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FATIGUE STRENGTH PROPERTIES OF LAMINATED VENEER LUMBER AND STRUCTURAL PLYWOOD

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Abstract: **Fatigue resistance of Laminated Veneer Lumber, Structural Plywood were investigated in this study for determining allowable design stresses for both materials as a percentage of Ultimate strength (Modulus of Rupture). Test were carried out at Selected stress levels to corresponded specific percentages of materials ultimate strength. Constant amplitude cyclic test of 1 Hz (60 cycles/minute) frequency were performed with six applied stress levels 80, 70, 60, 50, 40, 30 expressed as percentages of the materials ultimate strength.**

Results indicated that Laminated Veneer Lumber, Structural Plywood, were able to survive fatigue life of over 6 lakh cycles at stress level equal to 30 and 27% of average Modulus of Rupture (MOR) respectively. It was also observed that increase in the Rate of loading decreased the percentage of allowable design stresses for all the material and vice versa. The study shows that the allowable design stress for the design applications must be based on percentage of static MOR and the frequency of cyclic loading in order to satisfy safety and service requirements.

Keywords: **Allowable design stress, Laminated Veneer Lumber, Structural Plywood, fatigue, Modulus of Rupture (MOR).**

1. INTRODUCTION

In various applications, materials are subjected to repeated stresses. The behavior of materials under such load conditions differs from the behavior under a static load. When the material is subjected to repeated load cycles (fatigue) in actual use, designers are facing problems with predicting fatigue life, which is defined as the total number of cycles to failure under specified loading conditions. Fatigue testing gives more relevant data to predict the in-service life of materials and no sufficient data has been generated for Laminated veneer lumber & structural plywood which is used for furniture, housing and other structural applications viz; I Beams, ply-webbed box beams, floor joists and bearers, wall girts, lintel beams and roof framing beams, strutting beams, hanging beams, valley or hip rafters and ridge beams, header beams, rim board etc. The information related to fatigue strength properties of the wood composite becomes more essential. The strength properties available for the wood composites have primarily been determined by static tests only, as the strength properties determined by static loading do not provide any information of the material to predict its life in its actual use.

Fatigue failure of a material results from the sustained or cyclic application of stress less than is required to cause in elastic behavior or fracture under monotonic loading conditions. Damage initiates as micro cracks that subsequently aggregate, leading eventually to macro cracking and failure. The definition of fatigue given above is similar to that employed by the American society for testing and materials (ASTM, 1993), but incorporates a time argument because of woods rheological nature. Any material exhibiting flow behavior must exhibit fatigue that depends on the number of stress cycles and the rate of stressing and/or time under stress. Unfortunately, this has not been widely recognized in the past.

2. LITERATURE

Fatigue of materials is a common problem of members or structures which are subjected to cyclically impose loading Sandor, (1972). Studies dealing with fatigue behavior and allowable design stresses for wood based composites and BMB are very limited. Even when wood was used in the aircraft industry, fatigue was considered insignificant or at least covered by safety factors accounting for creep. As a result, very little work has been carried out on the fatigue response of wood based panels Tsai and Ansell, (1990).

Selected wood materials were evaluated by subjecting them to edgewise static load, constant amplitude cyclic load and cyclic stepped load in an effort to investigate the fatigue properties and their relationship with static properties Li Dai, (2007). Cyclic load fatigue tests on OSB joints with metal plates of four configurations were performed and compared with static moment resistance to determine the influence of the metal plate configuration, material and fastening system on the static to fatigue moment capacity ratio and on failure modes of joints Xiaodong Wang, (2007). He advised to design metal plated joints so that they will not be loaded to more than 40 percent of their static moment capacity. RJH Thompson, (2002) conducted fatigue performance on three materials and found that at high stress level MDF was superior to that of the OSB, which was superior to that of Chipboard and at low stresses the performances of the three materials are quite similar. Kommers, (1943) found that the fatigue performance of wood and laminated wood were not significantly different. However, the fatigue performance of particleboard has been shown to be inferior to that of laminated woods, this reinforces the need to research the fatigue performance of wood based panels.

Cyclic fatigue performance of panels with wood particles has been investigated in various studies. Z Bao & Eckelman, (1995) carried out flexural fatigue tests on Medium Density Fibre board, Oriented Strand board and Particle board loaded in flexure at a loading frequency of 0.30Hz. Peak σ ranged from 0.3-0.7 and tests continued until one million cycles or premature failure. Fatigue life reached an extremely large number ($>10^6$) when the stress level was 0.3 or less, leading to the deduction that the fatigue limit is about 30% of static strength. Specimens were loaded in planar-shear and inter laminar shear. Peak σ ranged from 0.38-0.90 for tempered hardboard, and from 0.45-0.90 for particle board. The loading frequency was 15 Hz with an R-ratio of 0.1. It has been shown that Stress and number of cycle's curves for tempered hardboard and various types of construction grade particle board made with synthetic adhesive are similar to those for solid wood loaded in tension parallel to grain or glued wood shear specimens McNatt, (1970) Mcnatt and Werren, (1976)

It was observed that Tanaka and Suzuki (1984) the fatigue life increased as the resin content was increased in four different flake boards (two random, one oriented and one shavings board). Also there was an increase in the fatigue strength with increasing strength of the adhesive bond. Clad and Schmidt, (1981) found that particle board with an increased resin content displayed superior behavior in fatigue. Sekino and Okuma, (1985) did not observe any differences in the fatigue performance of four commercial particle board loaded at frequencies of 1 to 2 Hz at various stress levels between 60 and 90% of the static bending strengths.

Bonfield et al. (1994) carried out flexural cyclic fatigue tests on structural grade particle board with relatively high adhesive content. Peak σ varied between 0.5 and 0.8, the loading frequency was about 5 Hz, the R ratio was 0.01, and matched static fatigue tests were conducted with static load levels equal to various peak stress levels in cyclic fatigue tests. Static fatigue specimens never fail before cyclic fatigue specimens loaded at the same σ.

From the literature it can be anticipate that the Strength properties determined by static loading alone will not provide any information of the material to predict its life in its actual use. Allowable stresses should be determined based on the percentage of the materials ultimate load (MOR).

3. MATERIALS AND METHOD

Wood composite panel Laminated Veneer Lumber (LVL) & Structural plywood of Boiling Water Proof (BWP) grade were taken for the study. All the boards were of exterior grade and bonded with Phenol formaldehyde resin. LVL of 1220 mm in length, 1220 mm in width and 40 mm in thickness two samples from same set were taken for the study. Nominal dimensions of structural plywood were 2440 mm in length, 1220 mm feet in width and 12 mm in thickness all edges were trimmed to 20 mm to avoid undulant and edge cracks during transportation. Four samples from each board were cut to dimensions of 150 x 75 mm from all corners of the board to determine Density and Moisture Content as per Indian Standard 1734 (Pt-1)-1983

Twenty-one specimens were prepared in along the grain direction from structural plywood of dimensions (50+48t) length x 50 mm width in along the grain direction, where ‘t’ is thickness of the board as per Indian Standard IS 10701-2012 clause 11.7.1 cross referred to 1734(Pt-11)-1983. Twenty-one specimens from LVL of dimensions (50+20t) length x 50 mm width, where ‘t’ is thickness of the board, as per Indian Standard IS 14616-1999 amendment number 1 June 2005 clause 8.2.3 cross referred to 1659(Annex J)-2004 were prepared. One set of 3 each for static speed test and one set of 3 each for 80, 70, 60, 50, 40, and 30% of materials ultimate stress(MOR) were grouped for fatigue testing.

Static speed bending test

Static speed bending test was conducted in accordance with IS 1734(Pt-11)-1983 and IS 1659(Annex J)-2004 for Structural in along the grain direction and LVL respectively. Universal Testing Machine (UTM) with load sensor of 2, 5, 10 KN capacities were used to perform the static bending tests. UTM is available in Indian Plywood Industries Research and Training Institute (IPIRTI) laboratory.

Modulus of Rupture (MOR) and Modulus of elasticity (MOE) Tests were carried out in simply supported single point loading condition, cross head movement was controlled by the machine and the speed was set to the thickness of the material being tested as per the above mentioned standards. Speed and span for all the boards used is as shown in Table 1. The loading block was rounded to ensure that no appreciable amount of crushing occurred. Load deflection curve was obtained and the values of MOE and MOR were calculated by the formula

$MOE = P'l^3/4bt^3y'$ and $MOR = 3Pl/2bt^2$

Where

P=Maximum load, N

l=Span Length, mm

b=Width of specimen, mm

t=Thickness of specimen, mm

y’=Deflection at proportional limit, mm

P’=Load at proportional limit, N

Table No. 1: Static bending test sample size with Speed and Span

Sl No	Material	Sample size L x W (mm)	Span, mm	Method	Speed, mm/min
1	LVL	(50+20t) x 50 mm	550	14616-1999 & 1659(Annex J)-2004	7
2	Stru Ply (Al)	(50+48t) x 50 mm	550	10701-2012 & IS 1734 (Pt 11) 1983	7

Fatigue bending test

Fatigue bending testing was carried out in Servo-Hydraulic actuator with calibrated load sensors of 2, 5, 10 KN. Above machine also available in Indian Plywood Industries Research and Training Institute (IPIRTI) laboratory. Six stress levels 80, 70, 60, 50, 40 and 30% of the average ultimate bending strength (MOR) of static speed test were selected to apply load. Corresponding span used in static speed bending strength was used for all the samples. One set of three specimens of same sample size used for static bending test were tested at each stress levels at 1 Hz frequency (60 cycles per minute), and all tests were run until the specimen fails or 6 lakh cycles were completed.

4. RESULTS AND DISCUSSION

Densities of both boards used for the study was in between 0.75 to 0.8 gm/cm^3. Moisture content prior to mechanical testing was maintained between 9 to 10% when tested as per Indian Standard 1734 (Pt-1)-1983

Static speed bending results of the boards were compared with respect to their standards. Both boards conformed to minimum specified values of their respective Indian standards with standard deviation (sd) is as shown in Table 2. Highest average MOR and MOE value of 104.1 N/mm^2 and 11048 N/mm^2 respectively were observed for LVL, Structural plywood tested in along direction had an average MOR value of 88.3 and MOE value of 10874 N/mm^2 respectively.

If a component or a structure undergoes repeated loading, however allowable design stresses based on the static ultimate strength may not be suitable since they do not take into account the materials fatigue behavior, as they do not ensure that the component will survive under cyclic loading. Thus it is important to develop a rational way of determining materials when they are used under cyclic loading conditions such as in front rails of a sofa or a bed frame.

Allowable design stresses and the fatigue life of a given material thus complement one another. Choosing a higher design stress will certainly cause a loss in fatigue life, it appears more reasonable to use fatigue strength rather than static strength to determine working stresses. Thus repeated loading cannot be disregarded; allowable design stress could logically be taken as that percentage of ultimate strength that will ensure that the expected fatigue life of a part will exceed the expected number of service life load cycles.

Fig 1 & 2 indicates that specimen life decreased as level of stress is increased. From the graph it is noticed that both LVL & Structural plywood withstood for over 6 lakh cycles at a stress level below 30, 27, 36 and 24% of their average MOR values respectively. From Fig 1 & 2 sudden failure of materials noticed for an average MOR of 80 and 70% the number of cycles to attain failure was within 1000, whereas for 60% of average MOR number of cycles to failure was within 4000. LVL had a fatigue life of 282687 cycles at a stress level of 30% of average MOR; Structural plywood had a fatigue life of 375330 cycles at a stress level of 27% of average MOR. In general, LVL & Structural plywood either had or would be excepted to have fatigue lives of at least 2 lakh cycles at stress levels of 30% of static MOR. Reducing further MOR reveals sample will not break up to 6 lakh cycles and the test was ended after completion of 6 lakh cycles and no residual deformation was noticed for both the samples. It appeared that basic design stresses for these materials might be set at 30% of MOR for 1 Hz frequency. If the loading frequency reduced by 0.5 Hz the allowable design stresses might be increased by another 10 to 15 % of the MOR value. The values obtained however must then be further reduced to take into account appropriate factors before a satisfactory design value can be determined. All other necessary adjustments such as Factor of Safety (FOS), Duration of Load Factor (DOL) etc.; should be included as they are required in conventional design procedures. This procedure would allow all major cyclic load applications to sustain repeated loads for their excepted service life without failure.

Table No. 2: Density, Moisture Content, Static speed bending MOR and MOE of both boards:

Material	**Result**		**Prescribed Values as per Indian Standard, N/mm^2**		**Result, N/mm^2**	
	Density, gm/cm^3	**Moisture Content,%**	**MOR**	**MOE**	**MOR**	**MOE**
Laminated Veneer Lumber	(avg)0.768	(avg)9.7	as per IS 14616-1999		(avg)104	(avg)11048
	(sd)0.002	(sd)0.1	50	7500	(sd)20.2	(sd)2871
Structural Plywood	(avg)0.799	(avg)9	as per IS 10701-2012		(avg)88.3	(avg)10874
	(sd)0.014	(sd)0.1	50	7500	(sd)11.2	(sd)904

*(avg) average values, (sd) standard deviation

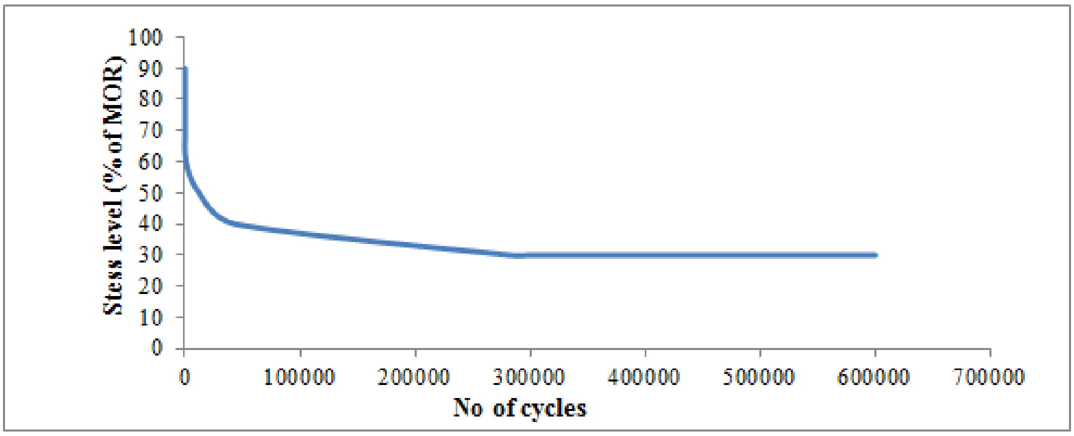

Fig. 1: S-N curve of LVL

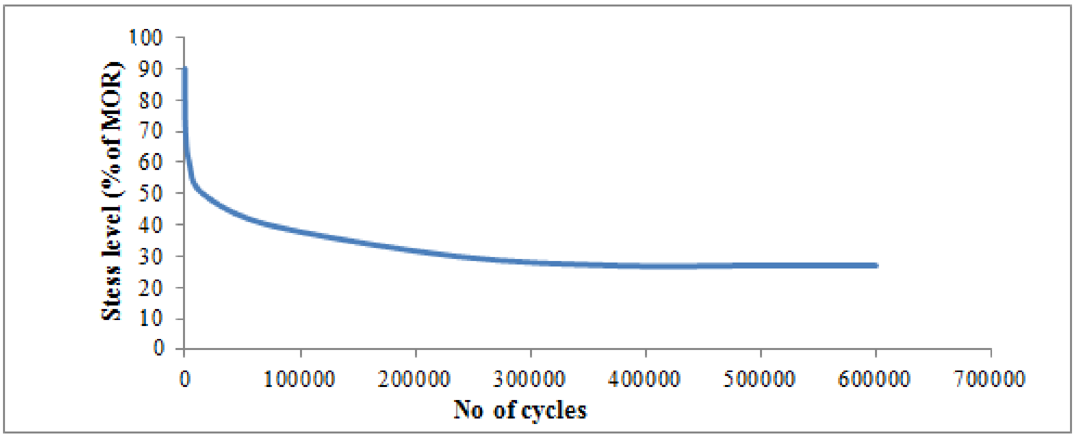

Fig. 2: S-N curve of Structural Plywood

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