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The Effect of Adhesive Content on the Properties of Molded Particleboards

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Abstract **–**The type of adhesive and overlay material used in the production of molded particleboards significantly influences the product properties. This study investigates the effect of different melamine content in melamine urea-formaldehyde (MUF) adhesive on the properties of molded particleboards. Wood chips along with planer and sawdust were used as raw materials for the production of test samples. The melamine content in the MUF adhesive was varied at 16%, 18%, and 20%. The physical and technological properties of the test samples were determined to assess the impact of melamine content in the MUF adhesive. The results indicate that as the melamine content in the MUF adhesive increases, the bending and screw holding strengths of the boards also increase, while both hot and cold water resistance improve. The lowest thickness swelling values were observed with 20% melamine content, with hot water resistance at 1.48% and cold water resistance at 0.58%. The highest mechanical properties were also achieved with 20% MUF, with a bending strength of 401.55 kgf/cm² and a screw holding strength of 18.16 kgf/mm.

Keywords – Particleboard, Melamine Urea Formaldehyde, Melamine Content, Screw Holding Strengths.

I. INTRODUCTION

Wood composite boards are materials made by the processes of chipping, fiberizing, adding adhesives, molding, and pressing wood. Composite boards are made by combining two or more different materials in desired proportions under specific conditions at the macro level [1]. Compared to solid wood, particleboards offer significant advantages such as lower cost, ease of processing, and adjustable resistance properties. They are among the most widely produced wood composite boards in the world and are commonly used in furniture production, interior decoration applications, ceiling and floor coverings, and prefabricated structures [2],[3]. However, wood and wood-based panels can change dimensions depending on the relative humidity and temperature at the place of use due to their tendency to absorb and release moisture. Additionally, wood materials can exhibit defects such as warping, cracking, and buckling [4].

Three main production technologies are typically mentioned in particleboard production: flat particleboard, oriented strand board (OSB), and molded particleboard. While the production technique is the same across all methods, the differences arise from the pressing technique, layering process, or the binder used. Based on the pressing method, the boards are classified as flat or oriented strand boards, while differences in layering result in single-layer, multi-layer, and OSB. Molded particleboards are produced using special molds to achieve the final shape of the product. Depending on the size and shape of the particles, particleboards can also be named as strand particleboards or flake particleboards [5].

Synthetic thermoset amino resins such as urea-formaldehyde, melamine-formaldehyde, and phenol-formaldehyde are used as adhesives in the production of particleboards, fiberboards, plywood, and OSB. Urea-formaldehyde is preferred for its low cost and adequate performance, while melamine resin is chosen for enhancing the material's strength and resistance to moisture [6], [7]. Melamine-formaldehyde (MF) adhesives are used as binders in moisture-resistant plywood and particleboard production and are as simple to apply and effective as urea-formaldehyde (UF) adhesives, but with greater resistance to water and air conditions. However, MUF adhesive is more economical than MF, though MF adhesive is stronger in terms of water resistance [8], [9]. Additionally, MF, which can harden at temperatures between 90-140 °C without any hardening agent, is preferred in the production of wood composites that require moisture resistance [10].

Molded particleboard is a material produced by layering wood chips bonded with synthetic resins into a desired product mold, then applying heat and pressure in molding presses to form the final product. Depending on pressing conditions and overlay features, industrially produced molded particleboards are manufactured using three different methods: Werzalit, Termodin, and Collipres. These methods involve using 15% to 30% adhesives and other additives based on the oven-dry weight of the product [11], [12], [13].

Werzalit particleboards, commonly available in the market, are produced according to the final use of the product and generally have covered surfaces. These boards, produced based on the specific conditions of their intended use, are manufactured using the Werzalit method in Turkey. Products produced in this manner are typically used for concrete formwork, exterior building components, storage pallets, chair and table tops and backs, paneling, and kitchen cabinet doors [14]. Molded particleboard products are particularly evaluated for producing building components in wet environments, such as resin-coated particleboard and fiberboard, or panels covered with wood, laminate, and PVC [15].

According to the TSE 4616 (2010) standard, molded particleboards should retain their shape as they come out of the mold, without bending, warping, or splitting [16]. The overlay material should cover all surfaces and edges completely, resulting in a smooth surface without bubbles or protrusions. There should be no cracks, scratches, impact marks, dents, or holes on the surfaces and edges. Additionally, there should be no color changes on the top and side surfaces.

The aim of this study is to determine the effect of adhesive content, which significantly impacts production costs, on the properties of molded particleboards. For this purpose, the effect of melamine content in melamine urea-formaldehyde (MUF) adhesive on some properties of molded particleboards was investigated.

II. MATERIALS AND METHOD

A. *Materials*

The raw materials used in the production of molded particleboards are classified into four groups: wood material, adhesive, surface overlay papers, and additives. The production of the test boards was carried out using school desk molds available in a commercial facility. The physical and mechanical properties of the obtained test samples were determined, evaluated, and examined.

A.1. Wood Material

The wood material consisted of an average of 30% coniferous (softwood) chips, 30% deciduous (hardwood) chips, and 40% sawdust and planer shavings from forest industry residues. The molded particleboards produced in this study comprised 60% ± 5 wood chips by weight.

A.2. Adhesive

In this study, melamine urea-formaldehyde (MUF) adhesive was used as the bonding agent for the production of molded particleboards. The melamine content in the MUF adhesive was varied at 16%, 18%, and 20%. For the production of the test boards, 25% MUF adhesive was used relative to the oven-dry weight of the chips. Table 1 presents the properties of the MUF adhesive used in the production of the test samples.

Table 1. Properties of MUF adhesive

Properties	**Values**
Solution (%)	65±1
Density (gr/cm3)	1300-1350
PH (25 °C)	9.0-9.5
Viscosity (Din/cPs 22°)	750-1000
Gel time (s,100 °C)	75-82
Flow time (s,20 °C)	100-130
Free HCHO (max %)	0.05-0.07

A.3. Surface Overlay Papers

The paper used for covering the upper and lower surfaces of the test boards was commercially obtained and impregnated with various resins. The characteristics of the paper used in the production of the test materials are briefly described below:

Barrier Brown Paper: Used for the bottom surface of the test samples, with a moisture content of 7.0-7.5%, raw paper weight of 150-160 g/m², impregnated weight of 300-305 g/m², and thickness of 0.32-0.35 mm.

Thick Kraft Paper: Provides durability and hardness to the product, with a moisture content of 7.5-7.8%, raw weight of 155 g/m², impregnated weight of 295-300 g/m², and thickness of 0.28-0.30 mm.

Thin Kraft Paper: Enhances surface durability and smoothness of the molded particleboard, with a moisture content of 7.5-8.0%, raw weight of 80 g/m², impregnated weight of 155-150 g/m², and thickness of 0.25-0.27 mm.

Crepe Paper: Prevents the board from sticking to the press molds and enhances the adhesion of Kraft and other papers, contributing to surface smoothness. This paper has a moisture content of approximately 5-7%, resin-impregnated weight of 70-80 g/m², and thickness of 0.12 mm.

Decorative Paper: Made from alpha cellulose and provides color and pattern on the product's top surface. The decorative papers used in this study have a moisture content of 5.5-6.0%, raw weight of 70-80 g/m², impregnated weight of 170-180 g/m², and thickness of 0.15-0.20 mm.

A.4. Additives

As the MUF adhesive used in this study contains melamine, no extra hydrophobic material was needed. Only a 1% ammonium chloride solution (20%) relative to the oven-dry adhesive weight was used as a hardener.

B. Method

The test examples were made using school desk molds measuring 45x110 cm and 20 mm thick. The wood chips were dried to a moisture level of 1-3% and screened to remove any undesired fine or coarse particles. After the adhesive application, the chips were weighed and manually spread into the mold considering the desired density and thickness factors. Initially, the mold was cold pressed at 150 bar for 4 minutes, then hot pressed in two stages. In the first stage, the molded product was placed under barrier brown paper on the bottom and crepe paper on the top and hot pressed for approximately 5 minutes at 160-170°C and 150 bar pressure. Before the second stage of hot pressing, a layer of 150 g/m² thin kraft paper, two layers of 300 g/m² thick kraft paper, and one layer of 80 g/m² decorative paper were placed on the top surface of the board. The prepared mold was then hot pressed at 170-180°C and 150 bar for 6 minutes in the second stage. To prevent defects such as warping and undulations, the produced boards were allowed to cool under pressure. The cooling process took approximately 20-30 minutes, depending on the product dimensions. Afterward, the test boards were sanded and conditioned to reach equilibrium moisture content. The properties of the produced test boards were determined according to the standards specified in Table 2.

Table 2. Standards used in determining board properties

TS 4616 (2010)	Particle Boards- Mould pressed and coated elements [16]
TS EN 326-1 (1999)	Wood- Based panels- Sampling, cutting and inspection- Part 1: Sampling test pieces and expression of test results [17]
TS EN 325 (2012).	Determination of dimensions of test pieces [18]
TS EN 317 (1999)	Particleboards and fibreboards- Determination of swelling in thickness after immersion in water [19]
TS EN 320 (2011)	Determination of resistance to axial withdrawal of screws [20]
TS EN 310 (1999)	Wood- Based panels- Determination of modulus of elasticity in bending and of bending strength [21]
TS EN 1097-10 (2014)	Tests for mechanical and physical properties of aggregates - Part 10: Determination of water suction height [22]
TS EN 14323 (2021)	Wood-based panels - Melamine faced boards for interior uses - Test methods [23]
TS EN 12722+A1 (2014)	Furniture - Assessment of surface resistance to dry heat [24]

III. RESULTS AND DISCUSSION

In this study, the effects of different MUF ratios on the some properties of particleboards were examined. The average densities and standard deviation values of the molded particleboard groups are given in Table 3.

Table 3. Average density of the particleboards.

Board Groups		Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Density (g/cm^3)
%16 MUF	X	49.95	50.10	16.46	35.73	0.86
	Sd	0.16	0.15	0.13	0.11	0.03
%18 MUF	X	50.25	50.08	16.45	35.60	0.86
	Sd	0.12	0.10	0.32	0.13	0.01
%20 MUF	X	50.05	49.90	16.64	35.64	0.85
	Sd	0.15	0.11	0.31	0.17	0.01

Sd: Standard deviation, X: Average value

This study investigated the physical properties of molded particleboards with varying contents of melamine-urea-formaldehyde (MUF) adhesive. The density results showed minimal variation across different MUF levels, with values of 0.86 g/cm^3 for 16% and 18% MUF, and 0.85 g/cm^3 for 20% MUF. This consistency in density suggests that the manufacturing process maintained uniformity irrespective of the MUF content.

The average 6-hour (hot water) and 24-hour thickness swelling values and standard deviation values of the molded particleboards groups are given in Table 4.

Table 4. Average thickness swelling of the particleboards

Board Groups		Thickness swelling in hot water (6 h) (%)	Thickness swelling (24 h) (%)
%16 MUF	X	7.21	2.71
	Sd	0.18	0.18
%18 MUF	X	3.97	1.3
	Sd	0.60	0.31
%20 MUF	X	1.48	0.58
	Sd	0.33	0.47

Sd: Standard deviation, X: Average value

Thickness swelling tests conducted over 6 hours (hot water) and 24 hours revealed significant improvements with higher MUF content. Specifically, 20% MUF resulted in the lowest swelling values of 1.48% (6 hours) and 0.58% (24 hours). These results are similar with Hse, Fu, and Pan (2008), who reported that adding melamine to urea-formaldehyde adhesives enhances water resistance [25]. Also, this improvement can be attributed to the increased cross-linking density provided by melamine, which reduces the ability of water to penetrate and swell the board. In different studies, it is stated that the addition of melamine into urea formaldehyde glue (UF) increases the resistance to water [26], [27].

Average water absorption height values (24 hours) of molded particleboards groups are given in Table 5. According to Table 5, it is seen that there is an improvement in water absorption values with increasing MUF use.

Table 5 Average water absorption value of the particleboards

Board Groups		Water absorption (24 h) (cm)
%16 MUF	X	2.69
	Sd	0.26
%18 MUF	X	2.20
	Sd	0.33
%20 MUF	X	1.50
	Sd	0.25

Sd: Standard deviation, X: Average value

Water absorption tests over 24 hours showed a clear decrease in absorption with increased MUF content, from 2.69 cm for 16% MUF to 1.50 cm for 20% MUF. These results comply with TS 4616 standards, which require water absorption to be ≤ 3 cm. This reduction in water absorption is critical for the longevity and durability of particleboards in humid environments. Previous studies by Zhou et al. (2014) and Young No & Kim (2007) support these findings, demonstrating that higher adhesive content and improved adhesive formulations can significantly enhance water resistance in particleboards [28], [29].

The resistance qualities of the boards against fading, staining, hot pots, water vapor, and cigarette fire were examined in order to assess the surface performance of molded particleboard groups. The results are given in Table 6.

Table 6. Surface performance of the particleboards

Test	%16 MUF	%18 MUF	%20 MUF
Resistant to water vapor	Spotless	Spotless	Spotless
Stand against cigarette fire.	Spotless	Spotless	Spotless
Resistant to fading.	Spotless	Spotless	Spotless
Resistant to staining.	Spotless	Spotless	Spotless
Resistant to hot containers.	Spotless	Spotless	Spotless

Surface performance tests, including resistance to water vapor, cigarette burns, fading, staining, and hot objects, indicated that all MUF levels met the TS 4616 standard, showing no significant defects. This consistent performance across different MUF contents highlights the effectiveness of MUF adhesives in maintaining surface integrity and resistance to common household hazards.

The average bending strength and standard deviation values of molded particleboard groups are given in Table 7.

Table 7. Average bending strength value of the particleboards

Board Groups		Bending strength (kgf/cm^2)
%16 MUF	X	346.62
	Sd	5.36
%18 MUF	X	368.59
	Sd	7.25
%20 MUF	X	401.55
	Sd	10.23

Sd: Standard deviation, X: Average value

The bending strength of the boards increased linearly with higher MUF content, from 346.62 kgf/cm² for 16% MUF to 401.55 kgf/cm² for 20% MUF, surpassing the TS 4616 minimum requirement of 200 kgf/cm². This trend is supported by studies from Hse et al., (2008) and Zanetti and Pizzi (2003), which suggest that higher adhesive content enhances mechanical properties. The increase in bending strength can be attributed to the improved bonding and rigidity provided by higher levels of MUF, which enhances the load-bearing capacity of the boards [25], [30].

The average screw holding resistance and standard deviation values of molded particleboard groups are given in Table 8.

Table 8: Average screw holding strength value of the particleboards

Board Groups		**Screw holding strength (kgf/mm)**
%16 MUF	X	15.30
	Sd	3.20
%18 MUF	X	16.88
	Sd	2.15
%20 MUF	X	18.16
	Sd	2.20

Sd: Standard deviation, X: Average value

Screw holding strength also improved with increased MUF content, from 15.30 kgf/mm for 16% MUF to 18.16 kgf/mm for 20% MUF meeting the TS 4616 standard of minimum 15 kgf/mm. This improvement is likely due to the increased density and adhesive content, which enhance the board's ability to hold screws securely. Studies by No & Kim (2007) and Zhou et al. (2014) have also indicated that increased adhesive content and board density positively impact screw holding strength, providing additional support for these findings [28], [29]. It is stated that there is a linear interaction between density change and screw holding strength [31].

The increasing MUF adhesive content in molded particleboards significantly improves their physical properties; including thickness swelling, water absorption, bending strength, and screw holding strength. These improvements are consistent with findings from existing literature, confirming that melamine addition to urea-formaldehyde adhesives enhances water resistance and mechanical performance. The study's results highlight the importance of optimizing adhesive content to achieve superior quality in particleboards. By comparing these results with previous studies, it is evident that higher MUF content contributes to better overall performance, making these particleboards more suitable for demanding applications.

IV. CONCLUSION

Molded particleboards, especially those intended for outdoor use, are produced using adhesives with high moisture resistance to ensure better physical and mechanical properties. The aim is to make the product durable under extreme conditions. This study investigates the effect of different MUF (melamine urea-formaldehyde) adhesive ratios on some critical physical and mechanical properties of molded particleboards.

The density values of the molded particleboards meet the TS 4616 standard requirement for indoor use, which is 0.70 g/cm³. The thickness swelling results for all MUF adhesive ratios were within the TS 4616 standard requirements for both 6 hours (≤12%) and 24 hours (≤5%). The water absorption height values of the test samples also met the TS 4616 standard requirement of ≤3 cm for all board groups.

Surface performance tests, including resistance to water vapor, cigarette burns, fading, staining, and hot objects, showed that all MUF adhesive ratios used in the study were sufficient. The bending strength and screw holding strength of the test boards at all MUF adhesive ratios met the minimum requirements of 200 kgf/cm² and ≥15 kgf/mm, respectively, as specified by the TS 4616 standard.

In conclusion, considering the conditions at the point of use, service life, and cost, determining the optimal adhesive usage ratio in the production of molded particleboards will provide benefits in terms of economy, human health, and environmental protection.

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