The Effect of Mat Layers Moisture Content on Some Properties of Particleboard

Abdullah Istek1, Ufuk Aydin2, Ismail Ozlusoylu1

ABSTRACT • In this study, the effect of mat moisture content on the physical and mechanical properties of particleboard was investigated. The experimental boards were produced by using 40 % softwood, 45 % hardwood chips, and 15 % sawdust. The formaldehyde resin/adhesive was used in three-layers (bottom-top layer 12 %, core layer 8 %). Multi-opening press was used during manufacturing the experimental particleboards. The physical and mechanical properties of boards obtained were identified according to the TS-EN standards. The optimum core layer moisture content was determined as 6 % and 7 % according to the results, whereas the moisture content of bottom and top layers was 14 %. Under these moisture content conditions, the bending strength was found to be 13.3 N/mm², the modulus of elasticity in bending 2466 N/mm², and internal bonding strength 0.44 N/mm². The optimum bottom-top layer moisture content was determined to be between 13 % and 15 % and 6.5 % for the core layer.

Keywords: wood-based panels; particleboard; mat moisture content; properties

1 INTRODUCTION

Particleboards (PB) are manufactured under heat and pressure of mat obtained from wood particles or other lignocellulosic material in particle with the addition of an adhesive. PB properties can be changed with some factors such as adhesive bonding, particle geometry, resin type and density variations due to random particle deposition during mat forming (Sanabria et al., 2013; Istek et al., 2010). The most important factors...
affecting the properties of board at the stage of pressing are the mat moisture, temperature, specific press pressure, press closing speed, and pressing duration. In a previous study, it was determined that, at 11 % mat moisture and mat thickness increased from 20 mm to 40 mm, the duration of core layer temperature increase to 100 °C was prolonged by 4 times (Hata, 1993). It was reported that the mat moisture content plays an important role in properties of MDF produced using phenol formaldehyde (FF) resin, and that the mean characteristics achieved at 12 % mat moisture content were found to be better than those obtained at 6 % and 9 % mat moistures (Chow and Zhao, 1992). The mat moisture contents higher than the limit were reported to cause bursting risk in PB production, while the lower contents caused brittle fracture following the pressing (Bardak, 2010; Kollmann et al., 1975). It was reported that moist PB mat is plasticized under the effects of temperature and pressure in pressing, which results in a stable structure (Güler and Sanca, 2016; Sedano-Mendoza et. al., 2010). The moisture of mat PB before the hot pressing is one of the most important factors affecting the heat transfer within mat, as well as the properties of PB (Park et al., 1999).

In PB production, the mean mat moisture is calculated by taking the particle concentration and core layer moisture into consideration since the surface layers and core layer have different moisture contents. The mat moisture plays a significant role in the surface smoothness and soundness of PB, the bubbling on surface during the pressing, and the production costs. In case of too low moisture in particles, the resin is absorbed by the particles and there may be insufficient resin in the medium for the required adhesion level (Lynam, 1969; Akbulut, 1998). In this case, no sufficient bond can be established on the surface layers of boards, and the board surface becomes loose and weak. High moisture content, on the other hand, may cause the burst of board after the pressing procedure (Lynam, 1969). During the board production, the water is sometimes sprayed on the mat surfaces in order to shorten the pressing time, to eliminate the pre-hardening, and to improve the surface structure (Kollmann et al., 1975). If the mat contained too much moisture, the board would contain visible and open vapor bubbles. As a result of that, the parallel shear resistance of surface decreases, and the moisture content of board increases. In order to prevent or minimize such results, longer pressing is required (Lynam, 1969). It was reported that, prior to the pressing procedure, if the mean mat moisture is higher than 15-16 %, the moisture cannot be vaporized sufficiently by using a short pressing time for the boards with the density of 0.65 gr/cm³ and, in addition to insufficient vaporization, the board will also burst from the core layer (Huş, 1979). In another study, it was emphasized that the high level of mat moisture content during the hot pressing procedure increased the formaldehyde emission (Kollman et. al., 1975; Roffael, 1982). Nemli et al. (2007) reported that, in PB production, the mat moisture contents higher than 13 % caused lower technological properties in boards. In another study, it was found that the mat moisture content in MDF board production plays an important role in internal bond strength (IB) and thickness (Hague et al., 1999).

The aim of this study was to investigate the effects of mat moisture content on the physical and mechanical properties of PB, and to determine the ideal mat moisture content for 3-layered PB production. The ultimate aim was to increase the production quality and to decrease the costs.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The experimental boards used in this study were produced in a company’s production line in Kastamonu, Turkey. All of the production parameters used in manufacturing the experimental boards are the same as those used in company’s products; the materials consist of 40 % black pine (Pinus nigra), 30 % sessile oak (Quercus petraea), 15 % poplar (Populus alba), and 15 % sawdust (90 % pine-10 % poplar). Particles were dried at 170 °C by using rotary drum dryer to reach the target moisture content (MC) at 1 % – 2 %. Urea formaldehyde (UF), which was used as adhesive, consists of (62 ± 1) % solid matter and its pH is 8.2 pH. This material was also produced in the same facility. As a hardener, 20 % ammonium chloride (NH₄Cl) solution was used based on 2.5 % of resin solid weight for the core layers and 1 % of resin solid weight for the surface layers. The experimental boards were produced in multi-opening press, and mat moisture contents are presented in Table 1, while the production conditions are specified in Table 2.

In determining the physical and mechanical properties of experimental boards, the Turkish standards that are compatible with European norms were used, and the results are presented in Table 3.

Table 1: Mat moisture content of experimental boards

| Board type | Board replications | Mat moisture content, % | Sadržaj vode, % |
|-----------|-------------------|------------------------|-----------------|
| A         | 3                 | 5.5                    | 14              |
| B         | 3                 | 6                      | 14              |
| C         | 3                 | 6.5                    | 14              |
| D         | 3                 | 7                      | 14              |
| E         | 3                 | 7.5                    | 14              |
| F         | 3                 | 8                      | 14              |
| G         | 3                 | 6.5                    | 12              |
| H         | 3                 | 6.5                    | 13              |
| I         | 3                 | 6.5                    | 14              |
| J         | 3                 | 6.5                    | 15              |
| K         | 3                 | 6.5                    | 16              |
| L         | 3                 | 6.5                    | 17              |
The effects of moisture content changes on the physical and mechanical properties were determined by keeping the mat moisture content of core layer at 6.5 % and by applying various moisture contents of bottom-top layers, and keeping the bottom-top layer moisture at 14 % and applying various moisture contents of core layer. The results are shown in Table 4.

When the mat moisture content of bottom-top and core layers was fixed at 14 % and 8 %, respectively, it was observed that the board generally burst at the end of hot press. Similarly, when the mat moisture of core layer was kept constant at 6.5 % and mat moisture contents of bottom-top layer were adjusted at 17 %, some of the boards burst when leaving the hot press in test production.

The densities of experimental boards were observed to vary between 600 and 609 kg/m³, and the density differences between the boards were at negligibly low levels. It was reported that the boards with density differences less than 10 % (TS EN 312) would exhibit similar mechanical properties and remain within the same group of boards (Istek and Siradağ, 2013).

The effects of mat moisture content changes in particleboard production on the water absorption and swelling properties are presented in Figures 1 and 2. As shown in Figure 1, as the top and bottom surface mat moisture contents increased from 12 % to 15 %, the water absorption characteristics of particleboards improved and increased again at 16 and 17 %.
moisture contents. As the mat moisture contents of core layer increased from 5.5 % to 7 %, the water absorption decreased and then increased again to 7.5 – 8 % moisture content level. The moisture content of the glued particle board sample should never exceed 10 – 12 % moisture content level. The moisture content of the core layer increased from 5.5 % to 7 %, the water absorption started to decrease after 7 % moisture content increased from 13 % to 17 %, the thickness swelling was negatively affected (Nemli et al., 2007). The effects of mat moisture changes in particleboard production on IB are presented in Figure 3.

Figure 3 indicated that, together with the increase of core layers mat moisture from 5.5 % to 6.5 %, it was determined that the IB strength of particleboard increased and started to decrease after 7 % moisture content.

### Table 4 Effects of mat moisture changes on particleboard properties

| Moisture value Sadržaj vode, % | Density Gustoća kg/m³ | Water absorption (2h) Upojnost vode (2h), % | Thickness swelling (2h) Debljiinsko bubrenje (2h), % | Internal bonding strength Čvrstoća raslojavanja N/mm² | Bending strength Čvrstoća pri savijanju N/mm² | Modulus of elasticity in bending Modul elastičnosti pri savijanju N/mm² | Screw withdrawal Otpor vijaka vijaka N/mm² | Surface soundness Meduslojna čvrstoća N/mm² |
|--------------------------------|------------------------|-------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 5.5                            | 603 (4.58)              | 83.23 (1.66)                              | 14.20 (0.17)                                  | 0.34 (0.02)                                    | 0.28 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.94 (0.03)                                   |
| 6                              | 607 (2.65)              | 80.97 (0.25)                              | 13.23 (0.25)                                  | 0.39 (0.02)                                    | 0.28 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.13 (0.02)                                   |
| 6.5                            | 605 (1.15)              | 76.53 (1.14)                              | 12.37 (0.12)                                  | 0.44 (0.01)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.94 (0.04)                                   |
| 7                              | 602 (2.52)              | 69.67 (1.53)                              | 11.87 (0.15)                                  | 0.39 (0.03)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.94 (0.04)                                   |
| 7.5                            | 609 (2.65)              | 79.01 (2)                                | 13.4 (0.53)                                   | 0.26 (0.02)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.94 (0.04)                                   |
| 8                              | 201 (5.1)               | 29.33 (5.1)                               | 5.17 (0.53)                                   | 0.04 (0.02)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.1 (0.03)                                   |
| 12                             | 602 (3)                 | 81.47 (1.10)                              | 13.03 (0.06)                                  | 0.35 (0.02)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.94 (0.04)                                   |
| 13                             | 608 (5.51)              | 80.20 (0.20)                              | 12.80 (0.10)                                  | 0.38 (0.02)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.1 (0.04)                                   |
| 14                             | 605 (4.73)              | 76.60 (0.53)                              | 12.43 (0.06)                                  | 0.41 (0.01)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.1 (0.03)                                   |
| 15                             | 605 (3)                 | 73.27 (0.64)                              | 12.10 (0.10)                                  | 0.38 (0.01)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.1 (0.02)                                   |
| 16                             | 600 (2.52)              | 78.80 (0.80)                              | 12.73 (0.25)                                  | 0.35 (0.01)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 1.03 (0.02)                                   |
| 17                             | 402 (47.83)             | 55.90 (1.5)                               | 9.50 (0.15)                                   | 0.17 (0.03)                                    | 0.32 (0.09)                                   | 0.94 (0.03)                                                                                                      | 0.55 (0.48)                                   |

The values in parentheses indicate the standard deviation. / Vrijednosti u zagрадama standardne devijacije.

Figure 2 The effects of mat layers moisture content changes on thickness swelling (2h) characteristics

Slika 2. Utjecaj promjene sadržaja vode u slojevima ploče na debljiinsko bubrenje (2h)
tent. Given the effect of mat moisture content change of bottom-top layer, the highest level of IB strength was observed to be 0.41 N/mm² at 14 % mat moisture content. According to TS-EN 312-1 (2012), P2-class 18 mm particleboards should have IB strength ≥ 0.35 N/mm². From this aspect, the highest level of IB strength was obtained at 6.5 % mat moisture for core layer and 14 % mat moisture for bottom-top layer.

High level of moisture content at surface layers and low moisture content at core layer ensure soundness of surfaces and the increase in bending strength (BS) and MOE values, as well as the decrease in IB strength (Maloney, 1977). Moreover, with the increase of surface layers moisture from 12 % to 20 % and core layer moisture from 8 % to 10 %, the IB strength increased by 10 % (Bardak, 2010; Kollmann et al., 1975). The effects of mat moisture changes in particleboard production on BS are presented in Figure 4.

With the increase of mat moisture content from 5.5 % to 6.5 % in core layer, as seen in Figure 4 the BS of particleboard increased, while the BS decreased at 7 % and 8 % moisture contents. Besides that, with the increase of mat moisture contents from 12 % to 16 %, the BS was seen to increase, while it decreased at 17 %. The increase of surface layers moisture to a certain content causes the increase in surface density, hydrogen bonds, and formation of sounder surface structure.

However, the decreasing MOE strength at moisture contents equal to and higher than 17 % can be explained with the non-removability of vapor from internal segments, as well as the absence of complete condensation. Nemli et al. (2007) reported that the BS values obtained at mean mat moisture of 17 % was lower than the value obtained at 9 % and 13 % mat moisture contents in particleboards. This was explained with the damage of resin bonds on the surface layers under the effects of vapor bubbles and hot pressure (Lynam, 1969; Johnson, 1956). In a study carried out by Hus (1979), it was reported that the total moisture of mat higher than 15 – 16 % before the pressing procedure increased the surface density, decreased the strength values, and caused the burst of board. The effects of mat moisture changes in particleboard production on modulus of MOE are presented in Figure 5. When the mat moisture content of top and bottom layer was between 18 % and 20 %, the maximum strength was achieved and the moisture exhibited the plasticizing effect (Bardak, 2010).

As seen in Figure 5, the MOE increased with the increase in mat moisture content of bottom-top layer from 12 % to 14 %, whereas it decreased together with the moisture content exceeding 15 %. Nemli et al. (2007) emphasized that the increase of mean mat moisture content of particleboards from 9 % to 13 % posi-
tively affected the MOE. According to TS-EN 312-1 (2012), the modulus of elasticity (MOE) of P2 class 18 mm particleboards should be \( \geq 1600 \text{ N/mm}^2 \). Similarly, with the increase of core layer moisture from 5.5 % to 6.5 %, MOE of particleboards increased and then decreased at 7.0 % and 8.0 % moisture contents. When the moisture content exceeded 8.0 %, some of the particleboards were observed to be not formed. The effects of mat moisture changes on the screw withdrawal are presented in Figure 6.

In case of high moisture in surface layers and low moisture in core layer, the surface layers are compressed more than core layer, and thus the BS and MOE levels increase in comparison to the uniform moisture samples, whereas the IB decreases. For this reason, the mean mat moisture content should be maintained within the acceptable limits in order to prevent the burst of boards after the pressing process (Maloney, 1977).

Under the production conditions of 8 % and 17 % core and bottom-top layer moisture contents, respectively, it was determined that the screw withdrawal characteristics do not meet the standard set in TS-EN 312-1 (2012) – the screw withdrawal of P2 class 18mm particleboards should be \( \geq 450 \text{ N/mm}^2 \) – but they meet the standards at other moisture contents. The highest

![Figure 5](image1.png)  
**Figure 5** The effects of mat layers moisture changes on modulus of elasticity in bending

![Figure 6](image2.png)  
**Figure 6** The effects of mat layers moisture changes on screw withdrawal

![Figure 7](image3.png)  
**Figure 7** The effects of mat layers moisture changes on the surface soundness
level of screw withdrawal was observed at 6.5 % core layer moisture and 14 % bottom-top layer moisture as 630 N/mm² and 633 N/mm², respectively. It was reported that the mat moisture content change and the press closure speed have no statistically significant effect on the screw withdrawal (Wong et al., 1998). The effects of mat moisture changes on the surface soundness values are presented in Figure 7.

Under the production conditions of 8 % and 17 % core and bottom-top layer moisture contents, respectively, it was determined that the surface soundness level did not meet the TS-EN 312-1 (2012) quality control standards (≥ 0.8 N/mm² for P2 class 18 mm particleboard), but they meet the standards at other moisture contents. The highest level of surface soundness value was observed to be 1.13 N/mm² at 6 % core layer moisture and 15 % bottom-top layer moisture.

4 CONCLUSIONS

4. ZAKLJUČAK

Today, the particleboards of desired quality properties can be produced by means of technology and additives used in wood-based board production. In this study, carried out in order to contribute to the production of particleboard under the production principle “low-cost and high-quality”, the appropriate mat moisture contents were determined and the particleboard characteristics were expressed. Accordingly;

It was determined that the change of mat moisture content does not affect the density of boards.

It was reported that the production of particleboard is not possible in case of glued core layer moisture of 8 % and above and glued bottom-top layers moisture content of 17 % and above.

The water absorption and thickness swelling values of experimental boards reach at optimum moisture contents between 6 – 7 % in core layer. However, if the core layer moisture content exceeds 7 %, the IB, water absorption, and thickness swelling were observed to be negatively affected.

The optimum water absorption and thickness swelling values were observed at 12 – 16 % bottom-top layer moisture contents, while negative effects were observed on the IB strength and thickness swelling at contents higher than 16 %.

The highest level of BS was found to be 13.13 N/mm² under the circumstances of 6.5 % core layer moisture and it was found to be 12.93 N/mm² at 16 % bottom-top layer moisture.

Optimum MOE was found to be around 2300-2400 N/mm² under the condition of 6 – 6.5 % core layer moisture and 14 – 15 % bottom-top layer moisture.

The acceptable level of IB strength was determined to be 0.42 – 0.44 N/mm² at 6.5 % core layer moisture and 14 % bottom-top layer moisture. It was determined that the results obtained at 6 – 6.5 % core layer moisture and 12 – 16 % bottom-top layer moisture meet the quality standards of TS-EN 312-1 (2012).

The optimum level of screw withdrawal strength was found to be 620 N/mm² at 6 – 7 % core layer moisture contents. The interval between 12 % and 16 % top and bottom layer moisture contents were identified as a suitable range for screw withdrawal.

The 12 – 15 % top and bottom layer and 6 – 6.5 % core layer moisture contents were obtained as suitable range for surface soundness.

It was determined that the production of particleboard was not possible at ≥ 8 % core layer moisture and ≥ 17 % bottom-top layer moisture contents under the production conditions in this study. According to these findings, the ideal production conditions for particleboard quality were found to be 6 – 7 % core layer moisture content and 13 – 16 % bottom-top layer, when other production parameters were kept constant. Besides that, in case of ≥ 8 % core layer moisture and ≥ 17 % bottom-top layer moisture contents, it was determined that the board would burst and that quality standards could not be met during the pressing process of particleboard production.

5 REFERENCES

5. LITERATURA

1. Akbulut, T., 1998: The Effect of Formaldehyde/Urea Mole Ratio and Mat Moisture Content on Some Properties of Particleboards. Review of the Faculty of Forestry, University of Istanbul, 48(2): 23-38.

2. Bardak, S., 2010: Bazı Faktörlerin Yonalevhanın Teknolojik Özellikleri Üzerine Etkileri (The Effects of Some Factors on the Technological Properties of Particleboard.). III. Ulusal Karadeniz Ormancılık Kongresi (III. National Black Sea Forestry Congress), vol. V: 1887-1898.

3. Chow, P.; Zhao, L., 1992: Medium-density fiberboard made from phenolic resin and wood residues of mixed species. Forest Products Journal, 42 (10): 65-67.

4. Güler, C.; Sancar, S., 2016: The Principle of a Particle Board Plant and The Effect of Pressing Techniques on Board Quality. Düzce University Journal of Forestry, 12 (1): 1-10.

5. Hague, J.; Robson, D.; Riepen, M., 1999: MDF process variables – An overview of their relative importance. In: Proc. of the 33th Inter. Particleboard/Composite Material Symp. T. M. Maloney (ed.). Washington State Univ., Pullman, WA.

6. Hata, T., 1993: Heat Flow in Particle Mat and Properties of Particleboard Under Steam Injection Pressing. Bull. For. and For. Prod. Res. Inst., No. 80. Japan. https://doi.org/10.11501/3070413.

7. Huş, S., 1979. Teknolojik Faktörlerin Yonalevhanın Özellikleri Üzerine Etkisi (The Effect of Technological Factors on the Properties of Particleboard). Review of the Faculty Forestry University of Istanbul, Series B, 29 (2): 1-9.

8. İstek A.; Siradag, H., 2013: The Effect of Density on Particleboard Properties. International Caucasian Forestry Symposium, 932-938. (Edition No. 251261).

9. İstek, A.; Aydemir, D.; Aksu, S., 2010: The effect of décor paper and resin type on the physical, mechanical, and surface quality properties of particleboards coated with impregnated décor papers. BioResources, 5 (2): 1074-1083.

10. Johnson, E. C., 1956: Wood particleboard handbook. The industrial experimental program of the engineering. Raleigh (NC): North Coralina State College.
11. Kollmann, F.; Kuenzi, E. W.; Stam, A. S., 1975: Principles of Wood Science and Technology. Springer Verlag, Berlin, Heidelberg, New York.
12. Lynam, F. C. 1969: Factors influencing the properties of wood chipboard. In: Mitlin L. (ed.). Particleboard manufacture and applications. UK: Press media Books Ltd.
13. Maloney, T. M., 1977: Modern Particleboard and Dry-Process Fiberboard Manufacturing. Miller Freeman Publications, San Francisco-California.
14. Nemli, G.; Aydin, I.; Zeković, E., 2007: Evaluation of some of the properties of particleboard as function of manufacturing parameters. Materials and design, 28 (4): 1169-1176. https://doi.org/10.1016/j.matdes.2006.01.015.
15. Park, B. D.; Riedl, B.; Hsu, E. W.; Shields, J., 1999: Hot-pressing process optimization by response surface methodology. Forest Products Journal, 49 (5): 62-68.
16. RoffaeL, E., 1982: Formaldehydehagabe von Spanplatten und anderen Werkstoffen. DRW Verlag, Stuttgart.
17. Sanabria, S. J.; Hilbers, U.; Neuenschwander, J.; Niemz, P.; Sennhauser, U.; Thömen, H.; Wenker, J. L., 2013: Modeling and prediction of density distribution and micro-structure in particleboards from acoustic properties by correlation of non-contact high-resolution pulsed air-coupled ultrasound and X-ray images. Ultrasonics, 53 (1): 157-170. https://doi.org/10.1016/j.ultras.2012.05.004.
18. Sedano-Mendoza, M.; Navarrete, P.; Pizzi, A., 2010: Effect of layers’ relative moisture content on the IB strength of pine tannin bonded particleboard. European Journal of Wood and Wood Products, 68 (3): 355-357. https://doi.org/10.1007/s00107-010-0452-8.
19. Wong, E. D.; Zhang, M.; Wang, Q.; Kawai, S., 1998: Effects of mat moisture content and press closing speed on the formation of density profile and properties of particleboard. Journal of Wood Science, 44 (4): 287-295. https://doi.org/10.1007/BF00581309.
20. ***TS EN 310, 1999 Wood – Based panels – Determination of modulus of elasticity in bending and of bending strength.
21. ***TS EN 311, 2005: Wood-based panels – Surface soundness – Test method.
22. ***TS EN 312, 2012: Particleboards – Specification.
23. ***TS EN 317, 1999: Particleboards and fibreboards – Determination of swelling in thickness after immersion in water.
24. ***TS EN 319, 1999: Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board.
25. ***TS EN 320, 2011: Particleboards and fibreboards – Determination of resistance to axial withdrawal of screws.
26. ***TS EN 323, 1999: Wood – Based panels – Determination of density.
27. ***TS EN 326-1, 1999: Wood – Based panels – Sampling, cutting and inspection, Part 1: Sampling test pieces and expression of test results.

Corresponding address:

Prof. Dr. ABDULLAH İSTEK
Bartın University, Faculty of Forestry
Department of Forest Industrial Engineering
74100 Bartın, TURKEY
e-mail: aistek@bartin.edu.tr