.08	4.02	6.05

Load at breaking = 3.1 kN

Maximum deflection = 7 mm

$$\text{Maximum fiber stress} = \text{modulus of rupture} = \frac{WL}{4Z} = \frac{3.1 \times 10^3 \times 400}{4 \times 11325} = 27.37 \text{ N/mm}^2$$

From graph [Fig. 5.(c)]

Load = 1 kN

Deflection = 2 mm

$$\text{Modulus of elasticity} = \frac{Wl^3}{48\delta l} = \frac{1 \times 10^3 \times 400^3}{48 \times \frac{75.5 \times 30^3}{12} \times 2} = 3924.45 \text{ N/mm}^2$$

Table 4: Tabulation of results

	Modulus of elasticity (N/mm ²)	Modulus of rupture(N/mm ²)
Top layer	3706.42	29.13
Bottom layer	3488	26.49
Middle layer	3924.45	27.37

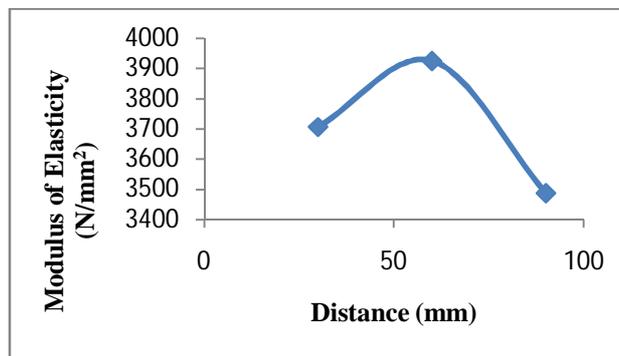


Fig. 6 Variation of modulus of elasticity with distance

Modulus of elasticity of middle layer is found to be greater than other two layers. So there is a need to provide the top and bottom layer with timber having more strength. Hence in the analytical work the layer whose grain angle having ultimate load capacity is chosen as the top and bottom layer. The modulus of rupture value variation is comparatively less.

X. FINITE ELEMENT ANALYSIS OF SOLID TIMBER AND GLUED LAMINATED TIMBER

The timber beam of length 176 cm breadth 6 cm and depth 10.8 cm was modelled with different grain angles in ANSYS Workbench so as to check which grain angled solid timber behaves better during loading conditions. The grain angles chosen were 0, 4, 8, 12, 16 and 20 degree. By the analysis of different models of solid timber it is possible to predict which grain angle behaves efficiently. By pacing this best grain angle on outer layers modelling of laminated timber of three layers has been done by varying the middle layer with other grain angles. The glued timber laminates has each layer of 3.6 cm each. The glue used for bonding of layers is ploy vinyl acetate with a frictional coefficient of 0.32.the load capacity of different glued laminated timber specimen is found out and their maximum deflection at that point is also determined. Solid timbers of six grain angles and glued laminated timbers with three layers are modelled using ANSYS 16. SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behaviour. The contact elements and target elements (CONTA 173 & TARGE 170) are laid on the parts of the model that are analyzed for interaction. The glue used for joining timber layer is poly vinyl acetate. The wood used is rubber wood and its properties are provided from Rubber Board. The timber beams are simply supported.

XI. SOLID TIMBER

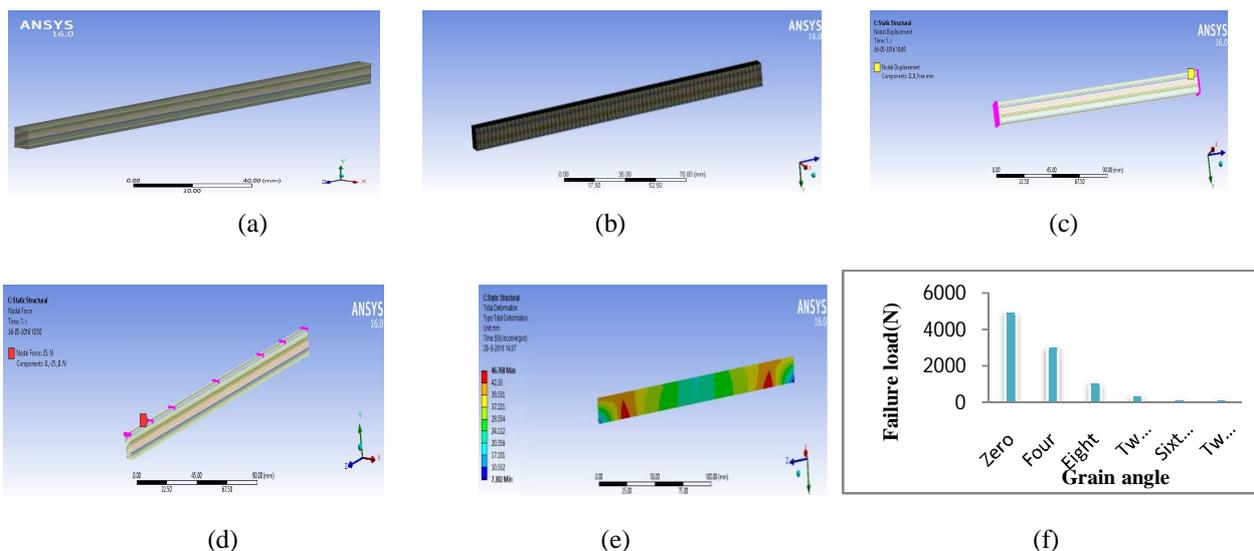


Fig. 8 Solid timbers (a) Modeling of zero degree grain angle solid timber (b) Meshing of zero degree grain angle solid timber (c) Support conditions of zero degree grain angle solid timber (d) Loading diagram of zero degree grain angle solid timber (e) Deflection diagram of zero degree grain angle solid timber (f) Bar chart showing Ultimate load capacity of different grain angle

Table 5: Tabulation of results of solid timber under axial loading

Solid timber	Failure load	Deflection (mm)	Strain energy (J)
0 degree grain angle	5000 N	46.76	113.987
4 degree grain angle	3100N	40.795	63.805
8 degree grain angle	1100 N	32.552	18.056
12 degree grain angle	400 N	20.5	1.575
16 degree grain angle	200N	16.264	1.400
20 degree grain angle	200N	11.584	1.100

Results shows that the solid timber with zero degree grain angle is having ultimate load bearing capacity. Fig. 8.(f) shows the variation of failure load for different grain angles. Here the solid timber with zero degree grain angles has more load bearing capacity of 5000 N with a maximum deflection of 46.76 mm. Zero degree grain angled solid timber has 38 – 96% increase in load capacity compared to other specimens. Hence selecting zero as the outer layers and varying the middle layer a scheme is prepared to test the six laminates of glued laminated timber, so that we get a best combination.

XII. GLUED LAMINATED TIMBER WITH THREE LAYERS

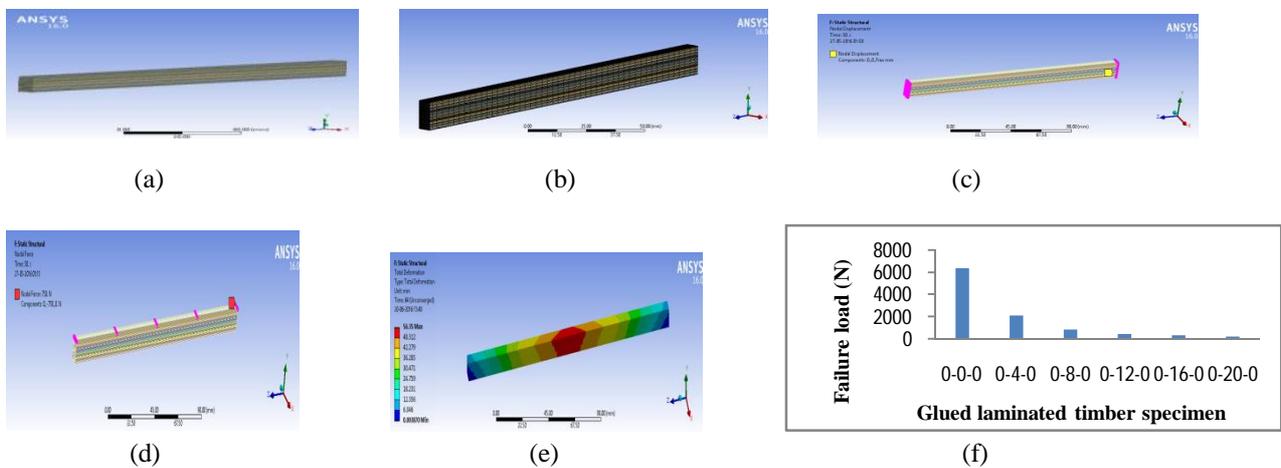


Fig. 9 Glued laminated timbers (a) Model of 0-0-0 glued laminated timber (b) Meshing of 0-0-0 glued laminated timber (c) Support conditions of 0-0-0 glued laminated timber (d) Loading conditions of 0-0-0 glued laminated timber (e) Deflection diagram of 0-0-0 glued laminated timber (f) Bar chart showing the load capacity of glued laminated timber

Table 6: Result of glued laminated timber specimens

Specimen	Maximum deflection (mm)	Failure load(N)	Strain energy (J)
0-0-0	56.335	6400	187.228
0-4-0	38.723	2100	40.321
0-8-0	25.69	800	9.930
0-12-0	20.994	400	4.001
0-16-0	4.1927	300	0.628
0-20-0	6.091	200	6.609

Six combinations of glued laminated timber were analyzed. Results of load carrying capacity for different combinations were shown in table 6. Fig. 7.9 (f) shows that variation of load capacity for different laminated timber specimens. Failure load of 0-0-0 specimen is 6400 N i.e. 31-67 % increases in load capacity compared to other combinations. It shows that glued laminated timber 0-0-0 is the best combination in terms of ultimate load and deflection.

XIII. LOAD DEFLECTION BEHAVIOUR

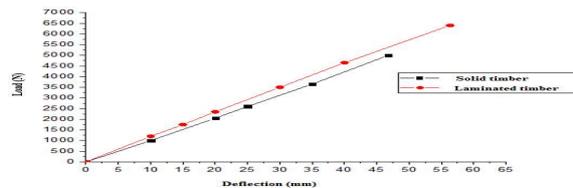


Fig. 10 Load Vs Deflection Graph of Solid Timber and Glued Laminated Timber

The analytical model was used to calculate ultimate loading capacity, stiffness and strain energy from the load – deflection behaviour of Solid timbers of different grain angles. The load – deflection behaviour shows that solid timber with zero degree grain angle is having better loading capacity of 5000N comparing all other cross-sections. The maximum deflection observed was for zero grain angles i.e. 46.76 mm. Load carrying capacity of 0-0-0 combination is found to be desirable compared to all other specimens. Since it has a load carrying capacity of 6400 N and deflection of 56.35 mm. Also glued laminated timber has proved to be more efficient than solid timber since it has an increase in load carrying capacity of 21.87 % compared solid timber having zero degree grain angles which is proved to be best grain angle in solid timber as shown in Fig.10.

XIV. STRAIN ENERGY

Strain Energy of the member is defined as the internal work done in deforming the body by the action of externally applied forces. This energy in elastic bodies is known as elastic strain energy. The analytical model was further used to compare the strain energies of different cross-sections of solid timber and glued laminated timber. It was observed that in case of solid timbers, zero degree angles absorbed maximum strain energy compared to all other specimens’ i.e. 113.987 kJ. In case of glued laminated timber 0-0-0 proved to be efficient since it absorb maximum strain energy i.e. 187.228 kJ. So there is an increase of 39 % compared to solid timber. Hence it leads to a conclusion that glued laminated timber is found to be desirable.

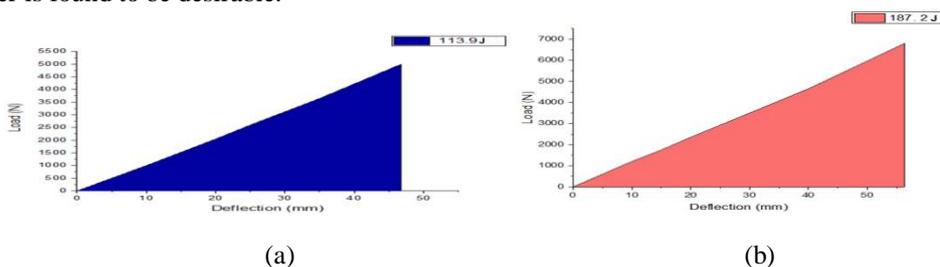


Fig. 11 (a) Strain Energy of Solid timber (b) Strain energy of glued laminated timber

XV. CONCLUSIONS

Solid timber beams of various grain angles such as 0, 4, 8, 12, 16 and 20 were analyzed using ANSYS to determine the ultimate load capacity. Axial loading is applied here. It has been observed that zero degree orientation give the maximum capacity. Selecting zero as the outer layers and varying the middle layer a scheme is prepared to test the six laminates of glued laminated timber.

1. Load deflection curves were generated for six combinations and plotted. The maximum stiffness for the glued laminate is observed to be 113 N/mm for 0-0-0 combination amounting to an increase of 5.3 % compared to solid timber. Hence 0-0-0 laminated is selected as desirable.

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

2. The load carrying capacity is also on the higher side for glued laminated timber of 0-0-0 combination with an increase of 21.87 % compared to solid timber of zero degree grain angles.
3. The glued laminated specimen has higher strain energy absorption of 39 % more than solid timber.

From these we can conclude that glued laminated timbers are proved to desirable than solid timber. The main reason for this is smaller thickness of timber laminates can be dried easier than the solid timber of large dimensions. So the chance of deterioration is less. Glulam provides the strength and versatility of large wood members without relying on the old growth dependent solid sawn timbers. It reduces the overall amount of wood used when compared to solid sawn timbers by eliminating the negative impact of knots and other small defects in each component. Glulam is two third the weight of steel and one sixth the weight of concrete. The high strength of laminated timbers enables glulam beams or arches to span large distances without intermediate columns, allowing maximum design flexibility than traditional timber construction. The size is limited only by transportation and handling constraints.

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