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Comparative Study on Physical and Mechanical Properties of Plywood Produced from *Eucalyptus* and *Poplar* Veneer

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Table of Contents

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Abstract

In a world where solid wood products are getting expensive due to irregular availability of traditional timber species, composites wood products made of alternate species are on the rise.In this study, two species i.e. Eucalyptus (*Eucalyptus spp.*) and poplar (*Populous deltoids)* were used in two components were given more attention, first manufacturing process of plywood, second physical and mechanical testing of the manufactured plywood to analyze which species can be used as an alternate to the traditional species. Three boards of Eucalyptus with phenol formaldehyde of five, seven and nine veneers made replicates of two. Similarly three boards of Eucalyptus with urea formaldehyde of five, seven and nine veneers made replicates of two. Same variation was used in board made by Poplar with same number of replications. The samples boards were tested physical and mechanical testing such as determination of density and moisture content, determination of water resistance, determination of static bending strength, test of adhesion of plies and static bending testing.All the physical and mechanical properties of plywood met the minimum criteria of IS 303 for plywood for general purposes, both the resins (UF and PF) based plywood demonstrated good results and can be competed the Indian Standard. The density of the eucalyptus plywood was higher than poplar plywood. Mechanical properties of the eucalyptus plywood were comparatively higher than that of poplar plywood. Increasing the number of ply, the MOR and MOE across value is increased as compared to along. Water resistance of UF resin completed all the three cycle successfully in 60°C boiling water test for 6 hours MR grade plywood similarly in case of PF resin three cycle of 100°C boiling water for 8 hours successfully pass the desired requirement and did not delaminate. Knife test to know the adhesion quality also gave excellent results in both the wood species.

Keywords: Plywood Manufacturing, Physical and Mechanical Properties

ယူကလစ်သစ်ပါးလွှာနှင့် ပေါ်ပလာသစ်ပါးလွှာတို့ကို အသုံးပြု၍ ထုတ်လုပ်ရရှိသော အထပ်သားပြားများ၏ ရူပနှင့်အင်အားဂုဏ်သတ္တိတို့ကို နှိုင်းယှဉ်လေ့လာခြင်း။

ဒေါ်စုမြင့်သန်း၊ လက်ထောက်သုတေသနအရာရှိ
သစ်တောသုတေသနဌာန၊ သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

ကမ္ဘာတွင် သစ်ထွက်ကုန် ပစ္စည်းများကို အခြေခံသစ်မျိုးများ ပုံသဏ္ဍာန်ကွဲပြား ခြားနားစွာ ရရှိနေသောကြောင့် ဈေးကြီးကြီးဖြင့် ဝယ်ယူနေရပါသည်။ သို့ဖြစ်ပါ၍ ပုံသဏ္ဍာန် ကွဲပြားခြားနားသော သစ်မျိုးများကို အစိတ်အပိုင်းများပြုလုပ်၍ သစ်ထွက်ကုန်ပစ္စည်းများ ထွက်ပေါ်လာပါသည်။ ယခုစာတမ်းတွင် စိုက်ခင်းအကြီးမြန်ပင်များ ဖြစ်သော ယူကလစ်နှင့် ပေါ်ပလာသစ်ပါး လွှာများကို အသုံးပြု၍ IS-303 နည်းဖြင့် အထပ်သားများကို ကနဦးပြုလုပ်ခဲ့ပါသည်။ သစ်ပါးလွှာ များကို ၅လွှာ၊ ၇လွှာနှင့် ၉လွှာထပ်၍ IS-1508 နည်းစနစ်ဖြင့် ပြင်ဆင်ထားသော ဖီနော်လ် ဖော်မယ်ဒီဟိုဒ်နှင့် ယူရီယားဖော်မယ်ဒီဟိုဒ်ကော်တို့ကို အသုံးပြု၍ သစ်အထပ်ပြား (၂၄)ခုကို ပြုလုပ် ဆောင်ရွက်ခဲ့ပါသည်။ ၎င်းတို့၏ ရူပနှင့်အင်အားဂုဏ်သတ္တိများ Physical tests (Moisture content, Density, Water Resistant and Adhesive of plies)နှင့် Mechanical tests (Modulus of Rupture and Modulus of elasticity) တို့ကို IS-1734 (1983) နည်းစနစ်ဖြင့် စမ်းသပ်လေ့လာခဲ့ပါသည်။ ယူကလစ်သစ်ပါးဖြင့်ပြုလုပ်ထားသော အထပ်သားပြား၏ MOE နှင့် MOR (Static Bending Strength) သည် ပေါ်ပလာသစ်ပါးဖြင့်ပြုလုပ်ထားသော အထပ်သားပြားထက် ပိုမိုကောင်းမွန်ကြောင်း တွေ့ရှိရပါသည်။ အဘယ်ကြောင့်ဆိုသော် ယူကလစ် အထပ်သားပြား၏ Density သည် ပေါ်ပလာ အထပ်သားပြားထက် များနေသော ကြောင့်ဖြစ်ပါသည်။ Modulus of Rupture and Modulus of elasticity တို့ကို သစ်ကြောကို ကန့်လန့်ဖြတ် အနေအထားနှင့် အလျားလိုက်အနေအထား (၂)မျိုးဖြင့် စမ်းသပ်ခြင်းတို့တွင် ကန့်လန့်ဖြတ် အင်အားသည် ပိုမို အားကောင်းနေကြောင်း တွေ့ရှိရပါသည်။ စမ်းသပ်ပြုလုပ် ထား သော အထပ်သားပြား ၅လွှာ၊ ၇လွှာနှင့် ၉လွှာတို့၏ ရူပနှင့်အင်အား ဂုဏ်သတ္တိတို့ကို IS-303 နည်းစနစ်ဖြင့် စမ်းသပ်မှုမှာ အားလုံးမှန်ကန်သော ဆုံးဖြတ်ချက်ဖြစ် ကြောင်းတွေ့ရှိရပါ သည်။ IS-1508 နည်းစနစ်ဖြင့် ပြင်ဆင်အသုံးပြုခဲ့သော ကော်များ (PF and UF) ၏ အရည် အသွေးမှာ

ကောင်းမွန်နေသောကြောင့် ကော်ကပ်စွမ်းအားမှာ အလွန်ကောင်းမွန်ကြောင်း တွေ့ရှိရပါသည်။ ရေစိုခံနိုင်စွမ်းအားကို နည်း(၂)နည်းဖြင့် စမ်းသပ် ဆောင်ရွက်မှုတွင်လည်း အောင်မြင်မှုရှိကြောင်း တွေ့ရှိရပါသည်။

Comparative Study on Physical and Mechanical Properties of Plywood Produced from *Eucalyptus* and *Poplar* Veneer

1. Introduction

Plywood is a building material composed of veneers, i.e. thin layers of wood, bonded together using adhesive. As a material, it is very frequently used for various applications, e.g. paneling, furniture, flooring, store fixtures, and doors.

Plywood that we see in the present form was developed after 1860. Patent records show that the development of "scaled/scale board" which comprised of cementing or fastening together of a number of "scale" of thin sheets of wood with the grains of successive pieces running crosswise. Since 1905, there was a slow but continuous development in plywood manufacture to turn it to an industry.

At the end of World War I, plywood industry entered into the modern era. Before 1914 plywood was known as "Veneered Stock" and the process was called as "veneering". In 1917, Forest Products Laboratory, Madison (USA), changed the name of "Veneered Stock" to plywood. World War II was followed by a rapid growth of the plywood industry. New building construction in response to the need of expanding population coupled with a high level of prosperity, demanded an increasing amount of use of plywood and consequently rapid growth of this industry.

The reasons for the commercial success of plywood lie in its good mechanical properties and its very effective balance in response to variations in temperature and moisture. However, since last decade several wood based products, i.e. Medium Density Fiberboard (MDF), Oriented Strand Board (OSB) have entered the traditional plywood market resulting in a significant competition for plywood sales.

Plywood has cross-bonded veneers where veneers are glued together at 90 degree to one another. It adds the value to the plywood such as dimensional stability, resistance against the splitting brand it makes the strength of the panel consistent across all directions. For greater strength properties the veneers are usually laid crosswise. Plywood panels are composed of at least three veneer layers.

One of the best advantages of plywood is that it can then be over-lied with various coating materials such as phenol and plastic & these coatings improve the plywood's resistance to wear impact, chemicals and weather. Films and laminates imprinted with various patterns improve the panel's frictional properties.

The market's supply demands ratio is variable for its own sufficiency to sustain when using regular woods, hence a need of alternate/plantation species arises. To check the suitability of those plantation species in plywood manufacture there is a huge view field 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.

1.1 Review of Literature

For getting better products between alternatives, comparative analysis study tool plays a crucial role in deciding and prioritizing different products. Same goes with the plywood product in which the overall property depends upon the cumulative of individual veneer or layer. In this regard, some comparative studies have been performed and described below.

Mechanical properties give an idea about strength of the product. Comparison of these properties gives us a range of products and their ability to serve under different conditions. In this regard Bal et al.(2014) determined the flexural properties and tensile shear strength of five-ply plywood panels produced with eucalyptus (*Eucalyptus grandis*), beech (*Fagus orientalis*), and hybrid poplar (*Populus x euramericana*). In that study plywood was made by urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF) and phenol-formaldehyde (PF) adhesives. The study showed that the effects of species of trees, direction of load, and type of adhesive on flexural properties were significant.

Increase in production of Eucalyptus based plywood in China showed the potential and availability of this species. Covering this aspect, a study was performed by Arnold et al. (2013)One comparative study was also performed by Bal et al. (2014).In this study, in three different combinations and five ply plywood boards were produced from rotary cut veneers of beech *(Fagus orientalisLipsky)*, eucalyptus (*Eucalyptus grandis W. Hill ex Maiden*) and hybrid poplar (*Populus × euramericana I-214* clone) using urea-formaldehyde (UF), melamine-urea formaldehyde (MUF) and phenol-formaldehyde (PF) adhesives. In this study,flexural properties of *Eucalyptus grandis* was found higher than beech.

Wei et al. (2016) performed a study to achieve value-added utilizations of plantation timbers, eucalyptus veneer/high-density polyethylene film composites were prepared, with process-factors (PF) (hot-pressing temperature, HT; hot-pressing duration, HD; hot-pressing pressure, HP; HDPE-film content, HC) and composite-properties (CP) (water-resistant bonding-strength, BS; modulus of rupture, MOR; modulus of elasticity, MOE) investigated. According to thermal analyses studies, 140 to 180 °C was appropriate for HT. Based on statistical analyses, HD was easier to affect CP, while MOE was easier to be affected by PF. Quantitative relationships between PF and CP were determined by the neural-network (ANN) modelling. In ANN simulation surveys, CP displayed Gaussian distributions (R2 > 0.9) when PF changed in current ranges, with positive correlations between BS and MOR (R2 ≈ 0.5). Combining ANN and the genetic-algorithm, optimal processes (HT, 160 °C; HD, 50 s/mm; HP, 1.3 MPa; HC, 6 layers) were found, and optimal results (BS, 1.30 MPa; MOR, 86.94 MPa; MOE, 8.33 GPa) were comparable to various reported poplar-plywoods. Microscopic images demonstrated that composite interfaces were formed by the mechanical interlocking. The optimal BS attained Chinese standards for water-resistant plywoods, so proposed composites can serve as water-resistant and formaldehyde-free building materials for furniture and interior design. Basically they have optimized the composite manufacturing process using HDPE adhesive followed by a comparison.

Lihong et al. (2012) worked on structural plywood production technology from Eucalyptus/poplar. In this study, that hot pressing temperature, pressing time, pressing pressure, veneer glue spread –four factors affect the bond strength of the structure plywood very significantly, but the difference among the three veneer glue spread levels is not significantly. Liu et al. (2019) worked to improve the product quality of traditional wooden building formwork. They utilized the resources of wood and evaluate the failure mode of the formwork. Carbon-fiber fabric (CF fabric) reinforced poplar/eucalyptus composite plywood were prepared by using fast-growing poplar (P) and eucalyptus (E) veneer as base materials and CF fabric as reinforcement material, four substrate composite structures (P/P, E/E, P/E, E/P) and four reinforcement positions (control/A, surface/B, core/C and surface-core/D) were considered in this study, the flexural properties and failure modes of plywood were tested and evaluated. Experimental results showed that the flexural performance of plywood as poplar/eucalyptus composite structure was better than pure poplar and eucalyptus. The increase in the longitudinal modulus of elasticity and modulus of rupture of the plywood was particularly understandable and the failure mode was shear delamination failure after the surface strengthened, besides, the core layer reinforced transverse plywood was greater obvious than the longitudinal plywood for the improvement in impact toughness. However, the plywood strengthened by the surface and core simultaneously had the best performance, and the structure which satisfies the strength requirements of building formwork are D-P/E and D-E/P. Experimental findings are accompanied with theoretical model. This also enlightened the concept of hybrid plywood rather than using veneers separately. Using eucalyptus and poplar in combination helps in improving the overall property of the plywood.

Some more studies were conducted covering these aspects have been described below:

IUFRO, Taipei 2007 stated, the forest plantations are replacing the native forest in the wood provision for industries. At world-wide level almost 50% of the provision comes from plantations.

As per the Anonymous (2008), a significant proportion of raw material available for solid utilizations, in the short and medium term, will come from forest plantations. For this reason it is interesting to show the comparison between the most abundant genuses.

Turnbull, (1991),states in his book that “Eucalyptus, because of their adaptation to a wide range of environments, fast growth, ease of management, and the valuable properties of their wood & pulp, will continue to have a major & often expanding role providing wood products, improved standard of living & environmental protection in several countries.”

Bansal, et al. (2002) observed that veneers suitable to manufacture plywood can be peeled by making modifications in lathe settings & drying of the veneers was possible without any major defects. Additionally it did not lead to any gluing problem with conventional Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) adhesives for the manufacture of plywood.

Balatinecz & Kretschmann (2001) have studied that machining, bonding, and finishing properties of poplar is good, which makes it suitable for vast conversion technologies like veneer peeling and flaking. Also due to their low density, the projected ideally acceptable peeling and flaking results can be achieved between 7 and 30°C. It has also been stated that poplar requires little or no preconditioning because of low density and high green moisture content. Additionally the low wood density increases an advantage in bonding of flakes and particles during the manufacture of composite panels because moderate pressure brings the individual flakes and particles into intimate contact, which ensures a medium-density board with good strength. Also, the pores in poplar wood are generally small enough to allow surface finishing without filler treatment.

Singh and Singh, (1994) developed black liquor lignin based phenolic adhesives for plywood to reduce the cost which replaced phenol with black liquor in it. Additionally an attempt was made to develop exterior grade plywood from *P. deltoides* using lignin based phenolic adhesive. The result showed that 30 per cent replacement of phenol can be done with black liquor from pine needles, concluding the plywood met the BWP grade and up to 50 per cent for BWR grade requirements.

Pandey &Rangaraju (2008) have expressed their concern over regular raw materials alarming gap in supply demands. They have suggested possible reforms to improve the efficiency of wood production, distribution and use.

2. Objectives

(1) To study the processes of Plywood making.
(2) To compare the physical and mechanical properties of Plywood produced from Eucalyptus and Poplar veneers.

3. Methodology

This consists of two parts.

1. Plywood Manufacturing
2. Physical & Mechanical Testing of manufactured plywood

3.1 Plywood Manufacturing

3.1.1 Material used

Eucalyptus & Poplar veneers

Veneers of Eucalyptus & Poplar were used for plywood manufacturing. Veneers were procured from the composite wood laboratory of FRI Dehradun.Eucalyptus (*Eucalyptus spp.*) and poplar (*Populousdeltoids)* species were selected for plywood manufacturing. The thickness of Eucalyptus veneers was 2mm and the thickness of Poplar veneers was 1.5mm. The thickness of the final plywood product will be depending on the thickness of individual veneer used while manufacturing.

3.1.2 Chemicals used

Phenol formaldehyde

A phenol-formaldehyde (PF) resin was used as wood adhesive for plywood. It is especially desirable for exterior plywood, owing to their good moisture resistance. PF resin was prepared in composite wood laboratory as per Indian Standards (IS 1508).

Urea formaldehyde

Urea Formaldehyde (UF) is widely used glue for plywood, particleboard, wood panels and bent laminations. Importantly it is not an expensive adhesive hence, cost-effective. UF resin was prepared in composite wood laboratory using resin preparing assembly following Indian Standards (IS 1508)

3.1.3 Process of plywood making

After procuring raw material from different sources, plywood was manufactured as per Indian standards (IS 303). Detailed process has been described below:

1. Eucalyptus and Poplar veneers were dried for different time period depending upon the thickness of the veneers (Fig 3). Higher moisture content affects the gluing procedure and ultimate strength of the final plywood product. Therefore, veneers were air dried and moisture content was brought upto the optimum range (12%- 8%).
2. Determination of the moisture content of Eucalyptus and Poplar veneers was done after regular time interval using oven dry weight method (Fig 4 & 5).
3. Preparation of the adhesives was done as described above and immediately used after its preparation (Fig 6 & 7).
4. Resin was applied on both sides of the core and cross bands i.e. Number two and four sheets in case of five ply-board, two, four and six sheets in seven ply-board, two, four, six and eight sheets in nine ply-board. Resin was speeded using resin brushes with hands (Fig 8).
5. The veneers were air dried for two days (Fig 9).
6. Sheets were assembled orthogonally or in cross-graining direction. (Fig 10). (Note: boards comprising an even number of plies, the direction of grain of the veneer in adjacent plies shall be at right angles to each other, in all cases, the grain on both faces of the assembly boards shall run in the same direction.)
7. After this, assembled veneers were hot pressed (Fig 11) as per the following plan:
   (a)The temperature at hot press was kept100-120℃ for UF resin and 140-150℃ for PF resin
   (b) Pressing time was kept 12 minutes for 5ply-board, 16 minutes for 7 ply-board and 20 minutes for 9 ply-board.
   (c)Optimum pressure was used depending upon the area of the plywood. Optimum pressure was calculated using the following formula:

Formula= (width×length/278) ×200

***Note:** 278 is the area of six pistons.

8. Final step of the plywood manufacturing was finishing, which includes trimming and sanding followed by marking of the samples (Fig 12 &13).Markings of the manufactured plywood were done in following way (as shown in Fig 14-17):

Table 1. Combinations of Eucalyptus ply.

No.	Species	Resin	No. of Veneers	Replications
1.	Eucalyptus	PF	5 ply	2
2.	Eucalyptus	PF	7 ply	2
3.	Eucalyptus	PF	9 ply	2
4.	Eucalyptus	UF	5 ply	2
5.	Eucalyptus	UF	7 ply	2
6.	Eucalyptus	UF	9 ply	2
				TOTAL= 12

Same replications were applied for poplar plywood as well described below:

Table 2. Combinations of Poplar ply.

Serial number	Species	Resin	No. of Veneers	Replications
1.	Poplar	PF	5 ply	2
2.	Poplar	PF	7 ply	2
3.	Poplar	PF	9 ply	2
4.	Poplar	UF	5 ply	2
5.	Poplar	UF	7 ply	2
6.	Poplar	UF	9 ply	2
				TOTAL= 12

In this way we got 24 number of plywood (12 Eucalyptus plywood and 12 poplar plywood). The above work was completed at FRI, Dehradun.

3.2 Physical & Mechanical Testing

For comparison of the plywood testing was necessary. After completing the manufacturing process, testing was conducted at IPIRTI (Indian Plywood Industries Research & Training Institute), Bengaluru. Therefore, plywood boards were couriered to Bengaluru for conducting tests. (Fig 14-29)
Following tests were conducted at IPIRTI, Bengaluru:

3.2.1 Physical Testing:

a) Determination of density and moisture content.
b) Determination of water resistance.
c) Test of Adhesion of plies.

3.2.2 Mechanical Testing

a) Determination of static bending strength.

a) Determination of density and moisture content

Objective

The determination of moisture content is necessary since it has a bearing on several important mechanical properties of plywood.

Test Specimen

Each test specimen was of the full thickness of the material and 75 mm wide and 150 mm long. Smaller specimens may be used when deemed necessary. The dimensions of the test specimens were measured to an accuracy of not less than ± 0.3 percent.

Apparatus: Oven and balance were required for the test is given in Fig 11.

Procedure

The test specimen was weighed. The specimen was then dried in an oven at a temperature of 103 ± 2°C until approximately constant mass was obtained. The specimen was weighed to an accuracy of not less than ± 0.2 percent according to IS: 1734 (Part 1) - 1983

Calculation

The density was calculated as follows:

Density, in $g/cm^3 = M_o/Lwt$

Where

Mo = oven dry mass of specimen in g,

L = length of the specimen in cm,

w = width of the specimen in cm, and

t = thickness of the specimen in cm.

The moisture content was calculated as follows:

Moisture content, percent = $(M_1 - M_o / M_o) \times 100$

Where

M_1 = initial mass of specimen, and

M_o = oven-dry mass of specimen.

b) Determination of water resistance

Objective

This test is intended to determine the acceptability of plywood panel glued by Phenol Formaldehyde in exterior conditions subjected to alternate drying and wetting or high humidity.

Test Specimen

From each board at least 4 test specimens each approximately 250 mm × 250 mm were cut from different positions in the board such that the grain of the face veneer was parallel to the length of the piece.

Apparatus

Water bath and thermometer are required to be used in test is given in Fig13 and 14.

I). Boiling Water Immersion Test

The specimens were kept submerged in a boiling water bath at 95̊±5̊C for 8 hours as per IS: 1734 (Part 6) - 1983). Then the test specimen were removed and cooled at room temperature for 16 hours. This process was repeated three times in total.

II). Moisture Resistance Test

The specimens were kept immersed in warm water at 60 ± 2°C for a period of 3 hours. These test pieces were removed from the water and cooled down to room temperature by plunging them in cold water. These wet pieces while still in wet condition were tested for 'glue shear strength' and 'adhesion of plies' according to methods laid down in IS: 1734 (Part 4)-1983* and IS: 1734 (Part 5)-1983† respectively.

c) Test for adhesion of plies

Objective

This test is intended to estimate the tenacity with which the bonding material holds the adjacent plies together.

Test Specimen

The test specimens were of the full thickness of the material and at least 250 × 250 mm. The specimens were preconditioned to a constant mass at a relative humidity of 65 ± 5 percent and at temperature of 27 ± 2°C.

Apparatus

1. The type of knife required to be used in the test. It may be made from a file. The cutting edge should be kept chisel sharp.

2. The test was carried out on a stout table to which is screwed a wooden batten against which the edge of the test piece.

Procedure

The knife was inserted with its cutting edge parallel to the grain of the outer veneer and worked into, or if possible, along a glue line and the veneer is prized upward. A hard and dense species of plywood requires considerable force to affect entry and to prize the veneer. In a soft timber, the knife tends to follow an easy course through the wood in this case it is essential that the knife be firmly guided along the glue line. (According to IS: 1734 (Part 5) – 1983)

Examples of cases when the bond just passes the requirements as indicated and this is judged by the relative amounts of wood fiber left on the core veneer, and the area prized off. The grading is assessed chiefly on the appearance of the break, but it was a concomitant requirement that force was needed to effect separation.

The bond is excellent, when it was difficult to find the glue line and impossible to keep the tool within it for more than 3 to 6 mm without cutting into adjacent wood. On prizing upwards, the veneer usually breaks off over a width only slightly greater than that of the tool.

The bond is poor, when the knife met little opposition in the glue line and the prize results in the easy removal of almost all the veneers from one side of the test piece. The separated veneers are usually almost free from adherent fiber.

3.2.2 Mechanical Testing:

a) Determination of static bending strength.

Mechanical testing of samples is necessary to find out the strength properties of plywood. In this study, Static bending testing procedure was used following Indian Standards (According to IS: 1734 (Part 11) – 1983).

Procedure:

The span was kept 48 times the nominal depth when the grain direction of the face plies of the test specimen is parallel to the span and 24 times the nominal depth when the grain direction of the face plies is perpendicular to the span.

The load was applied through an appropriate loading block for centre loading with a continuous motion of the movable head throughout the test till a failure is indicated. The rate of application of load shall be such that the unit rate of fibre strain is equal to 0.001 5 cm/cm of outer fibre length per minute within a permissible variation of ± 25 percent. The rate of motion of moving head may be calculated as follows:

$$\mathbf{N = zL^2/ 6d}$$

Where

N = rate of motion of moving head in cm/min,

z = unit rate of fibre strain in cm/cm of outer fibre length per minute = 0.001 5,

L = span in cm, and

d = depth of beam in cm.

The moisture content of the specimen and the temperature at the time of test shall be recorded.

Modulus of elasticity and modulus of rupture was calculated using following formulae (N/mm^2):

$$\mathbf{MOE= PL^3/ 4bh^3\Delta}$$

$$\mathbf{MOR = M^3P'L/2\ bh^2}$$

Where,

P = load in N at proportional limit;

L = span in mm;

b = width of the specimen in mm;

h = thickness of the specimen in mm;

P' = maximum load in N;

Δ = deflection at proportional limit in mm

4. Results and Discussion

Comparative analysis was done in order to know the physical and mechanical properties of plywood manufactured by two different species (Poplar and Eucalyptus). Here we compared these two species in respect to their number of ply (veneers) that is 5ply, 7ply and 9 ply. We also used two different types of adhesives such as Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) as a binding material. The board were prepared using pressure 415psi of 5 ply for 12minutes, 7 ply boards for 16 minutes and 9 ply boards for 20 minutes respectively. The temperature were maintained in hot press 100-120°C for UF resin and 140-150°C for PF resin. All the boards were tested and physio-mechanical properties were compared as per IS 303 general purpose plywood. The prepared board was tested for different physical and mechanical properties and the results are presented in different subheads as given below:

1. Physical and mechanical properties of plywood using 5 Ply Eucalyptus and Poplar with UF and PF resin (EUF5, EPF5, PUF5 and PPF5).
2. Physical and mechanical properties of plywood using 7 Ply Eucalyptus and Poplar with UF and PF resin (EUF7, EPF7, PUF7 and PPF7).
3. Physical and mechanical properties of plywood using 9 Ply Eucalyptus and Poplar with UF and PF resin (EUF9, EPF9, PUF9 and PPF9).

EUF5 = Eucalyptus Urea Formaldehyde 5 Ply	**PUF5** = Poplar Urea Formaldehyde 5 Ply
EPF5 = Eucalyptus Phenol Formaldehyde 5 Ply	**PPF5** = Poplar Phenol Formaldehyde 5 Ply
EUF7 = Eucalyptus Urea Formaldehyde 7 Ply	**PUF7** = Poplar Urea Formaldehyde 7 Ply
EPF7 = Eucalyptus Phenol Formaldehyde 7 Ply	**PPF7** = Poplar Phenol Formaldehyde 7 Ply
EUF9 = Eucalyptus Urea Formaldehyde 9 Ply	**PUF9** = Poplar Urea Formaldehyde 9 Ply
EPF9 = Eucalyptus Phenol Formaldehyde 9 Ply	**PPF9** = Poplar Phenol Formaldehyde 9 Ply

1. Physical and mechanical properties of plywood using 5 Ply Eucalyptus and Poplar with UF and PF resin (EUF5, EPF5, PUF5 and PPF5).

The prepared plywood was tested for physical properties such as density, moisture content, water resistance Moisture Resistance (MR Grade) for UF resin based board, Boiling Water Resistance (BWR Grade) for PF resin based board and Knife test. For mechanical test such as Modulus of Elasticity (Along and across) and Modulus of Rupture (Along and across). Table 3 presents mean observations of these physical and mechanical properties of Plywood.

Table 3. Mean physio-mechanical properties of 5 Ply Eucalyptus and Poplar plywood.

Mean	**MC (%)**	**Density (g/cm^3)**	**MOE (N/mm^2)**		**MOR (N/mm^2)**		**Water Resistance**	**Knife test**
			Along	**Across**	**Along**	**Across**		
EUF5	5.52	0.80	11654	2499	83.83	38.18	Pass (MR)	1st class
PUF5	5.28	0.57	8644	1735	80.99	25.93	Pass (MR)	1st class
EPF5	5.43	0.77	10637	2769	81.45	39.26	Pass (BWR)	1st class
PPF5	4.54	0.57	8208	2112	72.83	26.52	Pass (BWR)	1st class

Mean moisture content was found to be lowest in PPF5 (4.54%) and highest in EUF5 (5.52%). Density was observed more in Eucalyptus plywood as compare to Poplar plywood. It may be because of the Eucalyptus comes under hardwood category and Poplar in softwood. MOE and MOR were found Eucalyptus plywood EUF5 highest in both along as well as across the direction. The lowest MOR and MOE observed in PPF5. Water resistance, MR grade for UF based board and BWR for PF based board passed all the three cycle of the test. Knife test also gave best result in all four boards to meet the IS. Table 4 to 8 present the

ANOVA and Duncan's homogenous subset for 5 ply plywood from eucalyptus and poplar species.

Table 4. ANOVA for 5 ply plywood from Eucalyptus and Poplar Species.

5Ply (EUF5, PUF5, EPF5, PPF5)		Sum of Squares	df	Mean Square	F	Sig.
Moisture Content	Between Groups	2.982	3	.994	17.559	.000
	Within Groups	.906	16	.057		
	Total	3.888	19			
Density	Between Groups	.236	3	.079	133.447	.000
	Within Groups	.009	16	.001		
	Total	.246	19			
MOE (Along)	Between Groups	4.004	3	1.335	51.056	.000
	Within Groups	4182359.600	16	261397.475		
	Total	4.422	19			
MOE (Across)	Between Groups	3062705.350	3	1020901.783	29.339	.000
	Within Groups	556745.600	16	34796.600		
	Total	3619450.950	19			
MOR (Along)	Between Groups	344.479	3	114.826	7.110	.003
	Within Groups	258.408	16	16.151		
	Total	602.888	19			
MOR (Across)	Between Groups	784.597	3	261.532	83.730	.000
	Within Groups	49.977	16	3.124		
	Total	834.574	19			

Table 5. Duncan's subsets for MOE (Along) 5 Ply plywood

			Subset for ά = 0.05		
	5 Ply	N	1	2	3
Duncan[a]	**PPF5**	5	**8208**		
	PUF5	5	8644		
	EPF5	5		10637	
	EUF5	5			**11654**
	Sig.		.196	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.000.

Table 5. Duncan's subsets for MOE (Across) 5 Ply plywood.

		N	Subset for ά = 0.05			
			1	2	3	4
Duncan[a]	**PUF5**	5	**1735**			
	PPF5	5		2112		
	EUF5	5			2498	
	EPF5	5				**2769**
	Sig.		1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed
a. Uses Harmonic Mean Sample Size = 5.000.

Table 6. Duncan's subsets for MOR (Along) 5 Ply plywood.

		N	Subset for ά = 0.05	
	5 Ply		1	2
Duncan[a]	**PPF5**	5	72.83	
	PUF5	5		80.99
	EPF5	5		81.45
	EUF5	5		83.83
	Sig.		1.000	.306

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

Table 7. Duncan's subsets for MOR (Across) 5 Ply plywood.

		N	Subset for ά = 0.05	
	5 Ply		1	2
Duncan[a]	**PUF5**	5	25.93	
	PPF5	5	26.52	
	EUF5	5		38.18
	EPF5	5		39.26
	Sig.		.601	.345

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

Results are supported by previous studies (Baldassino,et al. 1998, Demirkır, C, 2005). The results of both MOR and MOE were good in eucalyptus. It is because of high density of eucalyptus which gave better results as compare to poplar.

2. Physical and mechanical properties of plywood using 7 Ply Eucalyptus and Poplar with UF and PF resin (EUF7, EPF7, PUF7 and PPF7).

Table 8. Mean physio-mechanical properties of 7 Ply Eucalyptus and Poplar plywood.

Mean	MC (%)	Density (g/cm^3)	MOE (N/mm^2)		MOR (N/mm^2)		Water Resistance	Knife test
			Along	Across	Along	Across		
EUF7	5.47	0.79	9312	3884	63.46	44.69	Pass (MR)	1st class
PUF7	5.72	0.55	8338	2137	61.47	36.39	Pass (MR)	1st class
EPF7	4.38	0.77	8063	3911	64.59	45.16	Pass (BWR)	1st class
PPF7	4.35	0.60	7382	2749	62.95	35.86	Pass (BWR)	1st class

Mean moisture content was found to be lowest in PPF7 (4.35%) and highest in PUF7 (5.72%). Density was observed to be more in Eucalyptus plywood as compare to Poplar plywood. MOE (along the grain) was found to be highest in EUF7 & lowest in PPF7. MOE (across the grain) was found to be highest in EPF7 & lowest in PUF7. MOR (along the grain) was found to be highest in Eucalyptus plywood EPF7 and lowest in PUF7. MOR (across the grain) was recorded highest in EPF7 & lowest in PPF7. Water resistance, MR grade for UF bonded board and BWR for PF bonded board passed all the three cycle of the test. Knife test also gave best result in all four boards to meet the IS. Table 10 to 14 present the ANOVA and Duncan's homogenous subset for 7 ply plywood from eucalyptus and poplar species.

Table 9. ANOVA for 7 ply plywood from Eucalyptus and Poplar Species.

	7Ply	Sum of Squares	df	Mean Square	F	Sig.
Moisture Content	Between Groups	7.686	3	2.562	206.817	.000
	Within Groups	.198	16	.012		
	Total	7.884	19			
Density	Between Groups	.225	3	.075	408.524	.000
	Within Groups	.003	16	.000		
	Total	.228	19			
MOE (Along)	Between Groups	9618809.35	3	3206269.783	5.558	.008
	Within Groups	9230368.40	16	576898.025		
	Total	1.885	19			
MOE (Across)	Between Groups	1.151	3	3837531.650	24.003	.000
	Within Groups	2558036.80	16	159877.300		
	Total	1.407	19			

MOR (Along)	Between Groups	25.065	3	8.355	.453	.719
	Within Groups	294.999	16	18.437		
	Total	320.064	19			
MOR (Across)	Between Groups	388.093	3	129.364	59.010	.000
	Within Groups	35.076	16	2.192		
	Total	423.168	19			

Table 10. Duncan's subsets for MOE (Along) 7 Ply plywood.
a. Uses Harmonic Mean Sample Size = 5.000.

	7 Ply	N	Subset for ά = 0.05	
			1	2
Duncan[a]	**PPF7**	5	7381	
	EPF7	5	8063	
	PUF7	5	8338	8338
	EUF7	5		9312
	Sig.		.076	.060

Means for groups in homogeneous subsets are displayed.

Table 11. Duncan's subsets for MOE (Across) 7 Ply plywood.
a. Uses Harmonic Mean Sample Size = 5.000.

	7 Ply	N	Subset for ά = 0.05		
			1	2	3
Duncan[a]	**PUF7**	5	2137		
	PPF7	5		2749	
	EUF7	5			3883
	EPF7	5			3911
	Sig.		1.000	1.000	.914

Means for groups in homogeneous subsets are displayed.

Table 12. Duncan's subsets for MOR (Along) 7 Ply plywood.
a. Uses Harmonic Mean Sample Size = 5.000.

	7 Ply	N	Subset for ά = 0.05
			1
Duncan[a]	**PUF7**	5	61.47
	PPF7	5	62.95
	EUF7	5	63.46
	EPF7	5	64.59
	Sig.		.307

Means for groups in homogeneous subsets are displayed.

Table 13. Duncan's subsets for MOR (Across) 7 Ply plywood.
a. Uses Harmonic Mean Sample Size = 5.000.

	7 Ply	N	Subset for ά = 0.05	
			1	2
Duncan[a]	**PPF7**	5	35.86	
	PUF7	5	36.39	
	EUF7	5		44.69
	EPF7	5		45.16
	Sig.		.581	.624

Means for groups in homogeneous subsets are displayed.

3. Physical and mechanical properties of plywood using 9 Ply Eucalyptus and Poplar with UF and PF resin (EUF9, EPF9, PUF9 and PPF9).

Table 14. Mean physio-mechanical properties of 9 Ply Eucalyptus and Poplar plywood.

Mean	MC (%)	Density (g/cm^2)	MOE (N/mm^2)		MOR (N/mm^2)		Water Resistance	Knife test
			Along	**Across**	**Along**	**Across**		
EUF9	5.06	0.72	7373	5825	63.78	55.50	Pass (MR)	1st class
PUF9	6.08	0.50	7282	5157	62.97	46.94	Pass (MR)	1st class
EPF9	4.00	0.70	6116	5377	60.34	52.16	Pass (BWR)	1st class
PPF9	4.35	0.56	6099	5276	59.42	58.37	Pass (BWR)	1st class

Mean moisture content was found to be lowest in EPF9 (4.00%) and highest in PUF9 (6.08%). Density was observed highest in Eucalyptus plywood EUF9. MOE (along the grain) & (across the grain) was recorded highest in EUF9 & lowest MOE (along the grain) was recorded in PPF9 and in PUF9 (across the grain). MOR (along the grain) was found to be highest in Eucalyptus plywood EUF9 & lowest in PPF9. MOR (across the grain) was recorded highest in PPF9 & lowest in PUF9. Water resistance, MR grade for UF based board and BWR for PF based board passed all the three cycle of the test. Knife test also gave best result in all four boards to meet the IS. Table 16 to 20present the ANOVA and Duncan's homogenous subset for 9 ply plywood from eucalyptus and poplar species.

Table 15. ANOVA for 9 ply plywood from Eucalyptus and Poplar Species.

9 Ply		Sum of Squares	df	Mean Square	F	Sig.
Moisture Content	Between Groups	12.672	3	4.224	496.516	.000
	Within Groups	.136	16	.009		
	Total	12.808	19			
Density	Between Groups	.166	3	.055	233.604	.000
	Within Groups	.004	16	.000		
	Total	.170	19			
MOE (Along)	Between Groups	7457235.30	3	2485745.117	56.902	.000
	Within Groups	698959.20	16	43684.950		
	Total	8156194.55	19			
MOE (Across)	Between Groups	1274588.95	3	424862.983	.898	.464
	Within Groups	7572596.00	16	473287.250		
	Total	8847184.95	19			
MOR (Along)	Between Groups	64.901	3	21.634	1.818	.184
	Within Groups	190.399	16	11.900		
	Total	255.300	19			
MOR (Across)	Between Groups	361.590	3	120.530	9.908	.001
	Within Groups	194.647	16	12.165		
	Total	556.237	19			

Table 16. Duncan's subsets for MOE (Along) 9 Ply plywood.

			Subset for ά = 0.05	
	9 Ply	N	1	2
Duncan[a]	**PPF9**	5	6099	
	EPF9	5	6116	
	PUF9	5		7282
	EUF9	5		7373
	Sig.		.899	.502

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.000.

Table 17. Duncan's subsets for MOE (Across) 9 Ply plywood

	9 Ply	N	Subset for ά = 0.05
			1
Duncan[a]	**PUF9**	5	5158
	PPF9	5	5276
	EPF9	5	5377
	EUF9	5	5825
	Sig.		.177

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

Table 18. Duncan's subsets for MOR (Along) 9 Ply plywood.

	9 Ply	N	Subset for ά = 0.05
			1
Duncan[a]	**PPF9**	5	59.42
	EPF9	5	60.34
	PUF9	5	62.97
	EUF9	5	63.78
	Sig.		.083

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

Table 19. Duncan's subsets for MOR (Across) 9 Ply plywood.

	9 Ply	N	Subset for ά = 0.05		
			1	2	3
Duncan[a]	**PUF9**	5	46.94		
	EPF9	5		52.16	
	EUF9	5		55.50	55.50
	PPF9	5			58.37
	Sig.		1.000	.150	.211

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

5. Conclusion

Following inferences are drawn on the basis of comparative study on physical and mechanical properties of plywood manufactured from eucalyptus and poplar veneers:

All the physical and mechanical properties of these plywood (5 ply, 7 ply and 9 ply) meet the minimum criteria of IS 303 for plywood for general purposes.

Both the resins (UF and PF) based plywood demonstrated good results and compete the Indian Standard.

The density of the eucalyptus plywood was higher than poplar plywood. Therefore the mechanical properties of the eucalyptus plywood are bit higher than poplar plywood.

It is interesting to note that while increasing the number of ply, the MOR and MOE across value is increasing as compare to along.

The water resistance of UF resin competes all the three cycle successful in 60°C boiling water test for 6hrs MR grade plywood.

In case of PF resin three cycle of 100°C boiling water for 8hrs successfully pass the desired requirement and does not delaminate.

Knife test to know the adhesion quality also give the excellent results in both the wood species.

Results of this study have shown that Eucalyptus plywood has higher strength properties in comparison to poplar plywood. Hence, utilization of particular plywood can be prioritised based on requirement of specific strength as it will promote the concept of sustainability because judicious utilization of resources is also conservation.

Compression of wood fiber leads to increase in overall density of the product. Comparative higher density of Eucalyptus veneers gave them an extra edge over poplar veneers. After hot pressing, there was subsequent increase in density, which has significant effect on overall strength properties of the plywood product. As a result, most of the combinations Eucalyptus plywood outraced poplar plywood.

This study opens up scope for future studies. Combination of both species can be used to determine the overall strength properties. Poplar and Eucalyptus plantations are grown hardwoods, therefore, to reduce excessive pressure on natural forest resources these species can be used for making efficient and well serving plywood products.

Keeping environmental prospect, formaldehyde emission is a major problem that a lot of researchers have reported. Therefore, replacing formaldehyde based chemicals (adhesives) or keeping the concentration up to a tolerable limit will be a challenging task in future.

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Photographs

Figure1. Marking of the samples

Figure 2. Veneer cutting

Figure 3. Air drying of the veneers

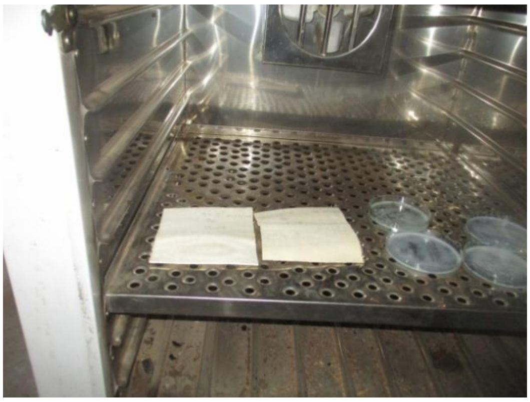

Figure 4. Veneers kept inside oven

Figure 5. Weighing of the veneer samples

Figure 6. Preparation of PF resin.

Figure 7. Preparation of UF resin

Figure 8 Resin application

Figure 9. Drying of veneer

Figure 10. Assembling of sheets

Figure 11. Hot pressing

Figure 12 Marking and measuring of plywood

Figure 13. Trimming of plywood

Figure14. Sample marking (width)

Figure 15. Sample marking (length)

Figure 16. Sample cutting

Figure 17. Prepared samples

Figure 18. Dimension measurement

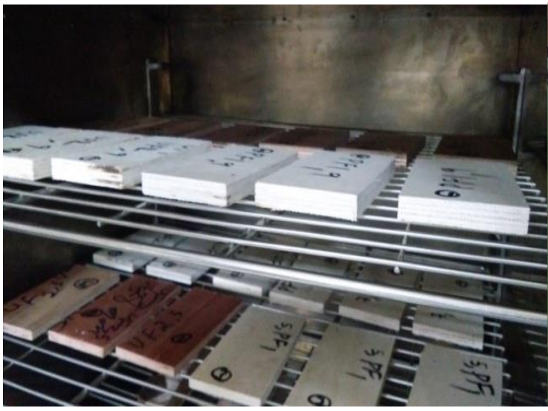

Figure 19. Samples kept inside oven

Figure 20. Oven

Figure 21. Samples for MR and BWR testing

Figure 22. MR testing of UF bonded plywood

Figure 23. BWR testing of PF samples

Figure 24. Adhesion testing tools

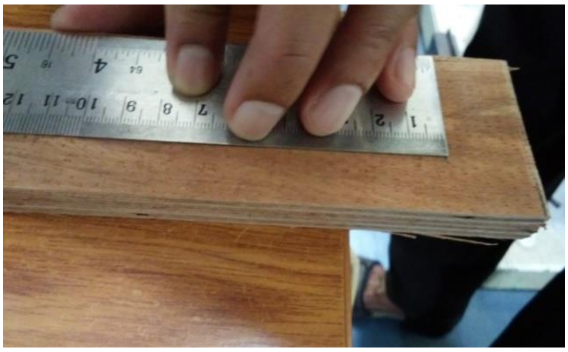

Figure 25. Measurement of span length

Figure 26. Finding centre of the sample

Figure 277. Sample mounting on UTM testing

Figure 288. Data entry for mechanical