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TECHNOLOGY OF PARTICLEBOARD'S PREPARATION BY COLD PRESSING AFTER HOT MAT COMPRESSION

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ABSTRACT

The article describes a method of preparing particleboards (PB) from fresh and recycled chips by a new technology of cold pressing after hot compression of the mat according to PCT/SK2023/000007 (ÚPV SR, 13.06.2023) using polyvinyl acetate (PVAc) glue. For comparison, the experiment was also carried out using urea formaldehyde (UF) glue and their mutual combination. The new method shortens hot pressing, or causes reduction of pressing temperatures, while the prepared PB released from pressure no longer spring and cure over time. The curing kinetics of both PVAc and UF adhesives were described by monitoring the flexural strength and modulus of elasticity of PB as a function of time after release of pressure.

Modeling of the PB pressing process based on PVAc glue, which consists of overheating the pressed cross-section of the board to 90°C and its subsequent cooling to a temperature when the board is already stable, i.e. below a temperature of 70°C, was carried out using of a hot and cold press, while the pressing cycle lasted 140 s. Shortening the pressing cycle to 100 s was achieved by applying the glue to the chips already preheated to 92°C.

Laboratory tests have confirmed that the mechanical properties of PB are in accordance with the requirements of EN 312/3 for chipboards for interior conditions, including furniture, for use in dry environments.

KEYWORDS: Particleboard's pressing, cushioning, cold pressing, fresh chips, recycled chips, polyvinyl acetate glue, glue curing.

INTRODUCTION

Particleboards (PB) are produced from wood chips from fresh wood with the possibility of reusing a certain percentage of chips from waste agglomerated materials so that they meet the physical-mechanical properties required by standards (Ihnát et al. 2018, Iždinský et al. 2020) and to the permitted content of free formaldehyde in the prepared PB was not exceeded

(Czarnecki et al. 2003). Glue is applied to dried chips, the chips are layered into a mat and pressed in multi-stage discontinuous presses or continuous presses at a temperature of pressing plates up to 250°C for 8 to 15 s per 1 mm board thickness (de Mets 1981, Koehler 1995, Kroll 2003, Hse et al. 2008, Weinkotz 2011, 2015, Iždinský et al. 2020). After pressing, the boards are air-conditioned in order to equalize the temperature and humidity in the cross-section of the board.

Adhesives based on urea formaldehyde resins (UF) (Iždinský et al. 2021) and melamine urea formaldehyde resins (MUF) (Hse et al. 2008), in various modifications with formaldehyde emission class E1, are used for the production of the mentioned boards. For PB, one-shot emission of up to 8 mg/100 g DTD is allowed, while the average formaldehyde emission is up to 6.5 mg per 100 g of PB (DIN EN 120: 2011). For the creation of low-emission composites based on wood, when it is necessary to achieve almost zero formaldehyde content (E0 emission level ≤ 1.5 mg/100 g), adhesives intended for internal use are advantageous (Krišťák and Réh 2021). PVAc based adhesives are unusable for the current PB production technology based on UF adhesives. Due to the short pressing time, the adhesive would not harden during pressing. The boards would then become cushioned, which would lose the necessary physical-mechanical properties. The possibilities of using a new hybrid resin based on the polymer methylenediphenyldiisocyanate/phenol-formaldehyde (pMDI/PF) (Dukarska et al. 2017) or sustainable adhesives on a biological basis to reduce formaldehyde are also being investigated (Antov et al. 2020).

The proposed cold pressing PB production technology according to PCT/SK2023/000007 (Lübke et al. 2023) using PVAc glue eliminates the need to dispose of old UF glue when using recycled chips up to 100%. Currently, the old adhesive is disposed of by hydrolysis (Pfleiderer Unternehmensverwalt 1994, Lykidis and Grigoriou 2011, Riddiough and Kearley 2001). The technology enables the use of recycled material by simply processing old PB (Lübke et al. 2020). The new technology uses the known thermal properties of the lignin-saccharide complex, when lignin is plasticized by heating (Bouajila et al. 2006), while this process is reversible. The advantage of the new technology is shortening or even eliminating hot pressing in a continuous press, where energy consumption is significantly reduced.

This work describes the laboratory preparation of 16 mm thick PB by cold pressing made from fresh and recycled chips using PVAc or UF glue and their combination. The achieved mechanical properties are in accordance with the requirements of EN 312-3: 2010 for particleboards for indoor equipment, including furniture, for use in dry environments. The curing kinetics of both PVAc and UF adhesive is described by monitoring the flexural strength and flexural modulus as a function of time after pressure release of the cold press. Prepared PB do not spring and are capable of immediate manipulation.

MATERIAL AND METHODS

Wood chips

Fresh chips for a surface and center of PB were obtained from the factory. The chips obtained were fractionated by sieving. Chips ranging in size between 0.3 mm to 2 mm were used for the surface layers, chips of size 2 to 4 mm were used for the middle layers. Recycled chips were obtained by disintegration of waste PB glued with UF glue with/without a surface top. Recycled chips with/without surface top were used in the experiment for both surface and center chips in a ratio of 1:1. The initially disintegrated pieces of PB were boiled in water for 30 min so that the relative humidity of the chips was at least 40% (Ihnát et al. 2017). A drum chipping device (Pallmann) with a fixed ring with longitudinal slits (54.1 x 5.5 mm) was used for their disintegration. The prepared chips were dried at a temperature of 105°C. The distribution of the prepared chips was determined by laboratory sieving after their drying (Tab. 1).

Tab. 1: Distribution of recycled chips from waste PB glued with UF glue and fresh chips obtained from the production plant.

	Recycled chips (%)		Fresh chips (%)	
Sieve (mm)	Without top foil*	With top foil*	Surface	Center
8	-	-	-	1.2
4	19.3	17.5	-	34.7
2	20.3	19.8	1.3	33.7
1	20.7	21.9	16.2	23.1
0,2	25.6	24.7	58.0	5.6
Residue	14.1	16.1	24.5	1.7

**Recycling for 30 min by boiling and chipping on a ring with longitudinal slits.*

Adhesives used

For preparation of PB, PVAc glue Duvilax D3 RS (Duslo a.s. Šaľa, SK) and UF glue Kronores CB 1100 F (Diakol Strážske s.r.o., SK) were used, with the addition of 5% hardener DAM 390 (Duslo a.s. Šaľa, SK) dry matter to the dry matter of the glue.

PB preparation

Preparation of PB using PVAc glue

Glue was applied to the prepared fresh/recycled wood chips with a relative humidity of 2.9% in the amount of 10% of the dry weight of the glue per dry weight of the chips in a glue applicator (Defibrator, SE). The adhesive mixture composed of PVAc adhesive contained a paraffin emulsion (30% water emulsion) in the amount of 0.8% paraffin per dry weight of chips. Amount of 5% water was added to the adhesive mixture to reduce the viscosity to achieve a good dispersion of the adhesive mixture when spraying on chips. In case of an adhesive mixture without paraffin emulsion, add a total of 6.9% water to the adhesive mixture. Surface and center chips are in 1:1 ratio. The individual components of the adhesive mixture are in the same representation for surface and center chips.

The created chipboard mat sized 370 x 290 mm was pressed in a hot press with a pressure of 120 kg/cm^2 to the required thickness of 16 mm. Board thickness was achieved by using spacers. The PB was heated in the hot press to a temperature such that the temperature in the center of the PB was in the range of 90 to 100°C. The temperature in the center of the chips mat was measured by a sticking thermal probe connected to a data logger. The temperature of the pressing plates was 150°C. After reaching the required thickness, the plate was immediately cooled and cold-pressed until it cooled down to the PB stabilization temperature below 70°C. At a cold press temperature of 17°C, time to reach this temperature was 88 to 110 s. After being removed from the cold press, the board was immediately formatted and conditioned at a temperature of 20°C and a humidity of 55%.

Preparation of PB using UF glue

Preparation of PB with a thickness of 16 mm was carried out using both fresh and recycled chips as in the previous case, using UF glue applied in an amount of 10% dry glue to dry chips with the addition of 5% hardener DAM 390 dry matter to dry glue. After applying the adhesive mixture, the moisture content of chips in the mat before its pressing reached 12.6%. The mat was pressed to a thickness of 16 mm in a hot press until a temperature of 100°C was reached in its center. Subsequently, the PB was cooled in the cold press while maintaining the thickness of the plate. The cold pressing time to reach a temperature below 70°C at an initial cold press temperature of 20°C was 135 s. The board was subsequently formatted and conditioned at a temperature of 20°C and a humidity of 55%.

Preparation of combined PB using fresh/recycled chips (1:1) and PVAc/UF adhesives (1:1)

Recycled chips were mixed with fresh chips in a 1:1 ratio. A 10% mixture of PVAc and UF glue (with added hardener DM 390) was applied to the prepared surface chips and center chips in a 1:1 ratio. The mat was created similarly to the previous cases.

Determination of properties of prepared PB

The following properties of the prepared samples were determined: bending strength and flexural modulus according to EN 310 and tensile strength value perpendicular to the plane of the board according to EN 319. Each stated value of flexural strength and flexural modulus is the average value of 12 tested samples and the value of the tensile strength perpendicular to the plane of the board is the average value of 24 tested samples. Determination of the property was carried out after 7 days of conditioning.

Curing kinetics of PB in cold pressing after hot compressing of the mat

Curing of PB was monitored by the change in flexural strength and modulus of elasticity as a function of time since removal from the cold press. The mat made of fresh chips was placed in a hot press and pressed to a thickness of 16 mm. Temperature of the pressing plates of the hot press was 150°C. The prepared PB was moved to a cold press when temperature in its center (core temperature) reached 98°C in the first case and a lower temperature of 90°C in the second case. In the cold press, the PB was pressed to a thickness of 16.0 mm, to the thickness of the steel spacers. The release of the pressing pressure of the cold press took place at the moment when the temperature dropped to the required board's stabilization temperature below 70°C (PCT/SK2023/000007, ÚPV SR, 13.06.2023). The PB taken from the cold press was immediately processed, i.e. was sawn on samples to determine the bending strength and to determine the modulus of elasticity. Both of these values were determined on samples gradually in time after removal from the cold press. The board does not spring in its thickness after removing. The samples after sawing were stored in an environment with a temperature of 20°C and a relative humidity of 55%.

Temperature and pressure diagram of the cold pressing process after hot compressing the mat

The course of temperature measured in the center of the pressed mat was recorded over time using a thermal probe connected to a data logger. The course of pressing pressure over time was recorded using manometers of the hot and cold press. A laboratory simulation of the continuous cold pressing process after hot pressing of the mat was carried out by combining hot and cold pressing so that the chips before hot pressing were heated to a temperature of 92°C in a drying oven or in a microwave oven. The total time of the pressing cycle was monitored.

RESULTS AND DISCUSSION

Strength properties of the prepared PB

The determined values of bending strength, modulus of elasticity and tensile strength perpendicular to the plane of the prepared PB are shown in tab. 2. It is clear from the achieved strengths that the PB prepared in this method meet the criteria set by EN 312-3. A decrease in the strength properties of PB prepared from recycled chips compared to those prepared from fresh chips was expected (Hua et al. 2022, Iždinský et al. 2020,2021, Ihnát et al. 2020). The positives in the creation of combined adhesive suspensions are to be found in the mutual concealment of the shortcomings of the individual components. The PVAc component helps to reduce the formaldehyde content in the adhesive mixture (Iqbal et al. 2021), while the urea content of the UF adhesive increases the thermosetting properties and water resistance of the bonded joint (Cui 2007).

Tab. 2: Properties of PB prepared by cold pressing after hot compressing of the mat (average values).

Glue basis	Properties	Recycled chips	Fresh chips	Requirements EN 312-3
PVAC	Bending strength ($N \cdot mm^{-2}$)	19.18 (9.21)	21.51 (5.28)	13.0
	Modulus of elasticity ($N \cdot mm^{-2}$)	1896 (7.93)	2291 (6.48)	1600
	Tensile strength perpendicular to the plane ($N \cdot mm^{-2}$)	0.72 (11.1)	1.07 (9.11)	0.35
UF	Bending strength ($N \cdot mm^{-2}$)	18.79 (10.32)	22.84 (8.23)	13.0
	Modulus of elasticity ($N \cdot mm^{-2}$)	2021 (6.21)	2343 (5.81)	1600
	Tensile strength perpendicular to the plane (N.mm-2)	0.71 (6,5)	1.37 (7.27)	0.35
Combined*	Bending strength ($N \cdot mm^{-2}$)	21.34 (9.54)		13.0
	Modulus of elasticity ($N \cdot mm^{-2}$)	2262 (8.12)		1600
	Tensile strength perpendicular to the plane (N.mm-2)	0.93 (7.96)		0.35

Combination of fresh/recycled chips (1:1) and PVAc/UF adhesives (1:1). Values in parentheses represent correlation coefficients.

Strength properties of the prepared PB as a function of time

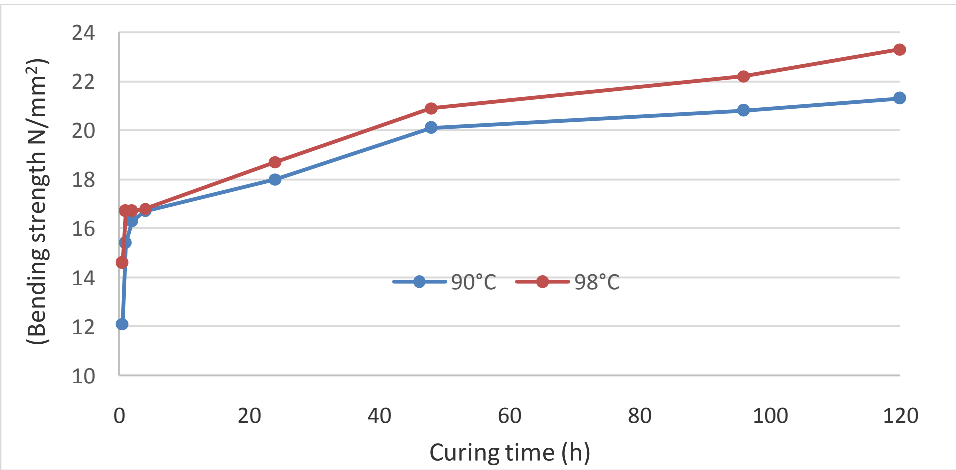
Properties of the prepared PB based on PVAc adhesives as a function of time

After removing the prepared PB from the cold press at a temperature below 70°C, there was no more cushioning, which could cause deterioration of their properties. It is apparent that it is not necessary to harden the adhesive during pressing in a hot press, as is the case with the current PB preparation technology using UF based adhesives. Tab. 3 contains the bending strength and modulus of elasticity in bending depending on the time of completion of cold pressing.

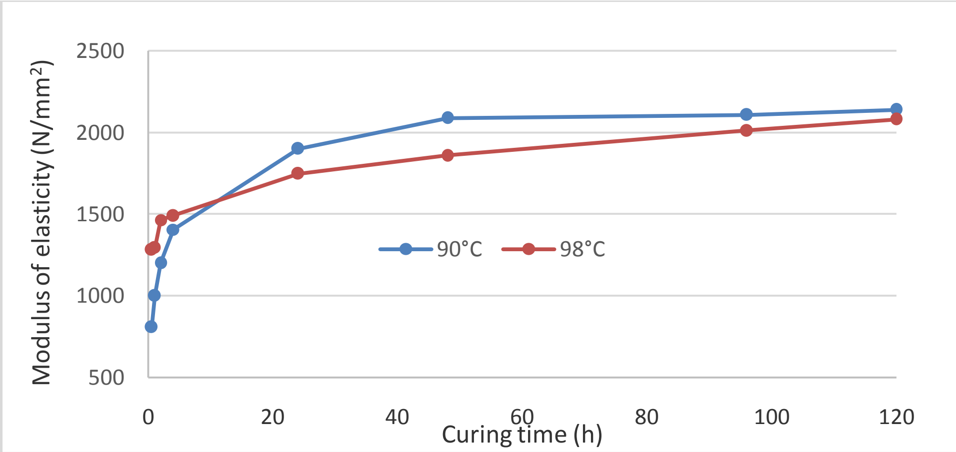
Tab. 3: Curing kinetics of prepared PVAc based PB.

Time (h)	Mat heating on 90°C		Mat heating on 98°C		Requirements EN	
	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)
0.5	12.1	807	14.6	1282	13.0	1600
1	15.4	1000	16.7	1293		
2	16.3	1200	16.7	1464		
4	16.7	1405	16.8	1490		
24	18.0	1900	18.7	1747		
48	20.1	2089	20.9	1858		
96	20.8	2107	22.2	2011		
120	21.3	2139	23.3	2081		

When the mat was heated to 98°C, the bending strength reached 14.6 N/mm2 already 0.5 h after being removed from the cold press, which exceeded the required standard values. The modulus of elasticity reaches the required values in a time range between 4 and 24 h. In the case when the mat was heated only to 90°C, the required values for the bending strength were reached after 1 h after pressing (15.4 N/mm2) and the modulus of elasticity again in the range of 4 to 24 h. Curing of PVAc adhesives is done by losing water from the adhesive by extraction or evaporation (Avramidis et al. 2011). The development of bending strength and modulus of elasticity in bending over time is shown in Fig. 1.



a)



b)

Fig. 1: Properties of the prepared PVAc based PB depending on the curing time. Curing kinetics depending on the temperature in the center of the mat: a) bending strength, b) modulus of elasticity.

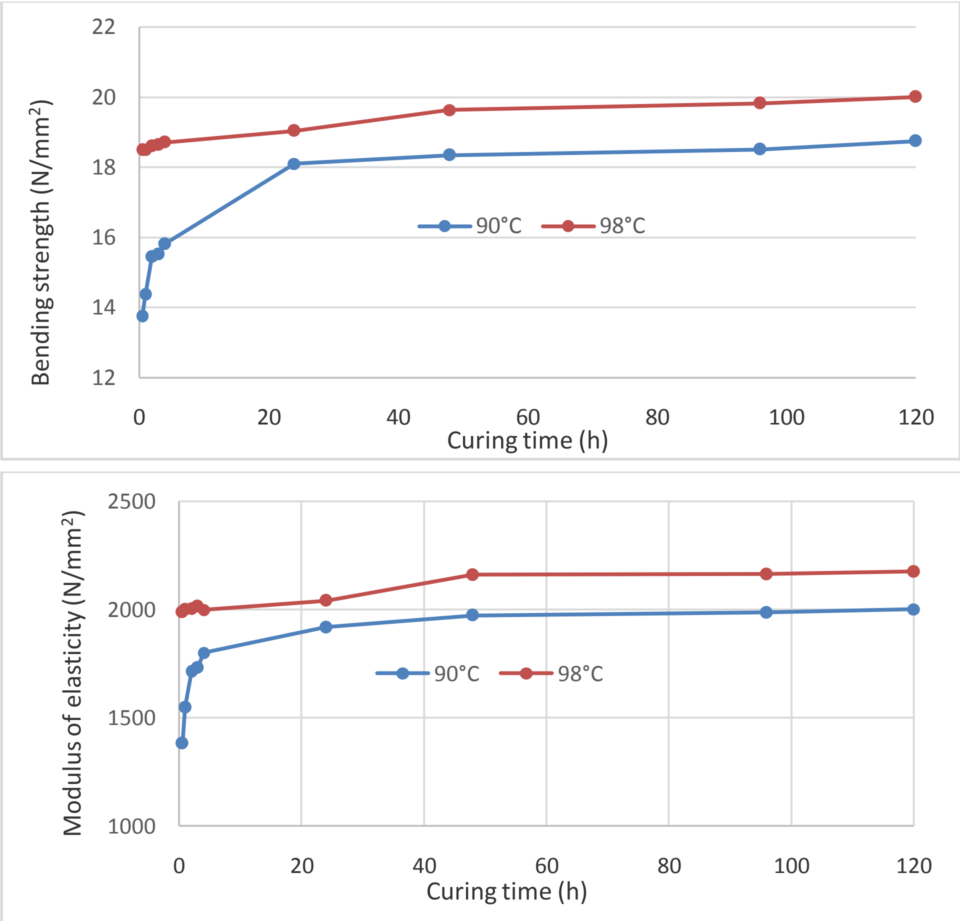
Properties of prepared PB based on UF adhesives as a function of time

From Tab. 4, it is clear that the PB properties have values at the level they reach after 24 h of curing already 0.5 h after removal from the press, if the mat of chips has been heated to 98°C. These values meet the requirements of EN 312-3. When the mat was heated to 90°C, the standard required values of bending strength were reached 0.5 h after removal from the press. The desired modulus of elasticity was achieved 1 to 2 h after removal from the press.

Tab. 4: Curing kinetics of prepared PB based on UF adhesive.

	Mat heating on 90°C		**Mat heating on 98°C**		**Requirements EN**	
Time (h)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)
0.5	13.75	1381	18.05	1988	13.0	1600
1	14.37	1548	18.51	1999		
2	15.45	1712	18.61	2001		
3	15.52	1731	18.65	1947		
4	14.82	1800	18.72	1997		
24	18.11	1917	19.05	2040		
48	18.35	1972	19.64	2159		
96	18.52	1985	19.83	2162		
120	18.75	2000	20.01	2174		

The presence of a catalyst is important for lowering the curing temperature of UF adhesives. The process is accelerated by its increased concentration. At a temperature of around 100°C, the thermoset resin already undergoes condensation and joining of wood particles in the hot press (Popović et al. 2011). After initiation of condensation, condensation also takes place at a reduced temperature, but more slowly. Curing is thus influenced by time during which the pressed mat remains in the hot press (Heinemann et al. 2004). The development of bending strength and modulus of elasticity in bending over time is shown in Fig. 2. Flexural strength and flexural modulus develop differently over time depending on the adhesive used. They are significantly affected by temperature of the pressed mat during hot pressing, which was demonstrated in the experiment by comparing them at temperatures of 90°C and 98°C measured in the middle of the profile.



a) b)

Fig. 2: Properties of prepared PB based on UF adhesives depending on curing time. Curing kinetics depending on the temperature in the center of the carpet: a) bending strength, b) modulus of elasticity.

Cold pressing process after hot compressing of the mat (PCT/SK2023/000007, ÚPV SR, 13.06.2023).

The essence of invention consists of the use of the properties of lignocellulose, which softens in lignocellulosic materials such as wood, straw, sugar cane and the like under the influence of increased temperature and water (Ihnát et al. 2015). The degree of plasticization increases by overcoming the glass transition with a gradual increase in temperature (Irwin1985, Bouajilaa et al. 2006, Baldwina and Goring1968). The essence of the proposed technology consists of combining the wood plasticization process with the opposite process, the process of its hardening by cooling into one technological unit. By cooling, the softened pressed mat of chips can be stabilized so that after the pressure is released, the wood particles do not spring back (cushioning) and the board has a stable thickness and shape achieved during hot pressing. This fact makes it possible to produce a board whose glue does not have to harden during pressing, but can harden gradually over a longer period of time depending on other technological requirements.

According to PCT/SK2023/000007, the mat of chips is preheated so that temperature in the center of the cross-section is 90-100°C. Such chips with applied glue are pressed under the specified conditions to the required thickness of 16 mm. After reaching the required thickness, the board is cold pressed and intensively cooled below 70°C. Such a PB no longer springs, its thickness remains constant even after the pressing pressure is released. The diagram of the cold pressing process after the hot compressing of the mat is shown in Fig. 3.

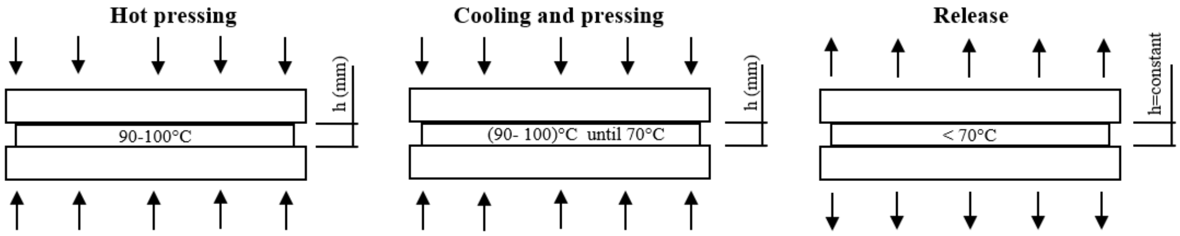


Fig. 3: Schematic of the process of preparing PB by cold pressing after hot compressing of the mat (PCT/SK2023/000007 (ÚPV SR, 13.06.2023).

Temperature and pressure diagram of the cold pressing process after hot compressing the mat

Fig. 4 shows the course of temperature and pressure during the cold laboratory preparation of PB based on PVAC, after the mat is pressed to the required thickness of 16 mm in a hot press and heated to a set temperature of 90°C by steam impact. After reaching the temperature of the chips in the center of the mat, the board goes into the cooling part of the press and cools below 70°C. In this case, the pressure release time is 140 s. The board does not spring and hardens over time.

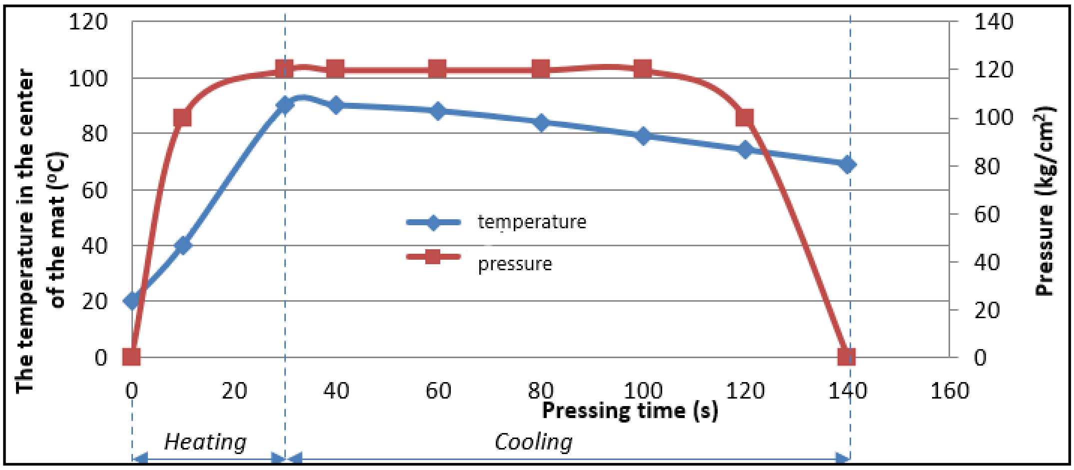


Fig. 4: Temperature and pressure diagram of PVAc based PB preparation by cold pressing after compressing a mat of chips at a temperature of 20°C, heated to a temperature of 90°C in the center of the PBS's cross-section in a hot press and subsequent cooling to 70°C and pressing at a press's plates of 17°C.

Model of the continuous process of cold pressing after hot compressing of the mat

Fig. 5 shows the course of temperature and pressure during the cold laboratory preparation of PB based on PVAC, so that the chips before hot pressing are already heated to the required temperature of 92°C in the drying oven (Fig. 6b). This shortens the heating time.

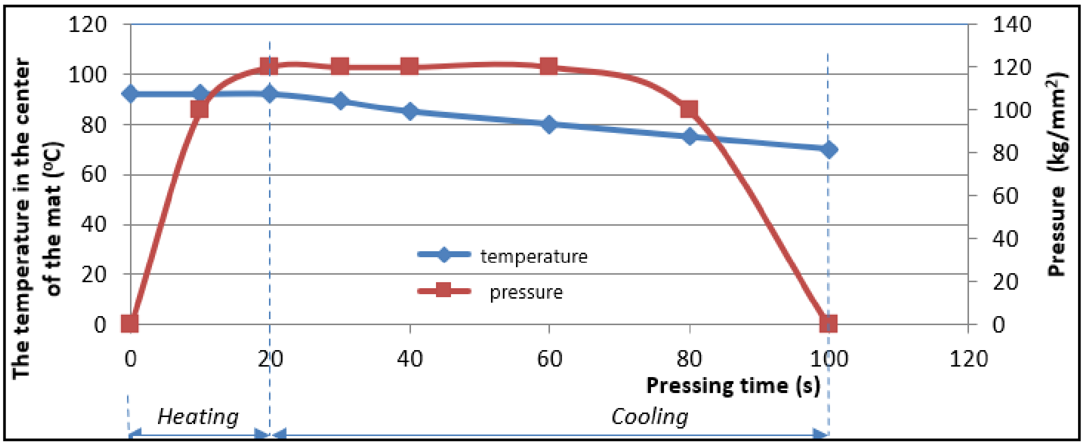


Fig. 5: Temperature and pressure diagram of the preparation of PVAc based PB by cold pressing after compressing the mat from of chips heated to a temperature of 92°C in a drying oven and subsequent cooling to 70°C and pressing at a press's plates of 17°C.

This laboratory method simulates the continuous process of PB preparation in case where adhesive is sprayed onto falling hot chips heated in a drying oven to 92°C (Fig. 6a). The mat of chips created in this way is pressed at a temperature of 92°C to a thickness of 16 mm. After reaching the required thickness, the mat is cooled in a cold press below 70°C. In this case, the pressure release time is 100 s. The plate does not spring and harden after release unlike other continuous hot pressing models (Heinemann et al. 2004).

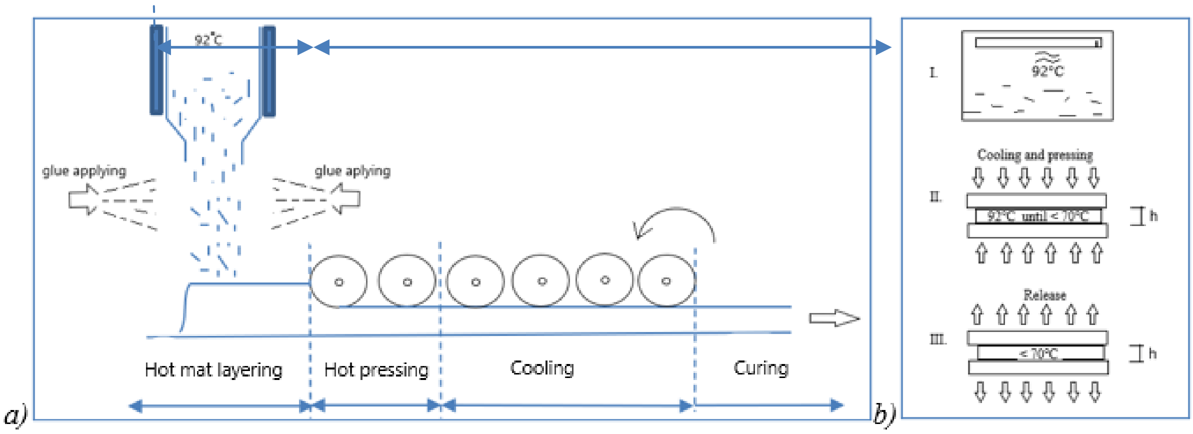


Fig. 6: a) Scheme of the model for applying PVAc glue to hot chips with the implementation of a continuous cold pressing process, b) laboratory simulation of the process.

The overall shortening of the pressing cycle is conditioned not only by shortening of heating but also of cooling time. In this case the mat is heated to 92°C in its entire cross-section. In the first case (Fig. 4), the temperature in the cross-section is unequal. In order to achieve the desired temperature in the center of the mat min 90°C by densification and steam impact (Thoemen and Humphrey 2003), the surface of the board must be heated to a higher temperature.

CONCLUSIONS

Conducted tests on the kinetics of curing of PB prepared by cold pressing technology after hot compressing of the mat according to PCT/SK2023/000007 using PVAc glue, UF glue or their combination confirm the possibility of curing of PB in time after the pressure is released. This fact is made possible by cooling of the PB prepared to a temperature below 70℃measured in the center of the pressed mat, when the shape of the wood chips is already stable and the board does not spring. The final physical and mechanical properties of the prepared PB are at the same level and meet the requirements of EN 312-3. The total pressing cycle time for cold pressing after hot mat compressing for 140 s was reduced to 100 s by simulating continuous pressing with adhesive injection on hot falling chips at a temperature of 92°C.

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