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EFFECT OF CHIP TEMPERATURE DURING BONDING ON PARTICLEBOARD PROPERTIES

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ABSTRACT

In the production of particleboard, the chips emerging from the drying oven usually pass into the bonding process without sufficiently cooling down. Moreover, along with the effect of friction during the bonding process, the increased chip temperature boosts the consumption of resin/adhesive and affects the properties of the board. This study investigated the effect of chip temperature during the bonding process on the properties of particleboard. With this aim, the effects were determined for six different temperatures (25 °C, 30 °C, 35 °C, 40 °C, 50 °C, 55 °C) measured during the bonding of the chips. According to the results, optimum board properties were obtained from the groups in which the chip temperature measured during the bonding process was 30 °C - 40 °C. Furthermore, it was determined that chip temperatures of above 40 °C during the bonding process significantly reduced the mechanical properties.

Keywords: Chip temperature, mechanical properties, particleboard, urea formaldehyde resin, wood-based panels.

INTRODUCTION

Wood-based composite boards are widely used in different areas of use today. Especially MDF and particle board stand out with their high-volume production among other board products. Although there has been a slight decrease in the amount of production due to factors such as economic fluctuations and pandemics in recent years, the production amounts of these products increase every year (Barbu and Steinwender 2009, Antov *et al.* 2020, FAOSTAT 2022.) Particleboard is a material that is widely used in many fields today. It is produced by pressing wood chips and other lignocellulosic raw materials together with an adhesive under temperature and pressure (Kalaycıoğlu and Özen 2009, İstek *et al.* 2017, İstek *et al.* 2019). Particleboards are produced from chips, as they provide a homogeneous distribution of mechanical properties at all panel points. Although the functional properties of particleboards are generally worse than solid wood, the panels can be modified, and the desired quality can be achieved by controlling the production process (Pedzik *et al.* 2021).

Factors such as raw material type, chip size and geometry, amount and type of adhesive, mat moisture, board density, and the pressing conditions used in particleboard production affect board quality and production costs (Nemli and Demirel 2007, Hassan *et al.* 2009, İstek *et al.* 2010, Sanabria *et al.* 2013, İstek and Sıradağ 2013, Mantanis *et al*. 2018). In particleboard production, the chip geometry and moisture of the chip used have been reported as being among the main factors affecting the properties of the boards (Frybort *et al.* 2008, Aydın 2016). As the chip size decreases, the particleboard surface properties have been found to improve, their

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dimensional changes to increase, and their strength properties to decrease (Atta-Obeng *et al.* 2012, Kehr 1966). The properties of boards produced from two different sizes of chips (1 mm and 2 mm) were compared and it was determined that the 2-mm chips yielded better physical and mechanical properties (Lias *et al.* 2014). It has been reported that in particleboard production, when the chip moisture in the outer layer is higher than that of the middle layer, board properties are improved and the surface smoothness enhanced (Nemli *et al.* 2006). Increasing the outer layer thickness in particleboard production not only increases the surface smoothness of the particleboards but also improves the physical and mechanical properties (Akbulut 1995). It has been emphasized that, in the production of particleboards, as the chips used in the surface layers become smaller, the number of chips per unit area increases, resulting in smoother surfaced boards and higher surface density (Wong *et al.* 1998, İstek *et al.* 2013).

In the production of wood-based composites, the type and amount of the binder and the internal bond strength directly affect the properties of the final product. Studies have been carried out on a number of factors that may affect board properties such as drying temperature, chip properties, different pressing conditions, etc. (Onuorah 2001, Cai *et al.* 2004, Kakaras and Papadopoulos 2004, Sarı *et al.* 2013, Cheng *et al*. 2016, Papadopoulos 2020). However, no study has dealt with the effect of chip temperature during bonding on board properties. In particleboard production, the chips are dried to a moisture content of 1 % - 2 % and generally, the bonding process is carried out before the chips are completely cooled. The plan to conduct this study was initiated because it has been stated that in industrial productions this situation increases resin/adhesive consumption and affects some of the board properties.

This study investigated the effect of different chip temperatures during the bonding process on properties in the production of particleboard. The findings were evaluated by statistical analysis, and the optimum chip temperature during the bonding process and its effects were determined.

MATERIAL AND METHODS

Material

The wood chips and urea formaldehyde (UF) resin used in this study were obtained from a commercial particleboard production facility. The chips used in the production of the test panels consisted of 30 % black pine (*Pinus nigra*) and 35 % beech/hornbeam (*Fagus orientalis*/*Carpinus betulus*) - 35 % poplar (*Populus nigra*) wood chip mixes. The adhesive used was E-1 class UF resin with a viscosity of 250-300 mPa·s 22 ºC, density of 1260 kg/m^3-1280 kg/m^3, and 62 % ± 1 % solid contents. In the production of the test panels, according to the full dry chip weight, 10 % UF resin was used with 20 % ammonium chloride solution (pH 6,3) at the rate of 1,5 %.

Test panels production

The test panels were produced as a single layer from 0,2 mm - 0,6 mm thick chips. Prior to bonding, the chips were oven-dried until 1 % - 2 % moisture content was reached. The chips were heated to 25 °C, 30 °C, 35 °C, 40 °C, 50 °C, and 55 °C before bonding. The bonding process was then carried out at the same temperatures by spraying the mixture into the drum rotating at 50 rpm. Test panels were planned in dimensions of 400 mm × 400 mm× 16 mm and with a density of 650 kg/m^3 and then produced under the conditions of 170 °C - 180 °C temperature, 160 bar - 180 bar pressure and 5 min pressing time.

Determination of panel properties

After the pressing, the test panels were kept under ambient conditions for 1 week, and the test samples were then prepared according to the TS EN 326-1 (1999) standard. The test samples were conditioned for one week in a climate-controlled conditioning cabinet at 20 ºC ± 2 °C temperature and 65 % ± 5% relative humidity according to the principles stated in TS 642- ISO 554 (1997). The moisture content (MC) of the test panels was determined according to TS EN 322 (1999) standard, their densities to TS EN 323 (1999), water absorption (WA) to TS EN 317 (1999), perpendicular tensile/internal bond strength (IB) to TS EN 319 (1999), modulus of rupture (MOR) and modulus of elasticity (MOE) to TS EN 310 (1999), screw-holding strength (SWS) parallel to the surface to TS EN 320 (2011), and surface strength (SS) to TS EN 311 (2005).

The results were evaluated via one-way ANOVA using the SPSS statistical program. The Duncan test was used to determine whether the effects of the chip temperature differences during the bonding process were significant (p <0,05) among the board groups. Thus, the production of the particleboard was evaluated by examining the effect of chip temperature variation during bonding on board properties. A total of 24 boards were produced, 4 for each experimental group. For each experiment, 15 pieces/group samples were used.

RESULTS AND DISCUSSION

In the particleboard production, the effect of the chip temperature on the board properties was determined, as given in Table 1.

Table 1: Physical and mechanical properties of test samples.

Group	Temp (°C)	Density (kg/m^3)	MC (%)	WA (2h) (%)	IB (MPa)	MOR (MPa)	MOE (MPa)	SWS (MPa)	SS (MPa)
A	25	655 ± 2,4a	7,6 ± 0,8c	71,80 ± 8,5a	0,73 ± 0,08b	16,62 ± 1,2a	2656 ± 234b	825 ± 58a	1,36 ± 0,05ab
B	30	659 ± 9,6a	7,09 ± 0,9b	80,63 ± 3,4b	0,82 ± 0,07c	15,70 ± 2,0a	2263 ± 239a	917 ± 52ab	1,28 ± 0,15a
C	35	648 ± 4,8a	7,02 ± 0,4b	74,54 ± 5,3ab	0,74 ± 0,07b	14,59 ± 1,7a	2370 ± 198ab	980 ± 77b	1,33 ± 0,09ab
D	40	657 ± 5,1a	7,06 ± 0,2b	81,44 ± 5,8b	0,77 ± 0,04bc	15,71 ± 2,5a	2377 ± 192ab	1043 ± 19b	1,45 ± 0,05b
E	50	656 ± 7,1a	6,61 ± 0,1a	76,56 ± 8,0ab	0,57 ± 0,06a	15,48 ± 1,0a	2333 ± 244ab	1006 ± 84b	1,22 ± 0,12a
F	55	655 ± 7,1a	6,61 ± 0,2a	78,74 ± 6,0ab	0,59 ± 0,02a	14,72 ± 1,2a	2216 ± 277a	1001 ± 58b	1,26 ± 0,05a

±: standard deviation. Means followed by the same letters (a,b,c) in the same column are not significantly (p <0,05) different.

As seen in Table 1, the average density values of the test panels were determined to vary between 648 kg/m³ and 659 kg/m³. The difference in chip temperature during the bonding process was determined not to have significantly affected the board density, with no statistically significant differences at the p <0,05 confidence level. The density varied between 1,08 % and 1,54 %, and because the variation rate was low, the density difference would not have significantly affected the strength properties statistically. According to TS EN 312 (2012) standard and also as emphasized by İstek and Sıradağ (2013) when the average board density deviation is ± 10 %, the other board properties will change significantly. It was determined that with the increase of chip temperature during the bonding, the humidity of the boards produced upon exiting the press had significantly decreased. After pressing, the lowest average equilibrium moisture content (MC) of 6,61 % was found for boards bonded at 50 °C – 55 °C chip temperature. It was found that the MC values of all board groups met the requirement (5 % – 13 %) set by the TS EN 312 (2012) standard. Regarding the physical properties of the boards, the effect of the chip temperature variation during bonding on the 2-h WA values was not fully revealed since the values obtained did not show a linear curve. The variation in the water absorption data exhibited a fluctuating pattern and statistically significant differences were found. According to the data obtained, the lowest WA value was measured in group A (71,83 %) and the highest in group D (81,44 %). As a result, the negative or a positive effect of the chip temperature variation during bonding on the water absorption property of the boards was determined. It is stated that being subjected to different drying methods and temperatures can affect the wood-water relationship in different ways (Aydın 2004). The effect of chip temperature changes during the bonding process on IB (internal bond strength) is given in Figure 1.

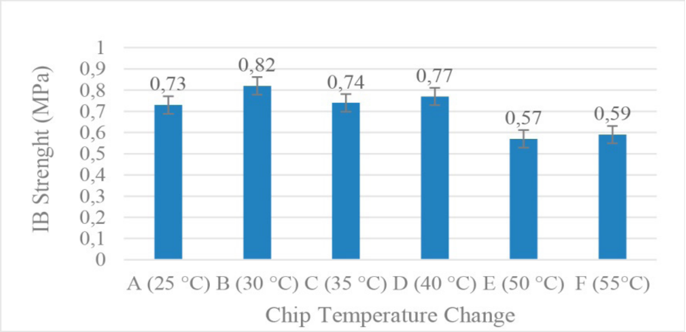

Figure 1: Effect of changes of chip temperature on IB.

As seen in Figure 1, when the IB data are analyzed, the lowest (0,57 MPa) was found for the E group and the highest (0,82 MPa) for the B group. In addition, no linear relationship was found between differing chip temperatures and IB strength; however, the IB decreased significantly at temperatures above 40 °C. Statistically significant differences (p <0,05) were determined between the groups. It was concluded from the evaluations that the chip temperature should be kept under 40 °C during bonding. The values obtained for all board groups were seen to meet those required for Type P2 boards for use in interior fittings (including furniture) in dry conditions (TS EN 312 2012). The effect of chip temperature during bonding on MOR (modulus of rupture) can be seen in Figure 2.

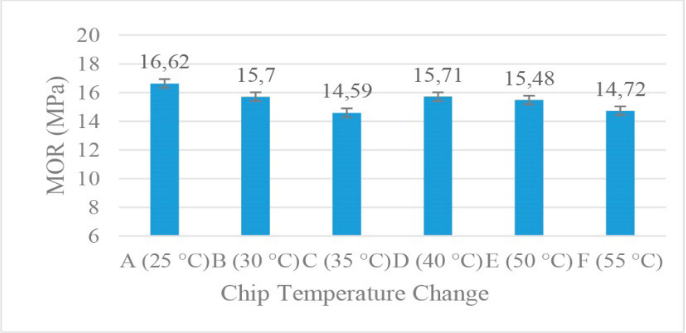

Figure 2: Effect of changes of chip temperature on MOR.

After the graph was examined, a nonlinear decrease in MOR was detected with increasing temperature, but this decrease was not statistically significant. It was understood that the increase in chip temperature during bonding accelerated the resin condensation, and in this period, the MOR decreased because the contact distance between the chip surfaces was far from the bonding distance. The highest MOR (16,52 MPa) was obtained at the lowest bonding temperature in the group A samples, and the lowest (average 14,59 MPa) in the group C boards. It was concluded that the chip temperature during the bonding process should not be higher than 25-30 °C in the production of boards where high MOR strength is desired. Although there was no statistically significant difference between the board groups in terms of the MOR, there were differences in terms of board usage classes. The C and F groups measured 14,59 MPa, which is the value sought for non-load-bearing boards for use in humid conditions (Type P3), while the B, D and E groups met the required value of 15 MPa for load-bearing boards for use in dry conditions (Type P4). The A group boards yielded the highest value, which was that required for load-bearing boards for use in humid conditions (Type P5) (TS EN 312 2012). The effect of chip temperature during bonding on MOE (modulus of elasticity) is shown in Figure 3.

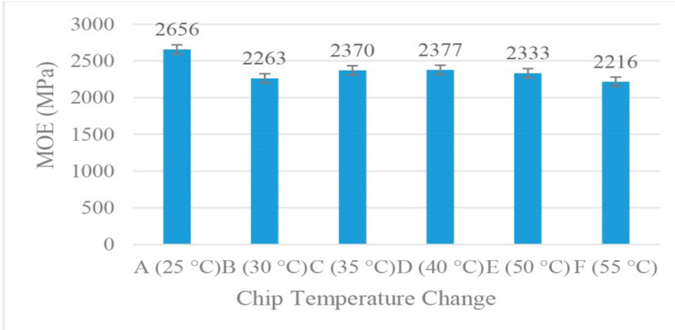

Figure 3: Effect of changes of chip temperature on MOE.

As seen in Figure 3, the average MOE value of the A group boards was 2656 MPa, which was higher than those of the other groups. The lowest MOE value was determined as 2216 MPa in the F group. It was observed that the MOE value did not depend on the variation of chip temperature during bonding, but a nonlinear decrease was seen with increasing temperature. A statistically significant difference (95 % significance level) was found between the A group and the B and F groups. According to the TS EN 312 (TS EN 2012) standard, group A provides the desired values for heavy load-bearing boards for use in dry conditions (Type P6), groups C, D and E for load-bearing boards for use in dry conditions (Type P4), and groups B and F for non-load-bearing boards for use in humid conditions (Type P3). The effect of chip temperature during bonding on SWS (screw-holding strength) can be seen in Figure 4.

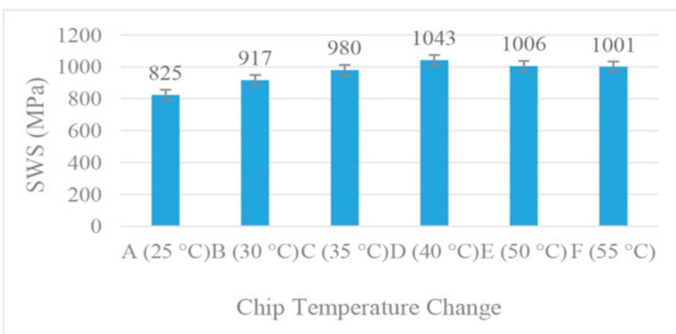

Figure 4: Effect of changes of chip temperature on SWS.

Figure 4 shows that the SWS rises with chip temperature increases of up to 40 °C during bonding, and then decreases. The highest value was calculated as 1043 MPa under the D group production conditions and the lowest as 825 MPa under production conditions of the A group boards. It was determined that the SWS of the A group boards was statistically lower than in the other groups. The effect of chip temperature during bonding on SS (surface strength) is shown in Figure 5.

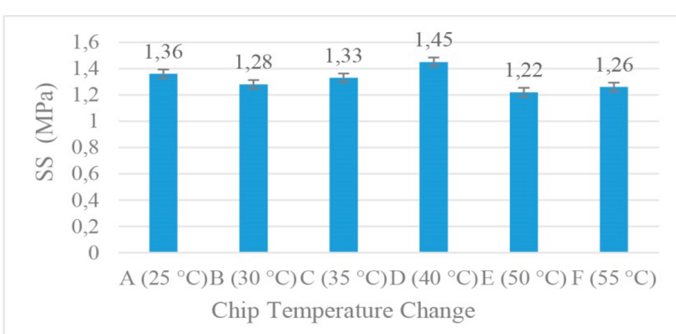

Figure 5: Effect of changes of chip temperature on SS.

As seen in Figure 5, the SS values of the D group boards at 1,45 MPa on average were found to be higher than in other groups. The lowest SS value was obtained in the F group as 1,22 MPa during the bonding process performed at 50 °C. It was observed that the SS value decreased at first, increased, and then decreased again, and did not depend on the chip temperature changes. In addition, as seen in Table 1, there was a statistically significant difference (95 % significance level) between the D group and the B, E, and F groups.

CONCLUSIONS

According to the findings, the chip temperature variation during the bonding process did not affect the board density. When the chip temperature during the bonding process was higher than 40 °C, the moisture content of the board emerging from the press was lower. Regarding the WA values of the boards, with the change of chip temperature, only the A group showed a statistically significant difference from both the B and D groups. No statistically significant change was observed in the MOR values. The highest MOE value (2656 MPa) was found in productions where the chip temperature was 25 °C during bonding. Furthermore, the MOE value did not show a linear change depending on the chip temperature. The IB value decreased by 19 % at 50 ºC - 55 °C during the bonding process compared to the other bonding temperatures. The screw-holding strength parallel to the surface was the highest (1043 N) at 40 °C during the bonding process. The surface strength increased up to the bonding temperature of 40 °C and then decreased. According to the TS EN 312 standard, all board groups met the IB, MOR, and MOE value requirements for boards used in indoor fittings (including furniture) (Type P2). When the chip temperature was higher than 40 °C during bonding, the bonded chips were partially clumped, thus negatively affecting the formation of a homogeneous board mat. At the same time, it was found that mechanical properties were adversely affected by the increase of the bonding temperature.

It was concluded that the consumption of resin and consequently, board production costs would be increased due to this situation. However, at 25 ºC - 40 °C during the bonding process, the tensile strength of the boards perpendicular to the surface increased. These findings show that measuring the chip temperature and maintaining it at certain levels during the bonding process is important in terms of resin consumption and board quality. Therefore, it was concluded that in particleboard production, a chip temperature of between 30 ºC and 40 °C during bonding is important in terms of board quality. Considering the systems, they use and in terms of board quality and resin consumption, manufacturers are recommended to carry out chip temperature measurements during bonding.

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