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NON DESTRUCTIVE EVALUATION OF MODULUS OF ELASTICITY OF LARGE SIZE WOOD BASED PANEL MATERIALS USING 'E' TESTER

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Abstract

As a first step in the direction of developing a non destructive test method for finding the modulus of elasticity/stiffness of large size wood based panels, a laboratory model of the mechanical 'E' tester was designed and fabricated. This equipment facilitates the panel industries for effective grading and quality control.

Investigations carried out to study the effect of width of the panel and effect of span length on modulus of elasticity[MOE] reveals that they are not significant for plywood panels ranging in thickness from 6mm to 18mm. Tests carried out to determine the scale factor [ratio of MOE of large size panel to MOE of small size specimen] for plywoods and blockboards reveals that MOE of large size plywood and blockbaord is more than that of small size specimens by 10 to 12%. A close correlation exists between MOE of large size plywood and blockboard panels and MOE/MOR of small size specimens.

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1. Introduction

The two important properties of any composite panel material are bond quality and stiffness/modulus of elasticity[MOE]. Currently, these properties are determined by destructive tests on small clear specimens. To ensure that the panels produced meet minimum requirements, Standards have been formulated. These Standards specify minimum requirement for bond strength, MOE, modulus of rupture[MOR] and other properties.

Manufacturers producing these panels generally have quality control programme to ensure minimum specification requirements. Typically these programmes involve testing as few as two panels per shift. Small specimens cut from the panels are tested using laboratory equipment and the results compared to Standards. While the results from these tests provide a valuable information, infrequent sampling and small specimen size means process variability may not be detected. Many hours may elapse between tests and if some problem creeps in, considerable amount of below grade product will be produced before being detected. Secondly, the small number of panels tested represents only a very small fraction of daily production, significantly reduces the ability to statistically separate changes mean panel properties from normal process variables.

These limitations of current quality control practices mean immediate feed back on panel properties are not available for process control purposes. As a result considerable variation in panel properties may occur. The variation coefficient fixed for small specimen testing is 21% for bond quality and 15% for MOE. This may lead to some doubt on the effectiveness of small sample tests to accurately predict average panel properties. Variations in panel properties mean that manufacturers must produce panels that on an average greatly exceed minimum code requirements. For example, let us say that MOE of the panel produced is 20% more than minimum requirement. As MOE is directly related to density, it amounts to saying that more wood has been consumed per panel. As the cost of wood is more than 40% of the variable manufacturing cost in these days, even small increase in panel density increases total cost considerably.

Non-destructive testing of full size panels for their properties will definitely help the industry for better monitoring of manufacturing process and there by reduce manufacturing cost. Because the properties of every panel are almost immediately known, small changes in process or raw material variables are quickly identified. With this information, manufacturing process can be more precisely controlled so that variation in the finished panel is minimized. Large safety margins are not required because any panel not meeting the specification requirement can be automatically identified and rejected. Mean properties can be adjusted closer to minimum specification requirements and there by panel cost can be reduced. This also provide a valuable marketing tool. Panels having higher than average strength can be sorted out and sold at premium prices for specific requirements. Manufacturers can also promote their products as being 100% tested and there by guarantee performance levels.

Hither to instruments like moisture meters, thickness gauges, weigh scales were in use as nondestructive testing devices. In recent times some exploratory work has been done to evaluate the bond quality of panels nondestructively. But, a few companies have already developed 'E' testers for measuring panel bending properties like MOE and stiffness. A brief review of the same is given below.

2. Literature survey

Perusal of literature reveals that very little work has been done in India in the recent past on NDT of wood based panels in general and no work has been done on the proposed work. Some of the recent works done in India are briefly discussed below.

2.1 Some of the recent literature available on NDT of wood and wood based panels in India.

With a view to highlight the status of NDT of wood and wood based panels in India in recent times, publications on works carried out in India have been listed separately.

K.Shyamasundar et.al. (1993) have determined the dynamic MOE and modulus of rigidity of plywood by free transverse vibration and torsion vibration techniques respectively and established relationship with static properties. K.Shyamasundar et.al. (1996) have explored the possibilities of using non-destructive longitudinal free vibration technique to find dynamic MOE of timber scantlings of different sizes for grading of sawn timber. K.Shyamasundar et.al. (1997) have determined the dynamic MOE and modulus of rigidity of wood based panel by vibration techniques. Correlations established between dynamic and static properties are also discussed. Y.M.Dubey and Sachin Gupta (1998) have used transverse vibration technique to estimate MOE & MOR some Indian Timbers. Relationships established between dynamic MOE and static MOE & MOR are also discussed. T.L.Shaji and M.S.Mathews (1999) have used ultrasonic pulse technique to assess structural integrity of timber elements in historic buildings. K.Shyamasundar et.al.(1999) have measured ultrasonic velocity through thickness of particleboards, prelamiated particleboards and medium density fiberboard and tried to establish correlation with internal bond strength [IB] of the same. K.Shyamasundar et.al. (1999) in his review paper has stressed the importance and need for developing NDT methods for Forestry and Forest Products in India.

However, sufficient number of literature from other countries on NDT related to the proposed work is available and some of them are briefly reviewed below.

2.2 Literature from other countries related to non-destructive evaluation of MOE of large size wood based panels:

Different concepts such as *vibration* and static loading have been employed in developing 'E' testers. Lars Bach (1982) reports the development of a prototype industrial Machine Stress Rating panel grader. Bending stiffness is obtained non-destructively and correlated with stiffness and maximum moment measured by destructive method. S.Bozhang and Cai zhiyong (1993) have described the forced vibration technique to evaluate the mechanical properties of full size particleboard non-destructively. Using the regression models developed, MOE, MOR and IB have been predicted to a good accuracy. R.J.Ross and J.J.Vogt (1985) have used longitudinal stress wave technique for non-destructive evaluation of wood based particle and fiber composite panels of width 150mm. It is concluded that stress wave speed and attenuation characteristics are useful predictors of static tensile and flexural properties. Useful correlation also has been obtained between wave speed, which is measured through thickness of the material and IB. J.Benicek (1993) explored the feasibility of hammer pulse method for non-destructive control of particleboard. Transverse pulse velocity measurement has shown greater dependence on strength properties than longitudinal pulse velocity. D.Greubei and S.Wissing (1995) have reported the non-destructive measurement of MOE and modulus of shear of single and three layer laboratory and industrial particleboards using bending vibrations. In their experiments frequency measurements have been made on boards clamped on one side. D.Adkins and K.J.Lyngcoln (1985) describes the development of a stress grading machine which measures the MOE of each panel at a proof load in bending under simple 3 point static bending. The machine is used to optimize the performance/cost ratio of structural plywood. Peter Lister, et.al.(1999) reports on PanelMSR – an On-Line Stiffness Tester for Engineered wood Panels. Here a technique known as post flexure method is used. The method involves applying a steadily increasing moment to both ends of a sample and measuring the resulting panel curvature. Stiffness, MOE and MOR are calculated from the resulting load-deflection information and maximum moment upon rupture.

Among the different methods used viz., natural frequency measurement, wave speed measurement and load-deflection methods, to measure panel bending properties such as stiffness and MOE, the load-deflection technique[static bending test] is best suited for industrial use. It is both simple and reliable and provide the most direct measurement of stiffness. The method is illustrated in Fig.1, and involves testing of samples loaded at the center and simply supported at the ends. The tester loads the samples at a specified rate and measures the corresponding deflection. Stiffness and MOE can be determined from the slope of the load-deflection curve using the well known equations given in figure 1. This method can also be applied to full size panels.

3. Scope and objective

The objective of the present investigation is to design and develop a laboratory model of 'E' tester and study its suitability for testing large size plywood and blockboard panels of different thickness.

4.Design and fabrica- tion of a laboratory model of 'E' tester for large size panels

The photo of the 'E' tester fitted with load and displacement indicators is depicted in figure 2. Major components of the equipment are load cell, displacement transducer, loading frame and adjustable load support arrangement. The overall dimensions of the equipment are 2400mm long, 1960mm wide and 1960mm overall height. It accommodates large panels of size 2.4M x 1.2M and thickness ranging from 6mm to 25mm. Span can be varied from 0.2meter to 2.4meters in steps of 0.1meter. Load support rollers are 870mm above the machine base.. The resolution of LVDT[linear voltage differential transformer] of stroke length 20mm is 0.01mm and that of load cell of capacity 500kg is 0.1kg. The load cell indicator has facility to tear off preload, if required, for direct measurement of load vs. deflection. The load applied gets uniformly distributed across the full width of the panel.

5.Materials and Methods

Full size Plywood varying in thickness from 6mm to 18mm and blockboards of thickness 19mm were used in the investigation. Details of the same are given in respective tables.

The panel whose MOE was to be determined was kept on the rollers adjusted for span length in such a way that the central line of the panel coincides with the central line of the loading member. An initial pre load depending on the thickness of the panel was applied such that the loading roller touches the entire width of the panel and also the load applied falls within the linear portion of the load deflection curve for the panel. LVDT was adjusted to zero. Load was gradually increased and loads corresponding to deflections of 3,6,9,12,15 &18mm were noted. Then the load was gradually decreased until the load was completely removed from the panel. The procedure was repeated about 5 to 10 times to collect load-deflection data. From the data, average load for deflections of 3,6,9,12,15 &18mm were calculated. A graph of average loads vs. deflections was drawn. From the linear portion of the graph slope was calculated to get the value of load per centimeter of deflection, (P/Δ), to be used in the formula for calculating MOE. Modulus of Elasticity [MOE]was calculated using the formula

$$MOE = \frac{(L^3)}{(4bd^3)} (P/\Delta) \ kg/cm^2$$

where L is span length in cm, b= width in cm, d=thickness in cm,

Suitability of the machine for measuring the modulus of elasticity of large size panels was ascertained by measuring the linearity of the load deflection plot and repeatability of results.

6.Results and discussion

i. *Effect of width of the panel on the MOE of large size plywood panels*

The results of the tests carried out to study the effect of width on MOE of large size plywood panels are given in table 1. From table 1 it is very clear that the increase in MOE for increase in width from 0.3mtr to 1.2mtrs is marginal. The values of variation coefficient ranges from 6% to 13%. In this connection it may be noted that the variation coefficient permitted for modulus of elasticity is 15% and the results obtained falls very much within the permitted value. Therefore, it may be concluded that the effect of width on MOE of large size plywood panels ranging in thickness from 6mm to 18mm is not significant. This is in agreement with the statement made by D.Adkins and K.J.Lyngcoln(1985) in their paper on Stress Grading to Australian Standards that the effect of shear deflection on MOE can be avoided by setting the span/thickness ratio well in excess of 20 to 1.

ii. *Effect of span length on the MOE of large size panels*

The results of the tests carried out to study the effect of span on MOE of large size plywood panels are given in table 2. When tests were carried out with 6mm plywood panels, results were more consistent for span of 0.5mtr. In other words slope of the load deflection curves were almost same when the tests were repeated at span of 0.5mtr. But, when the tests were repeated at span lengths of 1.0mtr and 1.5mtrs, the results were not consistent. This inconsistency might be due to the increase in flexibility of the panel at higher spans contributing to error in deflection measurements.

Where as, when the tests were carried out on plywood panels of thickness 9, 12 and 18mm, it is evident from table 2 that change in MOE w.r.t. span length was not significant.

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iii. *Relationship between MOE of large size plywood panels and MOE & MOR of small size specimens*

After obtaining the MOE of large size panel by 'E' tester, 10nos. of small test specimens from each of the plywood panels were subjected to 3 point bending test in universal testing machine as per IS:1734(Pt.11)-1983, to determine MOE and MOR. Graphical representations of the relationship between MOE of large size plywood panels and MOE/MOR of small size specimens are given in figures 3 and 4 respectively. The correlation coefficients obtained in both the cases shows that there is a close relationship between MOE of large size plywood panels and MOE/MOR of small size specimens.

iv. *Relationship between MOE of large size blockboard panels and MOE & MOR of small size specimens*

Figures 5 and 6 shows the graphical representation of the relationship between MOE of large size blockboard panels (grade I & II combined) and MOE/MOR of small size specimens. In this case also the correlation coefficients obtained shows that there is a close relationship between MOE of large size blockboards and MOE/MOR of small size specimens.

From the above results it may be inferred that the increase in MOE of large size plywood and blockboard panels w.r.t. MOE of small size specimens is around 10 to 12%.

7. Conclusions

1. The laboratory model of the mechanical 'E' tester designed and developed at IPIRTI is suitable for determining the MOE of large size plywood and blockboard panels and facilitates plywood and blockboard industries for effective grading and quality control.
2. The effect of width of the panel on MOE of large size plywood panels is insignificant.
3. The effect of span length on MOE of large size plywood panels is not significant for thickness greater than 6mm. For 6mm plywood span length of 0.5mtr is ideal.
4. Increase in MOE of large size plywood and blockboard panels w.r.t. MOE of small size specimens is around 10 to 12%.
5. A close correlation exists between MOE of large size plywood and blockboard panels and MOE/MOR of small size specimens.

8. Recommendation

Based on the laboratory model it is recommended to develop a mechanized model of 'E' tester for ultimately using in the industries manufacturing wood based panel products and also collect data on large number of samples for better statistical representation of results and to instill confidence in users.

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Table 1
Effect of width on MOE of large size plywood panels

Sl. No.	Material	Grade	Density (kg/m^3)	Span (mtr)	Modulus of elasticity (N/mm^2)				Statistical data		
					Width (mtr)				Average N/mm^2	Standard deviation N/mm^2	Coefficient of Variation,%
					0.3	0.6	0.9	1.2			
01.	5Ply,6mm	BWP	770	0.5	11396	12623	12734	13889	12661	882	6.9
02.	5Ply,6mm	BWR	690	0.5	6252	7104	7383	7529	7067	495	7.0
03.	9Ply,12mm	BWR	640	1.5	5058	5276	5340	5829	5376	282	5.2
04.	11Ply,18mm	BWR	690	1.5	5773	6065	7485	7828	6788	883	13.0
05.	11Ply,18mm	BWP	740	1.5	8450	8164	9439	9570	8906	609	6.8

Table 2

Effect of span on MOE of large size plywood panels

Width of panels = 1.2 Mtrs.

Sl. No.	Material	Grade	Density (kg/m^3)	Modulus of elasticity (N/mm^2) Span (Mtr.)			Statistical data		
				0.5 Mtrs.	1.0 Mtrs.	1.5Mtrs.	Average N/mm^2	Standard Deviation, N/mm^2	Coefficient of Variation,%
01.	5Ply,6mm	BWP	770	13889	8831	8463	10394	2475.6	23.8
02.	5Ply,6mm	BWP	643	7744	4576	4234	5518	1580.2	28.6
03.	7Ply,12mm	BWR	623	6971	6593	6259	6608	290.85	4.4
04.	9Ply,12mm	BWR	603	6742	5679	5580	6000	644.21	10.7
05.	9Ply,12mm	BWP	769	9753	8260	8190	8734	882.89	10.1
06.	9Ply,12mm	BWP	784	11321	10164	10026	10504	711.2	6.8
07.	9Ply,12mm	BWR	715	8523	6912	6869	7435	7434.6	10.3
08.	11Ply,18mm	BWP	772	9526	8225	8341	8697	587.8	6.7

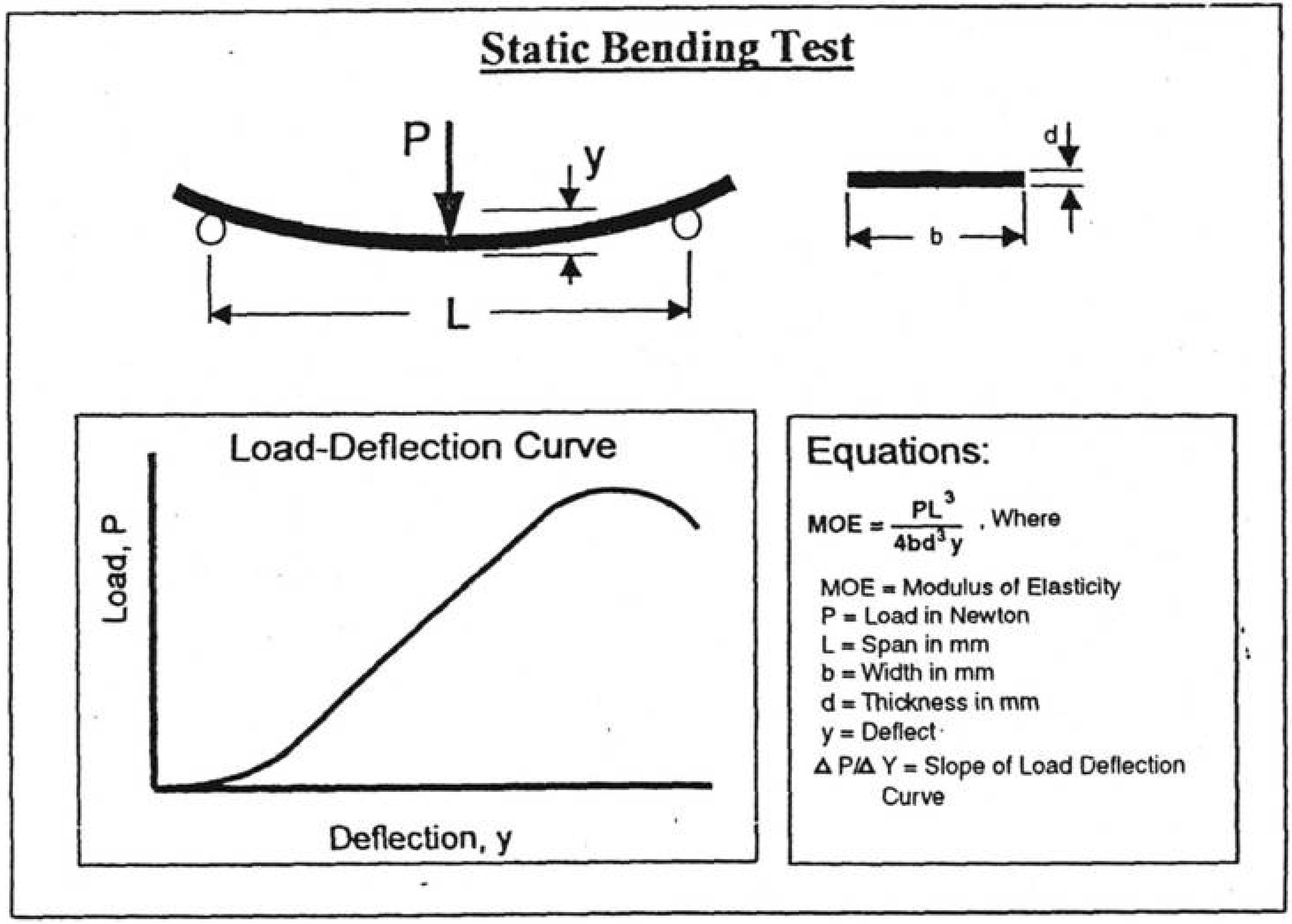

Static Bending Test
P
y
L
d
b
Load-Deflection Curve
Load, P
Deflection, y
Equations:
MOE = PL^3 / 4bd^3 y , Where
MOE = Modulus of Elasticity
P = Load in Newton
L = Span in mm
b = Width in mm
d = Thickness in mm
y = Deflect
Δ P/Δ Y = Slope of Load Deflection Curve

Fig 1

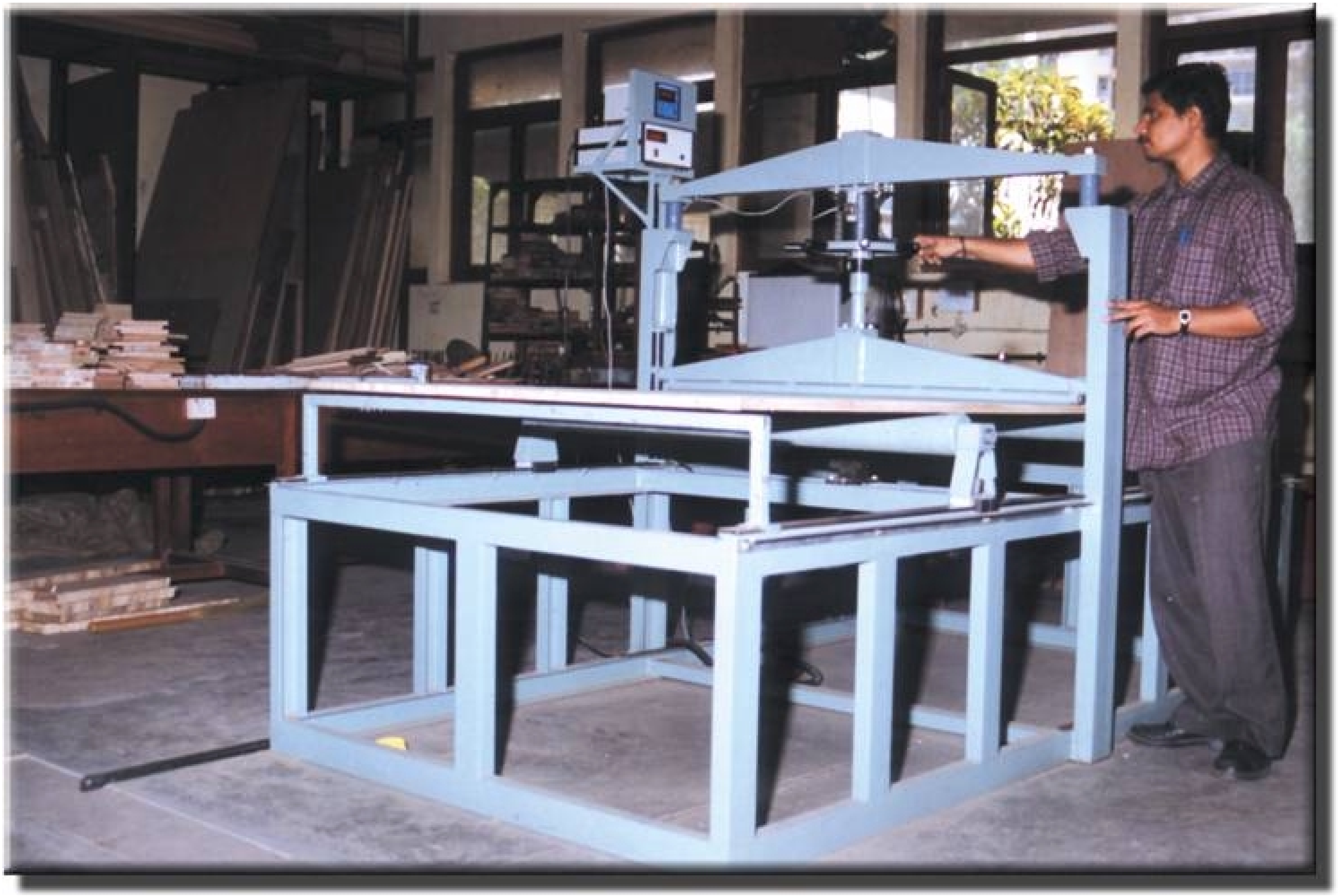
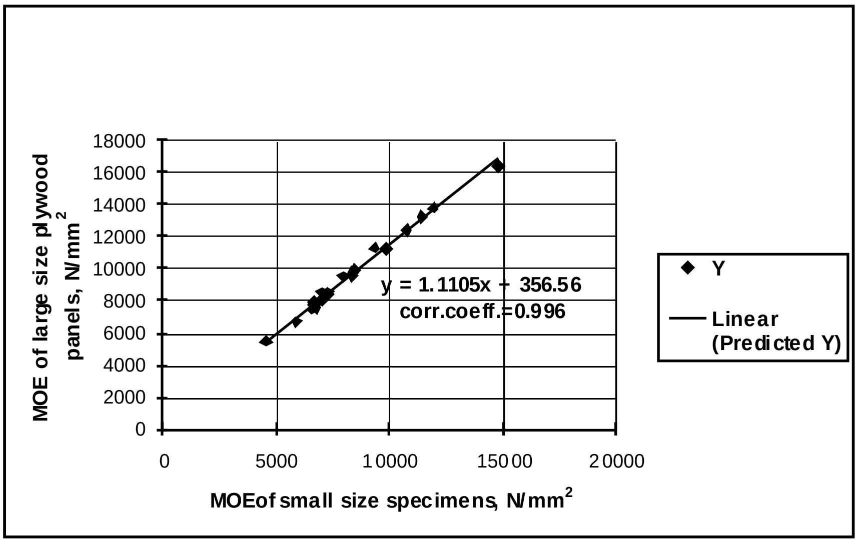


Fig.2


MOE of large size plywood panels, N/mm2
MOEof small size specimens, N/mm2
y = 1.1105x + 356.56
corr.coeff.=0.996
Y
Linear (Predicted Y)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
5000
10000
15000
20000

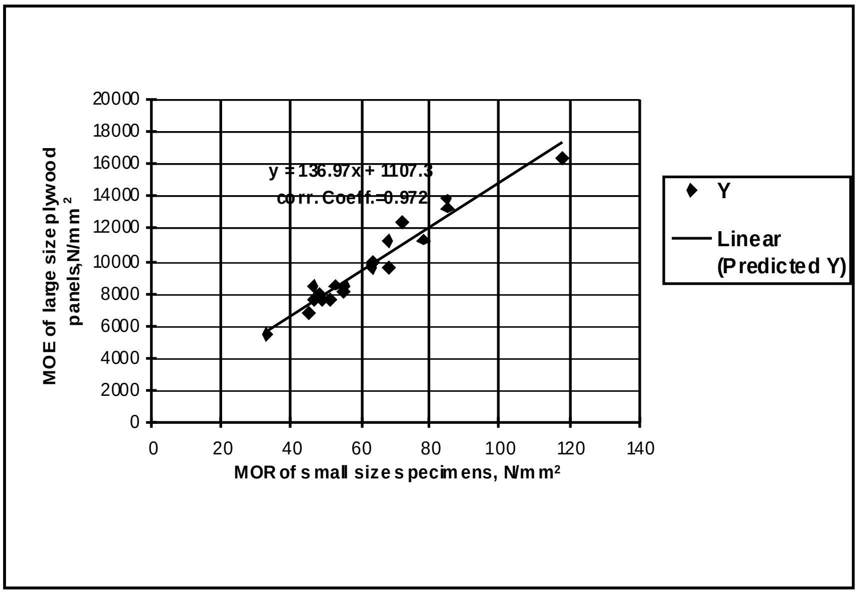

MOE of large size plywood panels,N/mm2
MOR of small size specimens, N/mm2
y = 136.97x + 1107.3
corr. Coeff.=0.972
Y
Linear (Predicted Y)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
20
40
60
80
100
120
140

Fig.5 Relationship between MOE of large size blockboards and MOE of small size specimens

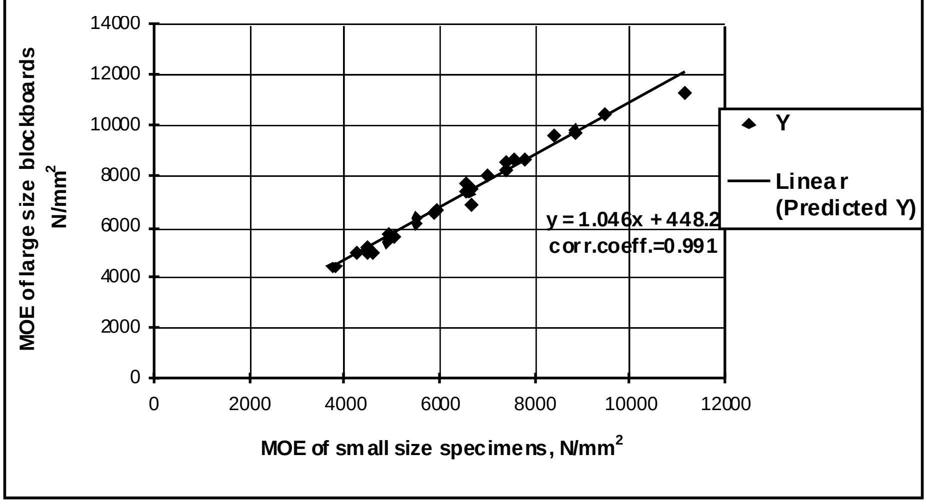


Fig.6 Relationship between MOE of large size blockboards Panels and MOR of small size specimens