Effects of Surface Lamination Process Parameters on Medium Density Fiberboard (MDF) Properties

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Medium density fiberboard (MDF) is widely utilized in furniture production. Most MDF in such applications has a surface laminate layer. The lamination process improves the physical and mechanical properties of the boards. The temperature, press time, and pressure values applied during the lamination process affect such properties. In this work, the lamination process was carried out using a constant temperature (180 °C), four different press times (18, 20, 22, and 24 s), and three different pressures (25, 30, and 35 kg/cm^2). The raw weight of the decor paper was 90 g/m^2 and UF and MF glues were used in its production. The properties of the laminated panels were then determined for each variation. In general, the water absorption and thickness swelling properties were improved at the lower pressure and higher press times. The internal bonding strength exhibited a linear change at different press times depending on increasing pressure values, whereas the changes in the bending strength and modulus of elasticity in bending were not statistically significant. It was concluded that the BS increased with rising pressure in the short-term lamination process and that the effect of the pressure on the BS declined with increasing press time.

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Keywords: Lamination; Impregnated; Fiberboard; Urea formaldehyde; Gloss; Scratch; MOE; Press time; Bending

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INTRODUCTION

Wood-based boards are frequently used in interior furnishings, furniture production, and various structural products. Medium density fiberboard (MDF) and particle board (PB) production capacity in Turkey has been increasing in recent decades. (İstek *et al.* 2017b). About 70% of MDF and PB products are used with resin-impregnated paper, and the remainder is used with applied surface treatments such as print coating and printing, wood laminate layers, and thermoplastic film application (O'Carroll 2004; Kandelbauer *et al.* 2010; Cavdar *et al.* 2013). Surface lamination processes increase the resistance of board products against water and moisture, provide dimensional stability, and render an aesthetic appearance (Nemli *et al*. 2005; İstek *et al*. 2010; Liu *et al*. 2015). In addition, they reduce formaldehyde release and improve some physical and mechanical properties of the boards (Nemli and Usta 2004; Liu and Zhu 2014; İstek *et al.* 2016; Kara *et al*. 2016; İstek *et al.* 2017a).

The alpha-cellulose paper used in the surface lamination process ranges in basis weight from 60 to 130 g/m^2, and it is applied as a self-adhesive coating saturated with thermo-set resin (Barret 1993; Sparkes 1993; İstek *et al.* 2010). Partial curing occurs with the drying after the resin-saturation process, and during the lamination process, the hot press curing is completed (Jackh 1993; Nemli and Usta 2004). The properties of the resins used in the paper impregnation process affect the properties of the boards. MF resin is preferred due to its strength, hardness, and resistance to scratching and moisture, whereas UF resin has the advantage of being economical (Composite Panel Association 2007; Nemli and Hızıroğlu 2009).

Nemli *et al.* (2003) investigated the effect of various press parameters and thickness values on the surface quality of continuously pressed laminates (CPL) and reported that the press temperature and press cycle affected abrasion and scratching. İstek *et al* (2010) stated that the pattern and glue type influenced the board properties, and that the physical and mechanical properties were increased significantly in PB covered with melamine-impregnated decor paper. The bending strength, modulus of elasticity in bending, thickness swelling, and water absorption properties of the board were found to improve with increasing the weight of the paper used in the lamination process, whereas the resin type did not affect the mechanical properties (Nemli *et al.* 2005). It has been emphasized that the type and technique of surface lamination affect the mechanical and thermal conductivity properties of PB (Nemli and Çolakoğlu 2005). Another study reported that different factors such as the coating and varnish material, as well as the resin mixture, had a significant effect on some surface properties (Nemli 2008). In the application of decorative paper lamination on particle board surfaces, Kara *et al.* (2014) emphasized that changes in press temperature and time produced different effects on properties such as scratch resistance, gloss, and surface soundness.

Studies on the lamination of board surfaces have investigated the effects of various coatings, glues, paper types, and variable pressing conditions on the surface properties of the boards. However, only a limited number of studies have examined the effect of the paper lamination press conditions on the physical and mechanical properties of the laminated boards. This study aimed to determine the effect of the lamination parameters used in the MDF surface lamination process by investigating the relationship between the variation of pressure and press time at a constant temperature on the properties of the boards.

EXPERIMENTAL

This study was carried out on the lamination line of a commercial enterprise. The MDF panels used were produced in the same facility. In the production of MDF boards, a mixture of 45% *Pinus brutia* and 55% *Fagus orientalis* wood chips were broken down into fibers. Prior to this process, the chips were steamed at 180 °C under 8.5 atm pressure for 2.5 min cooking time. According to the full dry fiber weight, 12% urea formaldehyde (UF) glue, 1% paraffin, and 1% ammonium chloride (NH_4Cl) were used as hardeners. The fibers were dried up to 9% in a tube dryer and then formed with an average board density of 630 kg/m^3 and a thickness of 18 mm. The MDF boards were produced under the conditions of 190 ±5 °C, 35 kg/cm^2 maximum pressure, and 2 min hot pressing using continuous pressing technology. After the hot pressing, the boards were cooled in a star cooler for 90 min and the sizing process was carried out. The star cooler, which is widely used in the industry for cooling wood-based boards, has a structure that can load and unload simultaneously with many compartments. In order to reach equilibrium moisture content, the boards were kept in storehouses for about one to two weeks. After the sanding process, the boards were covered with impregnated decor paper (90 g/m^2 weight) on the lamination line. During the decor paper impregnation, UF (50%) and MF (54%) glues were used at the levels of 124 and 93 g/m^2, respectively. In the lamination process, the effect of pressure and press time variations at a constant temperature on the properties of the board was determined. The lamination parameters used in the study are given in Table 1. After the lamination process, some properties of the boards were determined, including water absorption (WA), thickness swelling (TS), bending strength (BS), modulus of elasticity in bending (MOE), and internal bonding (IB), as well as the surface properties of gloss, porosity, curing degree, and scratch resistance.

Table 1. Pressing Parameters of Lamination

Temperature (°C)	Pressing Time Duration (s)	Pressure (kg/cm^2)
180	18	25
		30
		35
	20	25
		30
		35
	22	25
		30
		35
	24	25
		30
		35

Determination of Curing Degree and Surface Properties

Curing is the transformation, *via* polymerization reactions, of the layer formed by the lamination material on the surface into a hard film of thermoset material. To measure the degree of curing, 15 min after the lamination process, about 1.0 g of Rhodamine B solution was added to 1.0 L of 37% hydrochloric acid solution. At least two drops of the prepared solution were then dripped onto the board surface and left for 5 min. At the end of this period, the acid was wiped off with a cloth and the surface was compared with a color scale graded from 1 to 5. A result of grade “1” meant that the curing was insufficient, whereas grade “5” meant that the curing was too high, and grades “2” to “4” indicated that the degree of curing was sufficient (Kara *et al.* 2014). Porosity was determined by coloring an area of 25 cm^2 using a soft lead pencil and then applying a rubber eraser over the area, counting the remaining dark spots, and visually evaluating them under a microscope. The surface was classified at 0.5-unit intervals as 1.0 (no spots) = “very good” to 5 (wide spots) = “very bad” (Kandelbauer *et al.* 2010). Surface scratch measurements were determined using the Universal Scratch Tester 413 test device (Erichsen, Hemer Germany), and surface gloss was measured with the BYK-Gardner GmbH micro-TRI-gloss three-angle (20º-60º-85º) device (Altana-BYK, Wesel, Germany).

Test Standards for Physical and Mechanical Properties of Laminated MDF

Moisture content tests were performed according to TS EN 322 (1999), density by TS EN 323 (1999), TS following TS EN 317 (1999), WA test by ASTM D1037-12 (2020), BS and MOE following TS EN 310 (1999), IB according to TS EN 319 (1999), and scratch resistance by TS EN 14322 (2021). In addition, TS EN 326-1(1999) standard was used in the preparation of the test samples and TS EN 622-5 (2011) in the determination of the fiberboard properties. The data obtained were evaluated by analysis of variance (ANOVA) using SPSS 16 statistical analysis software, and the groups with significant differences were determined using the Duncan's test.

RESULTS AND DISCUSSION

Surface Properties

The results regarding the moisture content and some surface properties of the laminated boards are shown in Table 2. The effect of pressure variation on the surface properties was limited. However, in the variations in which the lamination press time was applied for 24 s, the gloss value increased with increasing pressure. It has been noted that the longstanding preference for lamination at high pressure, especially at low temperatures, yields brighter surfaces, and that gloss values increase in parallel with the increase in pressing time and board density (Kara *et al.* 2014; İstek *et al*. 2016).

Table 2. Surface Property Results at 180 °C

Pressing Time (s)	Pressure (kg/cm^2)	Moisture (%)	Gloss (Gu)	Porosity (P)	Curing Degree (°)	Scratch Resistance (N)
18	25	5.54	107 - 108	3	5	3
	30	6.29	107 - 108	3	4	3
	35	6.62	104 - 105	4	5	3
20	25	6.25	107 - 108	4	5	3
	30	6.3	107 - 108	4	5	3
	35	6.24	107 - 108	4	4	3
22	25	6.02	107 - 108	4	5	3
	30	6.17	107 - 109	4	5	3
	35	6.02	107 - 108	4	4	3
24	25	6.1	106 - 108	4	5	3
	30	6.32	107 - 109	4	5	3
	35	6.03	110 - 112	3	5	2.5

Porosity (*P*), degree of curing, and scratch resistance values did not show a linear change with varying pressing time and pressure values. Although the scratch resistance values were the same for all variations except 24 h-35 kg/cm^2, it was stated in one study that the type of glue was effective for scratch resistance, yielding values of between 3 and 5 (Nemli and Usta 2004). Although there was no linear change in the degree of curing, a higher degree of curing was observed at higher pressing times. Kara *et al*. (2014) reported that the curing value rose with the increase in pressing time, and that a high temperature and short pressing time were more suitable for curing. The *P* of a laminated board is evaluated as an indicator of the surface's affinity for dirt particles. Cases with a *P* value of less than 3 are considered excellent for industrial-scale boards, and it has been reported that the *P* value tends to increase with increase in the pressing time (Kandelbauer *et al*. 2010). The moisture content values of the boards ranged between 5.54% and 6.62%, which are within the value limits specified in the TS 64-1 EN 622-1 (2005) standard.

Physical and Mechanical Properties

The results and standard deviation values of the physical and mechanical properties of the laminated boards are given in Table 3. The ANOVA result values having a statistically significant difference at 95% confidence are indicated with different letters. Table 3 shows that there was an average increase of 15% in board density after the lamination process, compared to the unlaminated board density. When the TS and WA values were examined, the lowest were determined as 1.16% and 17.03%, respectively, in the 24 h-25 kg/cm^2 parameter. There was an increase with increasing press pressure for both TS and WA at all times, and statistically significant differences were observed at 18-s to 20-s and 22-s depending on the varying pressure values . Although this difference was seen between all pressure values at 18-s, it was determined at 35 kg/cm^2 for the 20-s and 22-s periods. The effect of the lamination parameters of pressure and pressing time on TS and WA is shown in Fig. 1, which indicates that there was an increase in TS and WA values with the rises in pressure, and a decrease with the rises in pressing time. İstek *et al.* (2016) found TS and WA values of 12.71% and 71.26%, respectively, in PB laminated for 30-s at 30 kg/cm^2 pressure. They reported that lamination parameters of pressure and pressing time did not have a significant effect on the TS or WA properties of the PB.

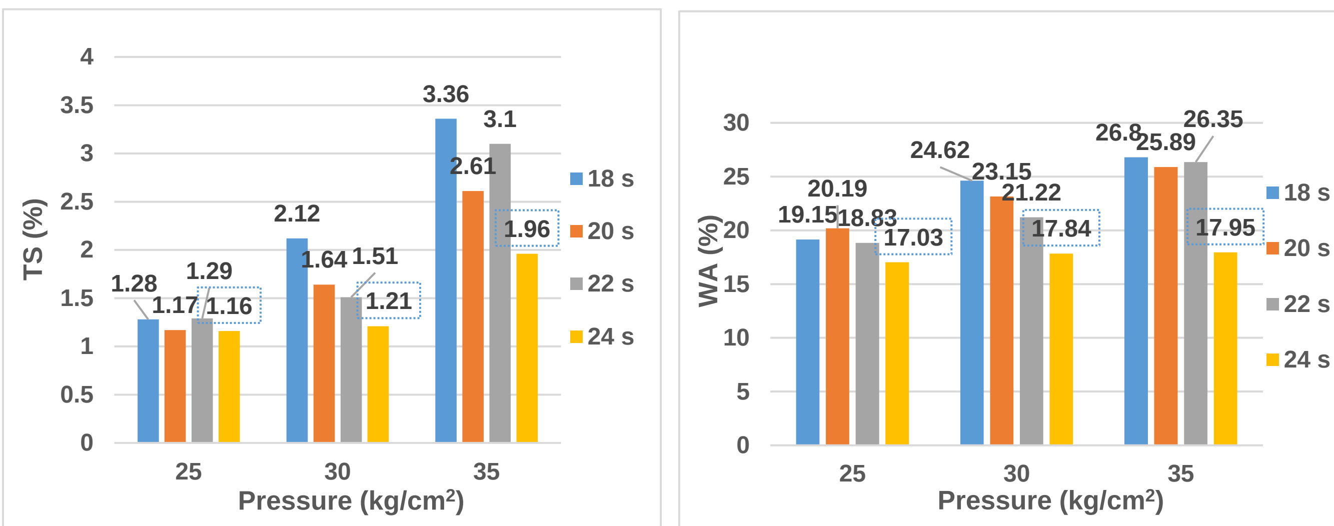

Fig. 1. Thickness swelling and water absorption

When the effect of lamination parameters on the mechanical properties of the boards was examined, no statistical difference was observed between the variations for BS and MOE values. However, in general, there was an increase in BS values with rising pressure at low pressing times, and the effect of pressure on the BS value decreased with the increase in pressing time. For MOE, on the other hand, there was an increase with the rise in pressure from 30 to 35 kg/cm^2 for all pressing times except 24 s, with the highest MOE values obtained at 25 kg/cm^2 pressure. When BS and MOE were evaluated together, the highest strength values were obtained as 25.65 N/mm² and 3222.25 N/mm², respectively, at a pressure of 35 kg/cm^2 for BS and 30 kg/cm^2 for MOE at 20 s pressing time.

Table 3. Physical and Mechanical Properties of Laminated Boards

Pressing Parameters			Laminated Board Properties					
Temp (C°)	Time (s)	Pressure (kg/cm²)	Density (kg/m³)	TS (%)	WA (%)	IB (N/mm²)	BS (N/mm²)	MOE (N/mm²)
180	18	25	719±18.08	1.28±0.09a	19.15±1.54a	0.91±0.06a	24.84±0.70	3219±131
		30	718±12.12	2.12±0.26b	24.621.41±b	0.89±0.07a	25.35±0.87	3136±78
		35	721±28.21	3.36±0.41c	26.8±0.76b	0.99±0.12b	25.58±1.13	3201±133
	20	25	724±6.56	1.17±a0.24a	20.19±0.62a	0.89±0.04a	24.59±0.67	3222±72
		30	722±8.89	1.64±0.21a	23.15±2.39ab	0.87±0.03a	25.41±0.53	3145±83
		35	726±4.00	2.61±0.46b	25.89±0.98b	0.96±0.04b	25.65±0.39	3189±72
	22	25	731±7.81	1.29±0.25a	18.83±1.45a	0.92±0.06	24.48±0.77	3172±75
		30	729±6.56	1.51±0.38a	21.22±0.38b	0.88±0.02	24.58±1.33	3076±110
		35	729±3.61	3.1±0.52b	26.35±1.90c	0.90±0.10	25.47±1.91	3129±163
	24	25	725±1.15	1.16±0.26	17.03±1.61	0.93±0.12a	24.31±1.07	3046.±157.68
		30	726±1.73	1.21±0.23	17.84±0.81	0.82±0.07b	24.1±1.91	3085.±81.08
		35	725±3.00	1.96±0.05	17.95±1.12	0.89±0.07a	24.41±2.25	3015.±220.19

±: Standard deviation. Groups with statistically significant differences for the same press time duration are indicated with different letters ($p < 0.05$).

Figure 2 shows the effect of pressing time and pressure on BS and MOE values. The BS values increased with rising pressure for the same periods except for 30 kg/cm^2 pressure and 24 s pressing time. Contrary to these results, it has been reported that the BS value in compressed wood may decrease because of fragmentation of the cell wall with increasing pressing pressure (Kutnar *et al.* 2009). When the effect of pressing time was examined at a constant pressure, it was determined that although the BS value decreased with the increase in pressing time, this decrease was linear for all pressing times at 25 kg/cm^2 pressure. Similarly, there was a linear decrease in the BS value as the pressing time increased from 20 s to 24 s at 30 kg/cm^2 and 35 kg/cm^2 pressure. In contrast to the BS, generally higher MOE values were observed at low pressure values. The strength values that decreased with the rise in the pressure from 25 to 30 kg/cm^2 increased with the rise in the applied pressure to 35 kg/cm^2 within the same pressing duration, except for 24 s. At the same pressure, the 18-s to 20-s pressing times yielded better MOE values than 22-s to 24-s. It is noteworthy that at 30 kg/cm^2 pressure, there was less difference between the MOE values depending on the times.

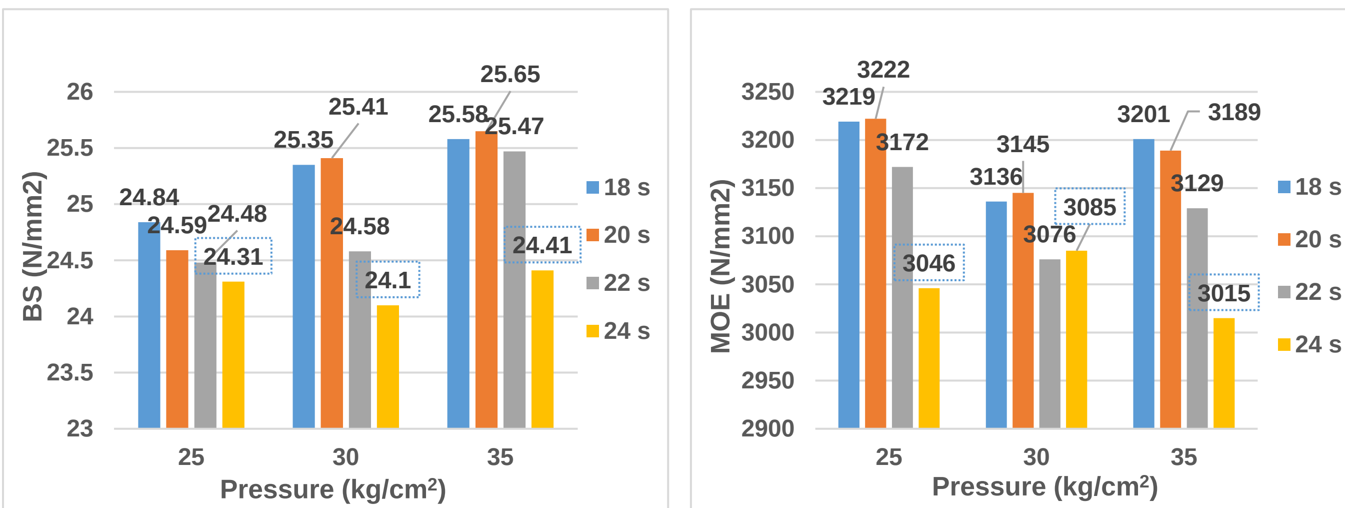

Fig. 2. Bending strength and modulus of elasticity

Büyüksarı (2012) stressed that in the PB lamination process, the effect of temperature on BS and MOE values was more important at high pressures. The BS and MOE values have been reported to increase when the lamination parameters for PB covered with impregnated decor paper were changed from 205 °C to 24 h-180 °C for 18 s under 30 kg/cm^2 pressure (İstek *et al.* 2016). These results demonstrated that in the lamination process, the pressing time and temperature had a significant effect on the BS and MOE values. In different studies, it has been stated that the structure became more fragile and the strength values decreased with the effect of rises in temperature (Jämsä and Viitaniemi 2001; Büyüksarı 2012). There was no linear change in the IB value according to increasing pressure values at different pressing times. Despite this, the lowest IB values were obtained at 30 kg/cm^2 pressure for all time periods, whereas there was an increase in IB values when the pressure was increased to 35 kg/cm^2. Statistically significant differences emerged with the pressure change for all pressing times, except for 22 s. These differences were seen at 35 kg/cm^2 pressure for 18 s and 20 s, and at 30 kg/cm^2 pressure for 24 s. The effect of lamination parameters on density and IB strength is shown in Fig. 3.

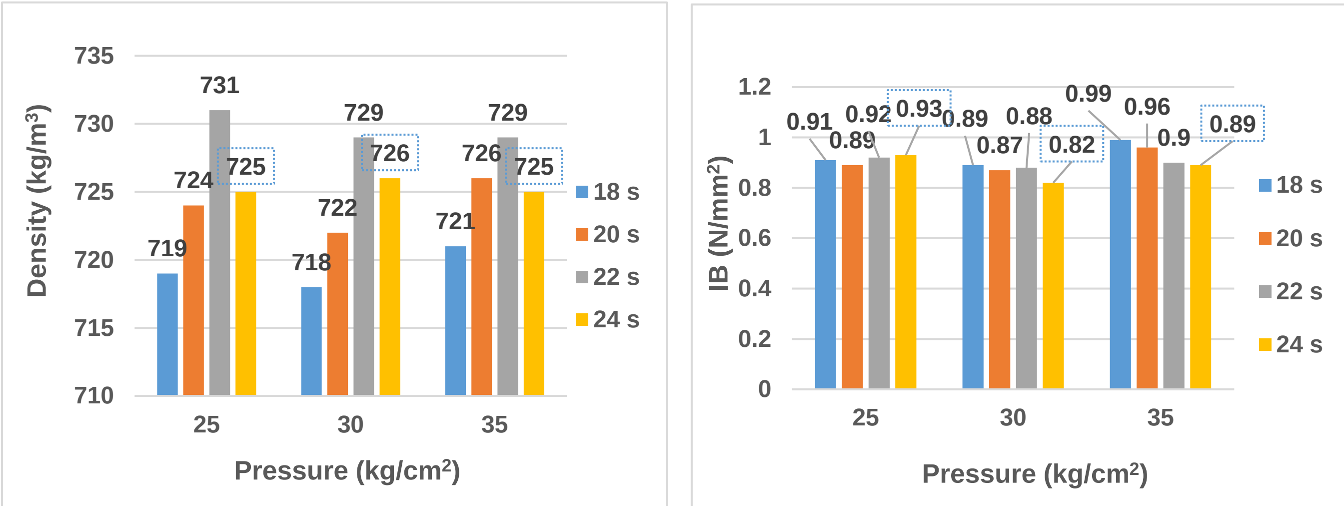

Fig. 3. Density and Internal bonding strength

For all pressure values, the density value rose linearly with the increase of pressing time, and fell at 24 s. In general, higher density values were obtained with increase in pressure. One study reported that rises in press pressure increased the board density (Ünsal *et al.* 2011). When the IB values were examined, there was less difference, especially at 25 kg/cm^2 pressure, in the strength values depending on the varying pressing times. Pressure and pressing time change did not have a linear effect on the IB strength variation, and the highest strength value was obtained as 0.99 N/mm^2 in the 18 s-35 kg/cm^2 application (the lowest pressing time and the highest pressure value). In a similar study, the highest IB strength was found with 0.97 N/mm^2, 18 s pressing time, and 30 kg/cm^2 pressure application (İstek and Özlüsoylu 2021). Furthermore, the results obtained were within the standard values, which can be attributed to the fact that the pressure used in the board production (35 kg/cm^2) was the same as the pressure used in the lamination process. When the pressure used in the lamination process is higher than the pressure used in the board production, a decrease in the IB strength has been noted (İstek *et al.* 2016). It shows that the IB strength increases with increasing time at low pressures and the internal structure will be more stable with increasing pressure in cases where it is not exposed to a crushing effect.

CONCLUSIONS

1. The pressing time and pressure variations applied in the lamination process partially affected the properties of the board surfaces such as brightness, porosity, and scratch resistance. There was an increase in the brightness value with the rises in pressure at a constant pressing time of 24 s.
2. The thickness swelling (TS) and water absorption (WA) values were positively affected at lower pressure and higher pressing times. The most suitable TS and WA values were obtained at 24 h-25 kg/cm^2 lamination conditions, and these values increased with rises in press pressure at all pressing time periods.

3. The highest internal bond (IB) value was determined as 0.99 N/mm² at 18 s-35 kg/cm² lamination conditions. There was no linear change in the IB value depending on increasing pressure values at different pressing times. At low pressing times, when the pressure was increased from 25 to 35 kg/cm², the IB strength decreased.
4. No statistically significant difference was found between the variations for bending strength (BS) and modulus of elasticity (MOE) values. However, in general, the BS values were higher with rising applied pressure for low durations, and the effect of the pressure on the BS value declined with the increase of the pressing time.
5. The physical and mechanical properties of the laminated boards obtained for all variations met the requirements for general-purpose use in dry and humid conditions, as specified in the TS EN 622-5 (2011) standard.

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