WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.6.10741080
e-ISSN 2729-8906
67(6): 2022 1074-1080 pp.

SHORT NOTES

COMPARATIVE STUDY ON PHYSICAL-MECHANICAL PROPERTIES OF PLYWOOD PRODUCED FROM *EUCALYPTUS GRANDIS* AND *POPULUS DELTOIDS* VENEERS

MANISH RANJAN, ANAND NANDANWAR, PRADEEP KUMAR KUSHWAHA
INDIAN PLYWOOD INDUSTRIAL RESEARCH AND TRAINING INSTITUTE
INDIA

(RECEIVED MARCH 2022)

ABSTRACT

Nine-ply plywood panels were produced from *Eucalyptus grandis* and *Populus deltoids* using urea-formaldehyde (UF) and phenol-formaldehyde (PF) adhesives. The physical and mechanical properties, such as moisture content, density, modulus of rupture (MOR) and modulus of elasticity (MOE) of the eucalyptus and poplar boards, were compared in this study. Samples were tested on both, along and across the grain. Higher values of MOR and MOE were observed for eucalyptus as compare to poplar. Density of ply board was observed as 500-560 $kg \cdot m^{-3}$ in plywood from poplar and 700-720 $kg \cdot m^{-3}$ in plywood from eucalyptus species. These differences were attributed to the variation in properties of veneer wood species. The effect of veneer wood species on some physical and mechanical properties of plywood was found statistically different.

KEYWORDS: Plywood, modulus of elasticity (MOE), modulus of rupture (MOR), moisture content, density.

INTRODUCTION

Plywood is important wood-based composites produced from different tree species, and it has some superior advantages compared to solid wood (Youngquist 1999, Parthiban et al. 2011). Plywood is produced from softwood as well as hardwood species and those determine the physical and mechanical properties of the plywood (Izekor et al. 2010, Izekor and Fuwape 2010, Srivastava 2005). The important factors that affect the physical and mechanical properties of plywood are: the density of the wood, species of trees, type of adhesives, thickness of the veneer,

number of plies, and the temperature at which the veneer was dried (Gillespie and River 1976, Ors et al. 2002, Aydın and Çolakoglu 2008, Rahman et al. 2012). In some other studies, the fast growing tree species are used extensively for the manufacture of veneer and veneer based composite materials have been tested. For example, some other researchers have investigated the fast growing species of hybrid poplar (Baldassino et al. 1998) and *Eucalyptus grandis* (Dias and Lahr 2004, Iwakiri et al. 2006, Juniar et al. 2009, Dutt and Tyagi 2011), as well as *Fagus orientalis* for use in manufacturing plywood (Ozalp et al. 2009).

Modulus of rupture (MOR) and modulus of elasticity (MOE) are the most important mechanical properties of load-bearing plywood for construction and industrial applications. In some comparative studies, unexpected results were obtained due to veneer heterogeneity (Bao et al. 2001, Bal and Bektaş 2012, Nacar et al. 2005, Roos et al. 1990). To check the suitability of those plantation species in plywood manufacture there is a huge problem in front of us. In this study a comparative analysis has been conducted by comparing physical and mechanical properties of plywood produced from eucalyptus and poplar veneer. In this study, our aims were: *(1)* To determine and to compare some mechanical properties of 9 ply plywood, *(2)* to compare the plywood bonded with UF and PF adhesives, and *(3)* to compare physical and mechanical properties like density, moisture content, MOR and MOE within and between the species and adhesive of plywood.

MATERIAL AND METHODS

Veneers of eucalyptus and poplar were procured from Forest Depot, Forest Research Institute campus, Dehradun for manufacturing plywood. 9 ply plywood were prepared and the thickness of eucalyptus and poplar veneers was 1.5 mm. To prevent from reduction of adhesion quality and poor strength of the board, the eucalyptus and poplar veneers were dried up to 8% moisture content in the drier before gluing veneers. Phenol formaldehyde (PF) and urea formaldehyde (UF) resins was used as wood adhesive for plywood. PF and UF resin was prepared in composite wood laboratory according to IS 1508 (1972). Resin was applied on both sides of the core and cross bands i.e. two, four, six and eight sheets in 9 ply board and resin was applied using resin brushes with hands. The veneers were kept for air drying for two days and sheets were assembled orthogonally or in cross-graining direction. After this, assembled veneers were hot pressed in 100-120°C temperature for UF resin and 140-150°C temperature for PF resin and pressing time was kept 20 min at 415 psi pressure for 9 ply board. The samples are kept in room temperature for curing. Final step of the plywood manufacturing was finishing, which includes trimming and sanding followed by marking of the samples. All the boards were tested as per IS 303 (1989) and physical-mechanical properties compared within and between the species and adhesives.

Data recorded were analysed statistically at 5% significance level to find out the variation between the type of boards i.e. eucalyptus or poplar veneer board, PF or UF resin based boards and the relationship between the observed physical and mechanical parameters. Data were analysed using 'SPSS' package (16.0). Different parameters taken into account during the course of study were subjected to ANOVA. Duncan test was also performed to compare

different sets by 'SPSS' for each parameter. The p value shown by 'SPSS' as 0.000 has been reported as < 0.001 in the present study.

RESULTS AND DISCUSSION

Comparative analysis was done in order to know the physical and mechanical properties of 9 ply plywood manufactured from two different species (poplar and eucalyptus) as well as two different adhesives (UF and PF). EUF9 denotes eucalyptus urea formaldehyde based 9 ply board, PUF9 poplar urea formaldehyde based 9 ply board, EPF9 eucalyptus phenol formaldehyde based 9 ply board and PPF9 poplar phenol formaldehyde based 9 ply board. Tab. 1 shows the mean values of moisture content, density, MOR, and MOE for along and across 5 test samples of each different type of plywood.

Tab. 1: Mean physical-mechanical properties of 9 ply eucalyptus and poplar plywood.

Mean	**MC** (%)	**Density** ($g \cdot cm^{-3}$)	**MOE** ($N \cdot mm^{-2}$)		**MOR** ($N \cdot mm^{-2}$)	
			Along the grain	Across the grain	Along the grain	Across the grain
EUF9	5.06	0.72	7373	5825	63.78	58.37
PUF9	6.08	0.50	6099	5157	59.42	46.94
EPF9	4.00	0.70	7282	5377	62.97	55.50
PPF9	4.35	0.56	6116	5276	60.34	52.16

Dimensional stability of lignocellulosic material is closely related to moisture content. Mean moisture content was found lowest in EPF9 (4.00%) and highest in PUF9 (6.08%). This may be due to the variation in density of plywood i.e., higher density of plywood restricts moisture uptake because higher board density results in a lower number of pores in the plywood. According to IS 303 (1989), Franz et al. 1975 and Kabir et al. 1995 the moisture content of standard plywood is below 15%. Therefore, the plywood made from eucalyptus as well as poplar follows the standard.

Density is directly proportional to the density of wood species. Eucalyptus species have 0.588 $g \cdot cm^{-3}$ average wood density whereas poplar have 0.370 $g \cdot cm^{-3}$ therefore eucalyptus plywood is denser than poplar plywood. The along and across samples produced from the same tree species and using the same adhesive were similar but along the samples had values of MOR and MOE that were clearly greater than the across samples. This result occurred because the load direction of the load machine was across to the grain direction in the surface layers of along the samples, whereas it was along to the grain direction of the surface layers of across the samples. Similar kind of results also observed by Izekor and Fuwape (2010) in case of teak. As a result, the flexural properties of along the samples were better than those of across the samples. Tenorio et al. 2011 reported that there would be significant differences in the physical properties of the plywood fabricated from the different raw materials by maintaining the same manufacturing conditions due to the variation in physical properties of raw materials.

The level of significance in Tab. 2 shows the ANOVA test results for moisture content, density, MOR and MOE (both along and across direction). The difference between and within the groups (adhesive and tree species) it was observed that MOR (along) and MOE (across)

insignificant and moisture content, density, MOR (across) and MOE (along) differs significantly at $p \leq 0.001$.

Tab. 2: ANOVA for 9 ply plywood from eucalyptus and poplar species.

9 Ply		df	Mean sum of square	F	Significance
Moisture content	between groups	3	4.224	496.516	< 0.001
	within groups	16	0.009		
Density	between groups	3	0.055	233.604	< 0.001
	within groups	16	0.001		
MOR (along the grain)	between groups	3	21.634	1.818	0.184
	within groups	16	11.900		
MOR (across the grain)	between groups	3	120.530	9.908	0.001
	within groups	16	12.165		
MOE (along the grain)	between groups	3	2485745.117	56.902	< 0.001
	within groups	16	43684.950		
MOE (across the grain)	between groups	3	424862.983	0.898	0.464
	within groups	16	473287.250		

Tabs. 3 and 4 show the Duncan's homogenous subset for MOR and MOE in both, along and across, surface of the 9 ply boards. MOR along the grain eucalyptus board gives better results as compare to poplar but there are no significance differences observed in species and adhesive. In case of across the boards the lowest MOR observed in poplar UF based adhesives and they differ significantly from eucalyptus UF adhesive based plywood. Similar kind of results also found in MOE but there was no significant difference in across the grain. MOE along the grain, no difference in the adhesive but they differ significantly between the species. This kind of results were also reported by Bekir and Ibrahim (2014) in different species.

Tab. 3: Duncan's subsets for MOR (along and across the grain) of 9 ply plywood.

Number of samples	**MOR** (along the grain) ($N \cdot mm^{-2}$) Subset for $\alpha = 0.05$		**MOR** (across the grain) ($N \cdot mm^{-2}$) Subset for $\alpha = 0.05$			
		1		1	2	3
5	**PUF9**	59.42	**PUF9**	46.94		
5	**PPF9**	60.34	**PPF9**		52.16	
5	**EPF9**	62.97	**EPF9**		55.50	
5	**EUF9**	63.78	**EUF9**			58.37
	Significance	0.083	**Significance**	1.000	0.150	0.211

Tab. 4: Duncan's subsets for MOE (along and across) 9 ply plywood.

Number of Samples	**MOE** (Along the grain) ($N \cdot mm^{-2}$) Subset for $\alpha = 0.05$			**MOE** (Across the grain) ($N \cdot mm^{-2}$) Subset for $\alpha = 0.05$	
		1	2		1
5	**PUF9**	6099		**PUF9**	5158
5	**PPF9**	6116		**PPF9**	5276
5	**EPF9**		7282	**EPF9**	5377
5	**EUF9**		7373	**EUF9**	5825
	Significance	0.899	0.502	**Significance**	0.177

CONCLUSIONS

In this study, 9 ply plywood panels were produced from eucalyptus and poplar veneers by using UF and PF resins as a binder and properties of the panels were tested to compare the physical and mechanical properties of plywood. The results indicate that the manufacturing of both the species plywood is feasible for the study and also meets the minimum requirements of IS 303 (1989). The eucalyptus boards get higher density as compare to poplar board and the moisture content is more in poplar boards. Thickness of the boards in these two species, the compression loss observed during hot press of the samples. The along and across samples produced from the same tree species and using the same adhesive were similar but along the samples had values of MOR and MOE that were clearly greater than the across samples. Mechanical properties of these two species and adhesion quality, there is no much significant difference were observed. Finally, the obtained variation in physical and mechanical properties of eucalyptus and poplar plywood were due to the difference in inherent characteristics of veneer wood species.

ACKNOWLEDGMENTS

The authors would like to thank the Indian Plywood Industrial Research and Training Institute Bangalore and Forest Research Institute Dehradun for providing necessary facilities for the research work.

REFERENCES

1. Aydın, I., Çolakoglu, G., 2008: Variations in bending strength and modulus of elasticity of spruce and alder plywood after steaming and high temperature drying. Mechanics of Advanced Materials and Structures 15(5): 371-374.
2. Bal, B.C., Bektaş, I., 2012: The effects of wood species, load direction, and adhesives on bending properties of laminated veneer lumber. BioResources 7(3): 3104-3112.
3. Baldassino, N., Zanon, P., Zanuttini, R., 1998: Determining mechanical properties and main characteristic values of poplar plywood by medium-sized test pieces. Materials and Structures 31: 64-67.
4. Bao, F., Fu, F., Choong, E.T., Hse, C., 2001: Contribution factor of wood properties of three poplar clones to strength of laminated veneer lumber. Wood and Fiber Science 33(3): 345-352.
5. Bekir C.B., İbrahim B., 2014: Some mechanical properties of plywood produced from eucalyptus, beech, and poplar veneer. Maderas Ciencia y Tecnologia 16(1): 99-108.
6. Dias, F.M., Lahr, F.A.R., 2004: Alternative castor oil-based polyurethane adhesive used in the production of plywood. Materials Research 7(3): 413-420.
7. Dutt, D., Tyagi, C.H., 2011: Comparison of various eucalyptus species for their morphological, chemical, pulp and paper making characteristics. Indian Journal of Chemical Technology 18: 145-151.

8. Franz, F.P., Kollmann, E.W., Kuenji, A., Stamm, J., 1975: Principles of wood science and technology. Vol. II. Wood based materials, Springer Verlag, New York, 239 pp.
9. IS 1508, 1972: Specification for extenders for use in synthetic resin adhesives (urea - formaldehyde) for plywood (First revision). Bureau of Indian Standard.
10. Gillespie, R.H., River, B.H., 1976: Durability of adhesives in plywood. Forest Products Journal 26(10): 21-25.
11. IS 303, 1989: Specification for general purposes plywood (First revision). Bureau of Indian Standard.
12. Iwakıri, S., Iwakiri, S., Razera, N.A., De Almeida, B.C., Petro, B.C., Chies, D., Prado G.F., Franzoni, J.A., Rigatto, P.A., Bettega, W.P., 2006: Evaluation of quality of phenolic plywood manufactured from *Eucalyptus grandis* Santa Maria. Ciencia Florestal 16(4): 437-443.
13. Izekor, D.N., Fuwape, J.A., 2010: Variations in mechanical properties among trees of the same and different age classes of teak (*Tectona grandis* L.F.) wood. Journal of Applied Science Research 6(4): 562-56.
14. Izekor, D.N., Fuwape, J.A., Oluyege, A.O., 2010: Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood. Scholars Research Library. Archives of Applied Science Research 2(6): 113-120.
15. Juniar, J.B.G., Mendes, L.M., Mendes, R.F., Mori, F.A., 2009: Plywood boards of eucalyptus: a case study of species and provenances. Cerne 15(1): 10-18.
16. Kabir, M.F., Bhattacharjee, D.K., Sattar, M.A., 1995: Strength properties of and drying characteristics of Eucalyptus wood grown in Bangladesh. Thai Journal of Forestry 14: 103-109.
17. Nacar, M., Hiziroglu, S., Kalaycioglu, H., 2005: Some of the properties of particleboard panels made from eucalyptus. American Journal of Applied Science (Special Issue): 5-8.
18. Ors, Y., Çolakoglu, G., Aydın, I., Çolak, S., 2002: Comparison of some technical properties of plywood produced from beech, okoume and poplar rotary cut veneers in different combinations. Journal of Polytechnic 5(3): 257-265.
19. Ozalp, M., Atılgan, A., Esen, Z., Kaya, S., 2009: Comparing the resistance and bending in the plywood which each made with different glues. Journal of the institute of science and technology of Dumlupınar University 18: 99-104.
20. Parthiban, K.T., Seenivasan, R., Vennila, S., Anbu, P.V., Kumar, V., Saravanan, V., Umesh Kanna, S., Rajendran, P., Subbulakshmi, V., Durairasu, P., 2011: Designing and augmenting pulpwood supply chain through contract tree farming. Indian Journal of Ecology (Special Issue) 38: 41-47.
21. Rahman, K.S., Alam, D.M.N., Islam, M.N., 2012: Some physical and mechanical properties of bamboo mat-wood veneer plywood. International Science Community Association, Journal of Biological Science 1(2): 61-64.
22. Roos, K.D., Shottafer, J.E., Shepard, R.K., 1990: The relationship between selected mechanical properties and age in quaking aspen. Forest Products Journal 40(7&8): 54-56.
23. Srivastava, M.B., 2005: Timber industries and non- timber forest products. CBS Publication, New Delhi, 518 pp.

24. Tenorio, C., Moya, R., Munoz, F., 2011: Comparative study on physical and mechanical properties of laminated veneer lumber and plywood panels made of wood from fast growing *Gmelina arborea* trees. Journal of Wood Science 57(2): 134-139.
25. Youngquist, J.A., 1999: Wood-based composites and panel products. In: Wood handbook: Wood as an Engineering Material. Pp 1-31General Technical Report FPL-113, USDA, Forest Service, Forest Products Laboratory, Madison, Chapter 10.

MANISH RANJAN*, ANAND NANDANWAR, PRADEEP KUMAR KUSHWAHA
INDIAN PLYWOOD INDUSTRIAL RESEARCH AND TRAINING INSTITUTE
POST BAG NO. 2273, HMT LINK ROAD OFF TUMKUR ROAD
YESHWANTHPUR 560022
BANGALORE
INDIA
*Corresponding author: manishranjan509@gmail.com