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# Manufacturing of Poplar (*Populus deltoides*) Particle Boards Using Radio Frequency curing of Urea Formaldehyde Adhesive.

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***Abstract: This study investigated the physical and mechanical properties of particle boards prepared from the lops and tops of poplar (Populus deltoides) using Radio frequency (RF) pressing and urea-formaldehyde (UF) adhesive. Boards were prepared with RF application times of 9, 12, and 15 minutes under pressures of 17.5, 21.0, and 24.5 kg/cm². Results showed that particle boards prepared at 24.5 kg/cm² with a 15-minute radio frequency application time performed well, meeting Indian Standard (IS: 3087) requirements. An inverse relationship between specific pressure (SP) and physical properties was observed, with increased SP leading to decreased moisture content, higher density, and reduced water absorption. In terms of mechanical properties, higher SP resulted in improved tensile strength (TS), modulus of rupture (MOR), modulus of elasticity (MOE), and screw withdrawal (SW) strength for both face and edge. These findings highlight the importance of specific pressure in enhancing the physical and mechanical characteristics of particle boards. Optimizing SP could lead to stronger, more durable boards, offering significant potential for improving quality in industrial applications using RF curing technology.***
***Key-words: Particle boards, RF curing, Populus deltoides, Urea-formaldehyde (UF) adhesive, Composite wood***

## I. INTRODUCTION

Wood-based composites are made by mixing thermosetting adhesives with wood fibers and then pressing them under high temperature and pressure. The bonding between the fibers is a complex process affected by several factors, such as the raw materials, manufacturing methods, processing conditions, surface treatments of the fibers, and especially the type and composition of the adhesive (Zhou et al., 2009). Thermosetting adhesives in composites are mainly formaldehyde-based, and a major issue with these adhesives is the release of formaldehyde. High levels of formaldehyde can be harmful to human health, making it difficult to recycle the final product (Gonzalez-Garcia et al., 2011).

Particleboard, also known as chipboard, is made by mixing small wood chips with glue and then compressing them, the main parts of particleboard are glue, wood chips, and some additives. After being pressed, the boards are dried and cut into shape to create particleboard panels (Marutzky 2018). Particleboard has become popular as a construction material due to its wide range of uses and low cost. It is environmentally friendly because it is made from waste materials like wood chips, sawdust, and wood shavings, which are combined with resin to create boards. Known as an engineered panel product, particleboard is produced by pressing wood particles or other plant-based materials, such as non-wood fibers, along with a binder using heat (Campbell et al., 2018).

Particle boards have many desirable qualities, such as high density, surface hardness, abrasion resistance, and durability. Adjusting board density and particle sizes can improve these properties. Different types of boards show different properties, and increasing the press time also enhances these qualities (Ghalehno et al., 2013). The relationship between board properties and manufacturing variables is complex, influenced by board densities, wood species, raw materials, and processing methods (McNatt 1973). The even distribution of particles and binders within the board's structure is crucial for improving its properties. Particle boards can be made in various sizes, shapes, thicknesses, and densities. They are used in applications like shelves, furniture, doors, cupboards, and other items (Kavitha et al., 2015). Additionally, particle boards are commonly used for cabinetry, tabletops, shelving, wall and floor panels, doors, furniture, and other non-structural architectural applications.

Urea-formaldehyde (UF) resin is commonly used as a binder in the manufacture of wood-based panels like medium-density fiberboard, particleboard, and hardwood plywood for indoor use. UF resin is valued for its clear glue lines, affordability, resistance to mold and fungi, and ease of use, including mixing, applying, and cleaning. It effectively bonds with most wood species in different combinations (Paul et al., 2008, Mamza et al., 2010) Formaldehyde (HCHO, CAS No. 50-00-0) based resins pose several environmental and health risks.

 

These include significant environmental issues and serious health hazards such as skin and respiratory irritation, skin sensitization, nausea, genotoxicity, and cancer (Łebkowska et al., 2017, Bekhta et al., 2021). Currently, approximately 95% of wood adhesives used in the production of wood-based panels are formaldehyde-based resins (Kumar and Pizzi, 2019a). UF resins dominate the global market, making up around 85% of all amino resins produced, with an estimated annual production of 11 million tons (Pizzi et al., 2020, Kumar and Pizzi, 2019b, Dae and woo, 2008). UF resins are thermosetting resins formed from a reaction between urea and formaldehyde. They are widely used in producing engineered wood-based panels due to their benefits, including low pressing temperatures, short pressing times, strong properties, chemical versatility, and relatively low cost (Kumar & Pizzi, 2019a; Dae & Woo, 2008; Wibowo et al., 2020; Mantanis et al., 2017; Bekhta et al., 2016; Dunky, 2003; Zhang et al., 2013; Jivkov et al., 2013). The primary drawback of UF resins is their lower water resistance compared to phenol and melamine formaldehyde resins (Kumar and Pizzi, 2019b) is the emission of hazardous volatile organic compounds (VOCs) and free formaldehyde from UF-bonded products, particularly when used indoors (Tudor et al., 2020a; Tudor et al., 2020b; Mirski et al., 2019).

The growth of particleboard production over the past four decades has been driven by the material's homogeneity, cost-effective utilization of wood and other lignocellulosic fibers and its economical binding method (Anon 2003). Global demand for composite wood products including plywood, oriented strand board (OSB), hardboard, particleboard, medium-density fiberboard (MDF) and veneer board has surged in recent times (Sellers 2000). Deforestation forest degradation and rising demand for wood-based panels have resulted in a prolonged shortage of raw materials within the sector (Çolak et al., 2007). Particle boards are composed of a blend of wood particles and adhesives. Wood is first broken down into particles during production and then adhesive is introduced to create a mat. This mat is subsequently subjected to controlled temperature and pressure. The mat's quantity is determined by weight with lower-density wood requiring a thicker mat. Typical particleboard densities range from 0.30 g/cm$^3$ to 0.50 g/cm$^3$. Higher-density woods can be combined with lower-density varieties. Wood density is a critical factor as it significantly influences particleboard quality. Lower-density wood results in higher-density compaction and increased particle-to-particle contact, yielding a more uniform product with enhanced load-bearing capabilities leading to improved flexural and internal bond properties in particle boards made from low-density wood (Dias et al., 2005).

Particleboard is a more affordable, denser, and uniform alternative to traditional wood and plywood, often used when cost matters more than appearance or strength. However, it can be improved visually by painting or applying wood veneers to the surfaces that will be visible (Oh et al., 2012; Hofstrand et al., 1984; Aisien 2015). Today, more than a hundred particleboard plants are operating globally, making particleboard one of the strongest reconstituted panel products and a popular substitute for wood and plywood. Urea-formaldehyde, a non-transparent thermosetting resin made from urea and formaldehyde heated with a mild base like ammonia or pyridine, is often used in particleboard production. This resin is known for its high tensile strength, flexural modulus, heat resistance, low water absorption, minimal mold shrinkage, high surface hardness, elongation at break, and excellent volume resistance (Duku et al., 2011; Amenaghawon et al., 2013; Mamza et al., 2014).

Particleboard properties are significantly influenced by factors like compaction rate, particle geometry, adhesive type and content, density, press conditions, and other processing variables. Among these board density is a critical determinant of particleboard and wood composite properties (Maloney 1977). Numerous studies have shown a strong correlation between board properties and its density as evidenced by research conducted by (Hiziroglu et al., 2005; Hayashi et al., 2003; Zhou 1990). UF resins are the adhesive of choice for more than 90% of wood-based panel products worldwide (Doosthoseini 2008). These resins offer several advantages including cost-effectiveness, non-flammability, fast curing, and a light color. However, they lack water resistance and formaldehyde emissions persist from the adhesive (Rowell 2005). Increasing the resin content enhances the physical and mechanical properties of wood-based panels as demonstrated by studies conducted by (Ashori and Nourbakhsh 2008; Nemli 2002). A radio-frequency hot press equipped with an installed radio-frequency heating device was designed to minimize the pressing time needed for thick boards. The rationale is that radio-frequency heating rapidly elevates the temperature within a thick board (Raddin 1967; Pungs and Lambertz 1962; Hopkins 1970). Nevertheless, due to the swift temperature rise the radio-frequency hot press is more susceptible to inadvertent blowout than a standard hot press as it generates high water vapor pressure within the board (Huang and Mori 1976). The utilization of radio frequency (RF) in wood adhesives relies on dielectric heating caused by electromagnetic waves. This process effectively heats materials with low heat conductivity (Wilson 1987; Pound 1973; Torgovnikov 1993). RF heating surpasses alternatives like hot-pressing in speeding up adhesive drying due to its superior efficiency. It selectively heats the wet glue line, limiting temperature increase in a dry substrate and minimizing adhesive degradation. Advantages include targeted heating, energy efficiency, uniformity, quick processing, compact equipment, and precise control (Gadhave and Vineeth 2022).

In this study, lops and tops of *Populus deltoides* were used to prepare particle boards using radio frequency (RF) curing of Urea-formaldehyde (UF) adhesive at a consistent concentration of 8% for all particle boards. The boards were subjected to three different pressures: 17.5, 21.0, and 24.5 kg/cm$^2$, in combination with varying time intervals of Radio Frequency (RF) application: 9, 12, and 15 minutes.

## II. MATERIALS AND METHODS

### *A. Raw Material and Adhesive*

Lops and tops of *Populus deltoides* were sourced from the Range Office of the Forest Research Institute in Dehradun, India, located at geographical coordinates, 30°19' N latitude and 78°04' E longitude. An 8% urea-formaldehyde (UF) solution was prepared to use as an adhesive in the production of particle boards.

### *B. Particles preparation*

The bark of lops and tops of *Populus deltoides* was carefully removed and then manually processed into small chips. These chips were then milled at three different settings to create finer particles, allowing for better adhesion in the final product.

After milling, the resulting wood particles were collected and weighed to determine the total mass available for further processing. To ensure the quality of the material, the particles were passed through a sieve machine to remove sawdust. After sieving, the material was weighed again for further processing.

### *C. Adhesive Preparation and Blending*

The preparation of the adhesive began with the careful selection of powdered urea-formaldehyde (UF). An 8% concentration solution was then formulated by dissolving the powdered UF in water. To enhance the curing process, 2% ammonium chloride was incorporated into the mixture as a hardener during the resin formulation.

To prepare a homogeneous mixture and prevent the formation of lumps, the solution was thoroughly blended. Once the adhesive was prepared, the wood particles were placed inside a drum-shaped resin blender, which was then securely covered to prevent any spillage during the blending process.

The application of the resin to the particles was accomplished using a spray gun, which allowed for precise and uniform distribution of the adhesive. The rotary motion of the resin blender further facilitated even coverage, ensuring that all wood particles were adequately coated. The process of mat formation and board preparation involves several critical steps that ensure the successful creation of composite boards.

### *D. Mat Formation*

The mat formation and board preparation process is a systematic approach that combines material science with engineering principles to produce high-quality composite boards.

The caul plates are heated to melt the wax, which is subsequently applied to their surface. This wax serves as a release agent, preventing the adhesive from sticking to the plates during the pressing process. A wooden frame measuring 61 cm x 61 cm is utilized to shape the blended particles. This frame is placed on top of the waxed caul plates, and the adhesive-coated particles are manually filled into the frame. This step is crucial for ensuring that the particles are evenly distributed and compacted.

### *E. Board Preparation*

Once the mat is formed, the next steps involve pressing and curing the mat to create the final boards.

1) *Pressing the Mat:* The filled frame is then placed in a radio frequency (RF) press. This press applies pressure to the mat, and exposed to different interval of radio frequency applications, which activates the adhesive and bonds the particles together.
2) *Board Specifications:* During this process, a total of 9 boards are prepared, each with a thickness of 12 mm. The boards are subjected to specific pressures of 17.5, 21, and 24.5 kg/cm², combined with varying RF application time of 9, 12, and 15 minutes. This variation allows for the assessment of how different pressures and RF application time affect the physical and mechanical properties of the boards.
3) *Conditioning:* After pressing, the assembled boards are conditioned at room temperature for approximately one week. This conditioning period is essential for stabilizing the boards and ensuring consistent moisture content before further physical and mechanical testing.

### *F. Sampling and Testing Procedures*

Sampling and testing were conducted following the guidelines set forth in Indian Standards: 2380-1 to 21 and IS:3087. These standards outline the procedures for evaluating the physical and mechanical properties of wood particle boards.

### *G. Physical Testing*

#### *1) Moisture Content (MC)*

This test measures the amount of water contained in the board, expressed as a percentage of its dry weight. Moisture content is critical because it can affect the board's strength, weight, and durability. Higher moisture levels might lead to decay or deformation, while lower levels could make the board brittle.

#### *2) Density*

$$\rho = \frac{\text{Mass}}{\text{Volume}}$$

Density is a measure of how compact the material is, calculated by dividing its mass by its volume. A higher density often indicates a stronger and more durable board, but it can also mean added weight, which might affect ease of handling and transportation.

#### *3) Water Absorption (WA)*

$$\text{WA } (\%) = \left(\frac{\text{Weight after immersion} - \text{Weight before immersion}}{\text{Weight before immersion}}\right) \times 100$$

Water absorption tests the ability of the board to absorb water over a set period of time. This is crucial for applications where the material may be exposed to moisture, as boards that absorb too much water can swell, weaken, or become prone to decay.

#### *4) General Swelling (GS)*

General swelling measures the overall expansion of the board's dimensions after exposure to moisture. This helps in understanding the stability of the material in wet conditions. Significant swelling can lead to structural instability.

#### *5) Surface Swelling (SS)*

$$\text{SS } (\%) = \left(\frac{\text{Surface dimension after immersion} - \text{Surface dimension before immersion}}{\text{Surface dimension before immersion}}\right) \times 100$$

Surface swelling focuses specifically on the changes occurring on the board's surface when exposed to water. This property is important for applications where the board's surface is exposed, as excessive swelling can damage finishes or coatings.

### *H. Mechanical Testing*

#### *1) Modulus of Rupture (MOR)*

Where:

- F = maximum load applied (N)
- L = span between supports (mm)
- b = width of the specimen (mm)
- d = thickness (depth) of the specimen (mm)

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Modulus of rupture is a measure of the board’s strength before it breaks. It indicates how much load the material can withstand before cracking or failing, which is essential for understanding the material's durability in structural applications.

*2) Modulus of Elasticity (MOE)*

Where:
- F = applied load (N)
- Δ = deflection at the center (mm)

MOE measures the stiffness of the material, or its ability to resist deformation under load. A higher MOE means the board is more rigid and less prone to bending, making it suitable for load-bearing applications.

*3) Tensile Strength (TS)*

$$\mathrm{TS} = \frac{F}{A}$$

Where:
- F= maximum load applied (N)
- A = cross-sectional area (mm²)

Tensile strength indicates the material’s resistance to being pulled apart. This is crucial for understanding how the board will perform under tension, ensuring that it can withstand forces trying to stretch or elongate it.

*4) Screw Withdrawal (SW)*

Where:
- F = force required to withdraw the screw (N)
- A= area of the screw thread in contact with the material (mm²)

Screw withdrawal tests evaluate how well screws hold in the material. This property is particularly important for boards used in construction, where screws may be used to fasten components. Good screw-holding capacity ensures strong connections between materials.

*I. Statistical Analysis*

After testing, a statistical analysis was conducted using SPSS (Statistical Package for the Social Sciences) version 16 to identify significant differences in material performance. A 95% confidence level was used to determine the significance of the results. The physical and mechanical tests help in assessing critical properties, while statistical analysis adds confidence to the consistency and reliability of the results.

1) *One-Way ANOVA:* The method was used to compare the means of different groups (e.g., boards with varying treatments or compositions) to observe the statistical significant difference in their properties.
2) *Duncan Test:* A post-hoc test used after ANOVA to determine exactly which groups are different from each other. It helps in identifying which specific treatments or samples are significantly different.

## III. RESULTS AND DISCUSSIONS

The results presented in the tables (1 and 2) provide a comprehensive analysis of the effects of pressing pressure (Sp) and RF application time on the physical and mechanical properties of prepared particle boards. The key physical properties evaluated include moisture content (M.C), density, water absorption at 2 hours (WA 2h) and 24 hours (WA 24h), general swelling at 2 hours (GS 2h), and surface swelling at 2 hours (SS 2h).

Table 1: Physical properties of particle boards prepared at RF application time of 9, 12 and 15 Min.

| Time (min) | SP ($kg/cm^{2)}$) | n | M. C (%) | Density ($g/cm^3$) | WA 2h (%) | WA 24h (%) | GS 2h (%) | SS 2h (%) |
|---|---|---|---|---|---|---|---|---|
| 9 | 17.5 | 9 | 11.21 (1.29) | 0.55 (0.06) | 76.81 (17.09) | 89.54 (18.06) | 19.03 (8.89) | 17.31 (9.44) |
| | 21.0 | 9 | 10.02 (0.86) | 0.64 (0.05) | 69.65 (12.67) | 82.37 (12.43) | 16.59 (3.59) | 16.35 (7.74) |
| | 24.5 | 9 | 10.26 (0.61) | 0.65 (0.05) | 59.67 (4.02) | 69.56 (3.34) | 18.50 (1.92) | 17.89 (2.82) |
| 12 | 17.5 | 9 | 9.11 (1.86) | 0.61 (0.05) | 73.60 (11.06) | 85.10 (8.66) | 12.46 (3.78) | 11.86 (3.46) |
| | 21.0 | 9 | 8.46 (1.72) | 0.65 (0.08) | 74.39 (11.02) | 87.83 (8.70) | 19.94 (4.13) | 17.16 (7.17) |
| | 24.5 | 9 | 7.92 (1.15) | 0.75 (0.05) | 65.93 (12.80) | 74.22 (13.20) | 18.04 (3.91) | 14.81 (5.18) |
| 15 | 17.5 | 9 | 8.56 (2.11) | 0.64 (0.11) | 74.6 (20.1) | 87.00 (15.7) | 16.60 (2.40) | 12.00 (5.50) |
| | 21.0 | 9 | 8.72 (1.86) | 0.68 (0.08) | 72.9 (15.4) | 85.90 (14.0) | 17.70 (1.70) | 14.70 (8.40) |
| | 24.5 | 9 | 5.32 (1.21) | 0.79 (1.10) | 21.6 (2.3) | 41.10 (6.2) | 7.80 (1.90) | 7.10 (1.80) |

Standard deviation mentioned the brackets below the values.
N = Number of samples taken. SP = Specific pressure. WA 2h (%) = Water absorption after 2h water soaking (%). WA 24h (%) =Water absorption after 24 h water soaking (%). GS 2h (%) = General swelling after 2h soaking (%). SS 2h (%) = Surface swelling after 2h soaking (%).

Table 2: Duncan's subset for physical properties of particle boards prepared at RF application time of 9, 12 and 15 Min.

| Time (minute) | SP ($kg/cm^{2)}$) | N | M.C (%) | Density ($g/cm^3$) | WA2H (%) | WA24 (%) | GS2H (%) | SS2h (%) |
|---|---|---|---|---|---|---|---|---|
| 9 | 17.5 | 9 | $11.21^a$ | $0.55^a$ | $76.81^a$ | $89.54^a$ | $19.03^a$ | $17.31^a$ |
| | 21.0 | 9 | $10.02^b$ | $0.64^b$ | $69.65^{ab}$ | $82.37^a$ | $16.59^a$ | $16.35^a$ |
| | 24.5 | 9 | $10.26^b$ | $0.65^b$ | $59.67^b$ | $69.56^b$ | $18.50^a$ | $17.89^a$ |
| | sig. | | $1.00^a$, $0.60^b$ | $1.00^a$, $0.56^b$ | $0.24^a$, $0.10^b$ | $0.25^a$, $1.00^b$ | $0.40^a$ | $0.67^a$ |
| 12 | 17.5 | 9 | $9.11^a$ | $0.61^a$ | $73.60^a$ | $85.10^a$ | $12.46^a$ | $11.86^a$ |
| | 21.0 | 9 | $8.46^a$ | $0.65^a$ | $74.39^a$ | $87.83^a$ | $19.94^b$ | $17.16^a$ |
| | 24.5 | 9 | $7.92^a$ | $0.75^b$ | $65.93^a$ | $74.22^b$ | $18.04^b$ | $14.81^a$ |
| | sig. | | $0.11^a$ | $0.18^a$, $1.00^b$ | $0.16^a$ | $0.58^a$, $1.00^b$ | $1.00^a$, $0.32^b$ | $0.06^a$ |
| 15 | 17.5 | 9 | $8.56^a$ | $0.64^a$ | $74.62^a$ | $86.96^a$ | $16.61^a$ | $11.98^{ab}$ |
| | 21.0 | 9 | $8.72^a$ | $0.68^a$ | $72.88^a$ | $85.89^b$ | $17.73^a$ | $14.71^a$ |
| | 24.5 | 9 | $5.32^b$ | $0.79^b$ | $21.6^b$ | $41.14^c$ | $7.78^b$ | $7.10^b$ |
| | sig. | | $0.85^a$, $1.00^b$ | $0.45^a$, $1.00^b$ | $0.80^a$, $1.00^b$ | $0.85^a$, $1.00^c$ | $0.25^a$, $1.00^b$ | $0.33^a$, $1.00^b$ |

Means for groups in homogeneous subsets are displayed at a confidence level of 95%.
Superscript abcd represents different subsets.

### *A. Moisture Content (M.C)*
The moisture content of the boards varied significantly across different conditions. For boards pressed for 9 minutes RF application time, the moisture content was highest at 11.21% (±1.29) for those pressed at 17.5 kg/cm², forming a distinct subset (a). Increasing the pressure to 21.0 kg/cm² reduced the moisture content to 10.02% (±0.86), while at 24.5 kg/cm², it was 10.26% (±0.61), both forming subset (b). When the pressing and the RF application time was extended to 12 minutes, moisture content dropped to 9.11% (±1.86) at 17.5 kg/cm² and further decreased to 7.92% (±1.15) at 24.5 kg/cm², both in subset (a). The most significant reduction was observed at 15 minutes pressing and RF application time, where moisture content reached its lowest point of 5.32% (±1.21) at 24.5 kg/cm², forming a distinct subset (b) compared to the other pressure levels. This indicates that higher pressure and longer pressing RF application time effectively reduce moisture retention.

### *B. Density*
Density values also showed a positive correlation with increased pressure and RF application time. For boards pressed at 9 minutes, the density was 0.55 g/cm³ (±0.06) at 17.5 kg/cm², forming subset (a). Increasing the pressure to 21.0 kg/cm² raised the density to 0.64 g/cm³ (±0.05), and at 24.5 kg/cm², it reached 0.65 g/cm³ (±0.05), both forming subset (b). When the pressing time was extended to 12 minutes, density increased to 0.61 g/cm³ (±0.05) at 17.5 kg/cm², forming subset (a), and peaked at 0.75 g/cm³ (±0.05) at 24.5 kg/cm², forming a distinct subset (b). The highest density recorded was 0.79 g/cm³ (±1.10) for boards pressed at 24.5 kg/cm² for 15 minutes pressing and RF application time, in subset (b). This trend indicates that higher pressure leads to better particle compaction, resulting in denser boards that are more suitable for structural applications

### *C. Water absorption (WA)*
Water absorption at both 2 hours and 24 hours decreased significantly with increased pressure. For example, at 2 hours, boards pressed at 17.5 kg/cm² absorbed 76.81% (±17.09) of water, forming subset (a), while those at 24.5 kg/cm² absorbed only 59.67% (±4.02), forming subset (b). At 24 hours, the difference was even more pronounced; boards pressed at 24.5 kg/cm² absorbed just 21.6% (±2.3), forming subset (b), compared to 89.54% (±18.06) for those pressed at 17.5 kg/cm², in subset (a). This demonstrates that higher pressing pressures enhance the adhesive bond between particles, significantly reducing water ingress and improving the boards' durability.

### *D. General Swelling (GS) and Surface Swelling (SS)*
General swelling and surface swelling also exhibited favorable results with increased pressure. At 2 hours, general swelling for 9 minutes was 19.03% (±8.89) for boards pressed at 17.5 kg/cm², 16.59% (±3.59) for those at 21.0 kg/cm², and 18.50% (±1.92) for boards at 24.5 kg/cm², all in subset (a). For boards pressed at 24.5 kg/cm² for 15 minutes RF application time, general swelling dropped to 7.78% (±1.90), forming a distinct subset (b). Surface swelling followed a similar trend, with the lowest value of 7.10% (±1.80) observed for boards pressed at 24.5 kg/cm² for 15 minutes RF application time, in subset (b). These results suggest that higher pressure effectively minimizes dimensional changes when the boards are exposed to moisture.
The mechanical properties of particle boards are crucial for determining their suitability for various applications. The data presented in the table (3 and 4) provides insights into how pressing specific pressure (SP) and time duration affect key mechanical properties, including tensile strength(TS), modulus of rupture (MOR), modulus of elasticity (MOE), and screw withdrawal (SW) for both face and edge orientations.

Table 3: Mechanical properties of particle boards prepared at RF application time of 9, 12 and 15 Min.

| Time (minute) | SP ($kg/cm^2$) | N | TS ($N/mm^2$) | MOR ($N/mm^2$) | MOE ($N/mm^2$) | N | SW (face) | SW (edge) |
|---|---|---|---|---|---|---|---|---|
| 9 | 17.5 | 12 | 0.41 (0.19) | 4.60 (2.05) | 523.29 (150.86) | 6 | 1304.00 (188.18) | 1171.80 (274.06) |
| | 21.0 | 12 | 0.60 (0.14) | 7.39 (1.42) | 783.95 (284.37) | 6 | 1563.30 (106.40) | 1321.40 (118.36) |
| | 24.5 | 12 | 0.77 (0.10) | 8.93 (0.75) | 1126.20 (329.82) | 6 | 1674.40 (131.05) | 1404.40 (136.04) |
| 12 | 17.5 | 12 | 0.48 (0.13) | 6.52 (2.23) | 663.42 (156.34) | 6 | 1528.30 (255.13) | 1088.70 (143.89) |

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|---|---|---|---|---|---|---|---|---|
| | 21.0 | 12 | 0.63 (0.10) | 7.29 (1.07) | 1347.70 (265.40) | 6 | 1733.30 (223.29) | 1338.20 (198.83) |
| | 24.5 | 12 | 0.90 (0.16) | 10.28 (1.58) | 1772.60 (407.07) | 6 | 1990.70 (150.87) | 1670.40 (120.74) |
| 15 | 17.5 | 12 | 0.53 (0.12) | 7.01 (1.27) | 656.22 (123.95) | 6 | 1359.11 (126.26) | 1042.24 (93.34) |
| | 21.0 | 12 | 0.61 (0.07) | 8.49 (2.35) | 897.64 (272.64) | 6 | 1626.83 (179.34) | 1320.26 (170.69) |
| | 24.5 | 12 | 0.95 (0.14) | 11.98 (1.39) | 2199.59 (248.91) | 6 | 2306.5 (242.39) | 2113.78 (165.75) |

Standard deviation mentioned the brackets below the values.

Table 4: Duncan's subset for mechanical properties of particle boards prepared at RF application time of 9, 12 and 15 Min.

| Time (minute) | SP (kg/cm$^2$) | N | TS (N/mm$^2$) | MOR (N/mm$^2$) | MOE (N/mm$^2$) | N | SW (face) | SW (edge) |
|---|---|---|---|---|---|---|---|---|
| 9 | 17.5 | 12 | 0.41$^{a}$ | 4.60a | 523.29a | 6 | 1304.00$^{a}$ | 1171.83$^{a}$ |
| | 21.0 | 12 | 0.60$^{b}$ | 7.39$^{b}$ | 783.95$^{b}$ | 6 | 1563.30$^{b}$ | 1321.38$^{a}$ |
| | 24.5 | 12 | 0.77$^{c}$ | 8.93$^{c}$ | 1126.20$^{c}$ | 6 | 1674.4$^{b}$ | 1404.41$^{a}$ |
| | sig. | | 1.00$^{abc}$ | 1.00$^{abc}$ | 1.00$^{abc}$ | | 1.00$^{a}$, 0.19$^{b}$ | 0.05$^{a}$ |
| 12 | 17.5 | 12 | 0.48$^{a}$ | 6.52$^{a}$ | 663.42$^{a}$ | 6 | 1528.30$^{a}$ | 1088.70$^{a}$ |
| | 21.0 | 12 | 0.63$^{b}$ | 7.29$^{a}$ | 1347.70$^{b}$ | 6 | 1733.30$^{ab}$ | 1338.20$^{b}$ |
| | 24.5 | 12 | 0.90$^{c}$ | 10.28$^{b}$ | 1772.60$^{c}$ | 6 | 1990.7$^{b}$ | 1670.40$^{c}$ |
| | sig. | | 1.00$^{abc}$ | 0.27$^{a}$, 1.00$^{b}$ | 1.00$^{abc}$ | | 0.12$^{a}$, 0.06$^{b}$ | 1.00$^{abc}$ |
| 15 | 17.5 | 12 | 0.53$^{a}$ | 7.00$^{a}$ | 656.22$^{a}$ | 6 | 1359.10$^{a}$ | 1042.20$^{a}$ |
| | 21.0 | 12 | 0.61$^{a}$ | 8.48$^{b}$ | 897.64$^{b}$ | 6 | 1626.80$^{b}$ | 1320.30$^{b}$ |
| | 24.5 | 12 | 0.95$^{b}$ | 11.98$^{c}$ | 2199.60$^{c}$ | 6 | 2306.50$^{c}$ | 2113.80$^{c}$ |
| | sig. | | 0.10$^{a}$, 1.00$^{b}$ | 1.00$^{abc}$ | 1.00$^{abc}$ | | 1.00$^{abc}$ | 1.00$^{abc}$ |

Means for groups in homogeneous subsets are displayed at a confidence level of 95%.
Superscript abcd represents different subsets.
N = Number of samples taken. SP = Specific pressure. TS = Tensile strength, MOR = Modulus of rupture. MOE = Modulus of elasticity. SW =Screw withdrawal.

*1) Tensile Strength (TS)*

At 9 minutes, the TS was lowest at 0.41 N/mm$^2$ (±0.19) for boards pressed at 17.5 kg/cm$^2$, forming subset (a). Increasing the pressure to 21.0 kg/cm$^2$ raised the TSPG to 0.60 N/mm$^2$ (±0.14), while at 24.5 kg/cm$^2$, the TS further increased to 0.77 N/mm$^2$ (±0.10), forming subset (c).

For 12 minutes, TS values improved, with 17.5 kg/cm$^2$, 0.48 N/mm$^2$ (±0.13), 21.0 kg/cm$^2$ , 0.63 N/mm$^2$ (±0.10), and 24.5 kg/cm$^2$ achieving 0.90 N/mm$^2$ (±0.16), forming subset (c). At 15 minutes, the TS reached its highest value of 0.95 N/mm$^2$ (±0.14) at 24.5 kg/cm$^2$, indicating the optimal conditions for tensile strength, while the values for 17.5 kg/cm$^2$ and 21.0 kg/cm$^2$ were 0.53 N/mm$^2$ (±0.12) and 0.61 N/mm$^2$ (±0.07), respectively, both forming subset (a).

*2) Modulus of Rupture (MOR)*

The MOR followed a similar trend. At 9 minutes, the MOR was 4.60 N/mm$^2$ (±2.05) for boards pressed at 17.5 kg/cm$^2$, forming subset (a). Increasing the pressure to 21.0 kg/cm$^2$ raised the MOR to 7.39 N/mm$^2$ (±1.42), while at 24.5 kg/cm$^2$, the MOR further increased to 8.93 N/mm$^2$ (±0.75), forming subset (c).For 12 minutes, the MOR values improved significantly, with 17.5 kg/cm$^2$ yielding 6.52 N/mm$^2$ (±2.23), 21.0 kg/cm$^2$ yielding 7.29 N/mm$^2$ (±1.07), and 24.5 kg/cm$^2$ achieving 10.28 N/mm$^2$ (±1.58), forming subset (c). At 15 minutes, the MOR reached its highest value of 11.98 N/mm² (±1.39) at 24.5 kg/cm², indicating optimal conditions for rupture strength, while the values for 17.5 kg/cm² and 21.0 kg/cm² were 7.01 N/mm² (±1.27) and 8.49 N/mm² (±2.35), respectively, both forming subset (a).

*3) Modulus of Elasticity (MOE)*

The MOE also showed significant improvements with increased pressure and Rf application time. At 9 minutes RF application times, the MOE was 523.29 N/mm² (±150.86) for boards pressed at 17.5 kg/cm², forming subset (a). Increasing the pressure to 21.0 kg/cm² raised the MOE to 783.95 N/mm² (±284.37), while at 24.5 kg/cm², the MOE further increased to 1126.20 N/mm² (±329.82), forming subset (c).For 12 minutes Rf application time, the MOE values improved, with 17.5 kg/cm² yielding 663.42 N/mm² (±156.34), 21.0 kg/cm² yielding 1347.70 N/mm² (±265.40), and 24.5 kg/cm² achieving 1772.60 N/mm² (±407.07), forming subset (c).

At 15 minutes Rf application time, the MOE reached its highest value of 2199.59 N/mm² (±248.91) at 24.5 kg/cm², indicating optimal conditions for stiffness, while the values for 17.5 kg/cm² and 21.0 kg/cm² were 656.22 N/mm² (±123.95) and 897.64 N/mm² (±272.64), respectively, both forming subset (a).

*4) Screw Withdrawal (SW)*

The screw withdrawal resistance for both face and edge orientations also improved with increased pressure and RF application time. At 9 minutes RF application time, the face SW was 1304.00 N (±188.18) for boards pressed at 17.5 kg/cm², forming subset (a), while the edge SW was 1171.80 N (±274.06). Increasing the pressure to 21.0 kg/cm² raised the face SW to 1563.30 N (±106.40) and edge SW to 1321.40 N (±118.36), forming subset (b). At 24.5 kg/cm², the face SW increased to 1674.40 N (±131.05) and edge SW to 1404.40 N (±136.04), forming subset (c).For 12 minutes RF application time, the face SW values were 1528.30 N (±255.13) at 17.5 kg/cm², 1733.30 N (±223.29) at 21.0 kg/cm², and 1990.70 N (±150.87) at 24.5 kg/cm², forming subset (c). The edge SW values were 1088.70 N (±143.89), 1338.20 N (±198.83), and 1670.40 N (±120.74) respectively. At 15 minutes RF application time, the face SW reached 2306.50 N (±242.39) at 24.5 kg/cm², while the edge SW was 2113.78 N (±165.75), indicating optimal conditions for screw withdrawal resistance.

The minimum passing values for the mechanical and physical properties of medium-density particle boards as per IS 3087:2005:

- Density range: 0.5 to 0.9 g/cm³
- Moisture content: 5 to 13%
- Water absorption after 2 hours soaking: 30% max
- Thickness swelling after 2 hours soaking: 15% max
- Modulus of rupture (MOR): 11 N/mm²
- Modulus of elasticity (MOE): 1600 N/mm²
- Tensile strength perpendicular to surface: 0.3 N/mm²
- Screw withdrawal strength: 1000 N

Based on the comparison of the measured values for the physical and mechanical properties of the medium-density particle boards with the minimum passing values specified in IS 3087:2005, the following can be concluded:

The boards pressed at 24.5 kg/cm² for 15 minutes RF application time demonstrated superior performance, achieving a moisture content of 5.32%, a density of 0.79 g/cm, and water absorption of only 21.6% after 24 hours, all of which are well within the acceptable limits set by the standard. Mechanical properties also exceeded requirements, with tensile strength (TS) reaching 0.95 N/mm², modulus of rupture (MOR) at 11.98 N/mm², and modulus of elasticity (MOE) at 2199.59 N/mm². Additionally, screw withdrawal resistance for face and edge orientations was recorded at 2306.50 N and 2113.78 N, respectively. Overall, the findings confirm that the optimized pressing conditions significantly enhance the durability and structural integrity of the composite boards, making them suitable for various applications in compliance with IS 3087.

## IV. CONCLUSION

In this study 9 boards of *Populus deltoides* were prepared with UF adhesive using RF Technology. The results shows that with increased RF application time and specific pressure results in enhanced physical and mechanical properties of particle boards, meeting the required limits as per Indian standard: 3087. Boards prepared at specific pressure 24.5 kg/cm² for 15 minutes RF application time resulted in a moisture content of 5.32%, a density of 0.79 g/cm³, and water absorption of 21.6% after 24 hours, all within the permitted limits defined by the standard. Mechanical characteristics improved significantly, with TS reaching 0.95 N/mm², MOR at 11.98 N/mm², and MOE at 2199.59 N/mm² and screw withdrawal resistance, with face SW at 2306.50 N and edge SW at 2113.78 N, The findings highlight the critical importance of specific pressure in optimizing the performance characteristics of Particle boards, giving useful insights for improving their strength, durability, and overall quality in practical applications.

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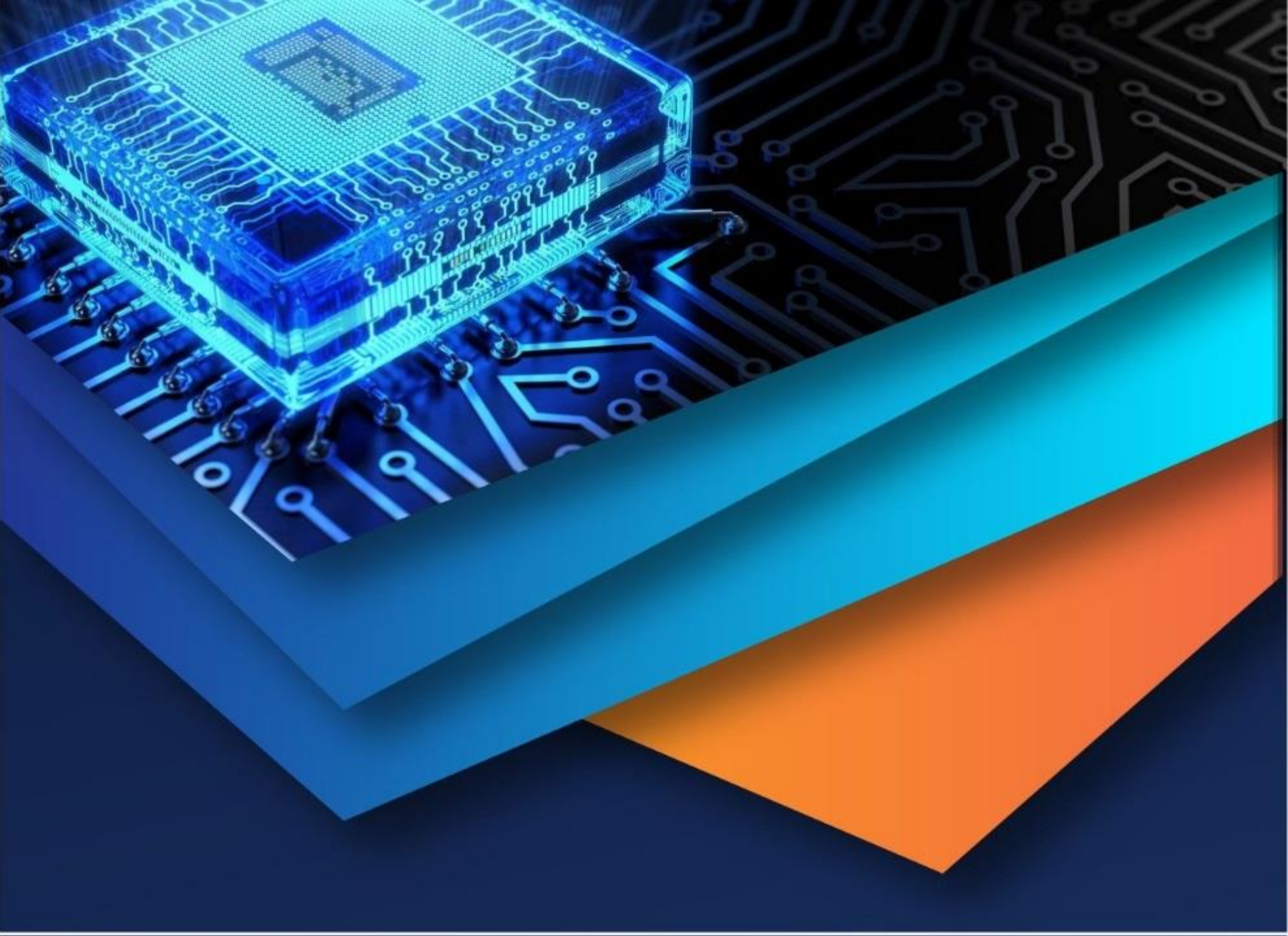


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