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THE EFFECT OF PINE PARTICLE MOISTURE CONTENT ON PROPERTIES OF PARTICLEBOARDS RESINATED WITH PMDI

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ABSTRACT

The effect of pine particle moisture content (within the 2÷25% range) on properties of particleboards resinated with PMDI was investigated in this study. The conducted investigations showed that along with an increase in particle moisture content (up to 15%) an improvement is observed in the mechanical properties of manufactured boards, i.e. modulus of rupture, modulus of elasticity and internal bond. No significant effect was found for particle moisture content on water resistance of boards, measured by their swelling in thickness after 24h and internal bond after the boiling test.

Key words: particleboard, PMDI resin, particle moisture.

INTRODUCTION

The reason for undertaking numerous studies on the effect of particle moisture content on strength properties of particleboards resinated with PMDI is the potential danger that isocyanate groups required for particle resination might react with water even before pressing, forming polyureas and CO_2. The effect of moisture content is not considered to be uniform. On the one hand, it is stated that moisture content may be within the 2-25% range, with no deterioration of resination quality [1, 4]. Also studies by Palardy et al. [5] showed that using isocyanates it is possible to manufacture flakeboards from material with a very high initial moisture content (25%). However, those authors suggested that in case of using material with such a high moisture content it is necessary either to apply longer pressing times or a higher degree of resination (8%). Taking into consideration the economic aspect neither of these solutions is cost-effective. On the other hand, some authors defined the maximum tensile strength at particle moisture content of approx. 10% [7, 2, 3]. Within the framework of extensive studies Johns et al. [2, 3] investigated the effect and interactions of flake moisture content, pressing temperature, pressing time and thermal finishing on the strength of flakeboards resinated with PMDI in the amount of 3%. In those investigations the authors applied flakes with moisture contents of 4, 10 and 18%, conducting the process of mat thickening in such a way that in all the variants similar thickness profiles are obtained. It was found that among all the investigated factors moisture content of resinated flakes had the biggest effect on modulus of rupture and internal bond. Between 4 and 10% no

significant difference was observed, while moisture content of 18% caused a drastic drop in the strength of the manufactured boards. In comparison to strength properties of boards obtained at flake moisture content of 4% the decrease in tensile strength at high flake moisture content was approx. 30%. The adverse effect of high flake moisture content on properties of boards was observed throughout the whole range of pressing temperatures applied by those authors (150, 180 and 205°C). In contrast, according to Roffael [6] drying particles to very low moisture contents (even below 1%) leads to changes in those properties which play a significant role in the resination process. For example, the pH level of their water extracts decreases and buffering capacity in relation to bases increases. It is probably the cause of a decrease in the internal bond of manufactured boards, manifested more distinctly in case of wet rather than dry tests. The author suggested that particle moisture content-in case of manufacturing particleboards resinated with PMDI–should fall within the 5-6% range.

It is an open question to what degree these controversial results of experiments on the effect of particle moisture content on strength properties of boards resinated with PMDI are dependent on varying experimental conditions. It could have been essential whether particles were conditioned to the required moisture content before resination or sprayed with appropriate amounts of water directly before resination.
Thus, the aim of this study was to investigate if and to what extent the distribution of water on particles affects properties of particleboards resinated with PMDI.

MATERIALS AND METHODS

The applied materials

Particles of pine wood (*Pinus silvestris L.*) produced under commercial conditions were used in the experiments. Before they were applied in the production of boards they were sorted in order to remove dust and fraction passing through a 2-mm square-hole screen.

Polyisocyanate resin (brand name Lupranat® M 20 FB by BASF) was used in the experiments. Properties of the applied resin are presented in Table 1.

Table 1. Characteristics of resin used in experiments

Kind of determination	Properties of PMDI resin		Method of determination
	actual properties	properties stated by the manufacturer	
Density at 25°C, g × cm^{-3}	1.23		DIN 51 757
Viscosity at 25°C, mPa·s	200	170-250	DIN 53 018
NCO-content, g × 100 g^{-1}	31.2	30.0-32.0	ASTM D 5155-91A
Acidity as HCl, mg × kg^{-1}	97	≤300	ASTM D 1638-74
Appearance	brown liquid	-	-

Preparation of particles

Prior to pressing, particles were either dried to moisture contents of 2 and 5% or wetted to moisture contents of 10, 15, 20 and 25%, while wetted particles were air-dried prior to resination. The first batch was air-dried for 1h, whereas the second-for 7 days. Moisture contents of particles used in the production of boards are presented in Table 2.

Table 2. Moisture contents of particles used in production of boards

Assumed particles moisture content	Actual particles moisture content	
	after 1 h	after 7 days
%		
2	2.6	2.6
5	5.5	5.5
10	10.2	10.4
15	14.9	15.4
20	19.4	21.9
25	22.5	24.4

Production of particleboards

One-layer boards of 500 × 600 × 12 mm with the density of 700 kg × m^{-3} were manufactured from such air-dried particles under semi-commercial conditions applying the following pressing parameters:

- pressing time 5 min
- unit pressure 2.5 MPa
- temperature 200°C
- degree of resination with PMDI 8%

Additionally, temperature inside the boards was measured during the pressing process with a device equipped with a probe. Temperature values were read every 15 s.

Properties of the produced boards were investigated in accordance with the relevant standards:

- modulus of rupture MOR and modulus of elasticity MOE according to EN 310,
- internal bond IB according to EN 319,
- internal bond after the boiling test according to EN 1087-1,
- swelling in thickness after 24h soaking according to EN 317.

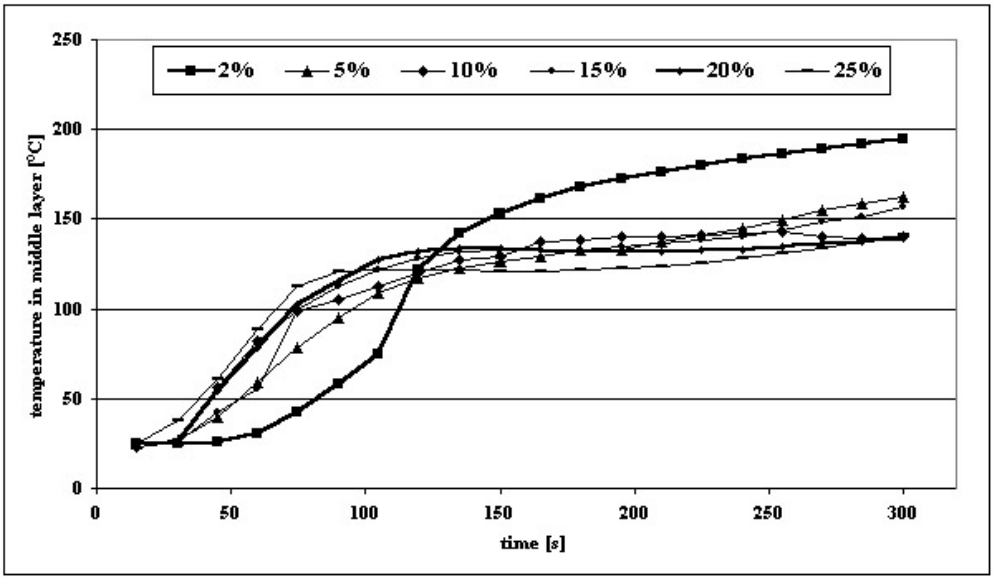
For each investigated property a total of 12 tests were performed, and prior to the determination of the mean arithmetical value and the coefficient of variation dubious results were rejected using the Q Dixon test.

RESULTS AND DISCUSSION

Analysis of temperature distribution in the middle layer of boards during pressing

The course of temperature distribution in the middle layer of boards resinated with PMDI depending on the moisture content of particle mat is shown in Figure 1. It results from the curves that the final temperature of this layer to a considerable degree depends on the particle moisture content and is the highest when particles with the lowest moisture contents (2 and 5%) were applied in the production of boards, especially 2% moisture content, where practically the temperature of heating press platens is obtained. Boards produced from particles with moisture contents exceeding 5% (10-25%) exhibit faster increase in temperature at the beginning of the pressing process, while the higher the particle moisture content the more rapid the increase. In the final period of the pressing process the temperature of these boards is lower than that of boards made from particles with low moisture contents. The above dependencies result from the fact that water is a very good thermal conductor, thus heat is supplied from heating press platens to the inside of the board faster at higher particle moisture contents. However, after reaching approx. 125°C (which corresponds to pressing time within the range of 2 min) heat is intensively recovered by water vapour, large amounts of which are generated at high particle moisture contents, and in connection with this the temperature rise is lower. On the other hand, due to the lower amount of water in particles and as a consequence also water vapour produced during the pressing process of boards with low particle moisture contents they initially heat up more slowly, at the same time reaching higher final temperatures.

Fig. 1. The course of temperature distribution in the middle layer of boards resinated with PMDI depending on the moisture content of particle mat



The effect of particle mat moisture content on mechanical properties of produced boards

Table 3 presents mechanical properties of particleboards resinated with PMDI, which were produced not longer than 1 h after water in the amount required to obtain the assumed particle mat moisture content was applied on the surface of particles.

Table 3. Mechanical properties of particleboards produced from particles subjected to air-conditioning for 1h prior to their resination with PMDI

Particles moisture content	MOR		MOE		IB	
%	MPa	V*,%	MPa	V, %	MPa	V, %
2	18.8	*11.3*	2940	*14.8*	1.15	*8.8*
5	17.0	*8.9*	2930	*13.5*	1.17	*9.0*
10	22.9	*13.0*	3590	*13.5*	1.31	*13.2*
15	24.0	*20.4*	3740	*14.2*	1.43	*5.9*
20	22.6	*12.0*	3410	*12.0*	1.31	*8.5*
25	22.8	*9.3*	3490	*6.5*	1.13	*11.6*

* Variation coefficient

As results from the data included in the table, the lowest mechanical properties were found for boards with particle mat moisture content within the 2-5% range. An increase in particle moisture content above 10% resulted in their improvement, whereas the highest modulus of rupture and internal bond values were obtained for particle boards produced from particles with the moisture content of 15%. These boards also had the highest modulus of elasticity. Thus, water found on the surface of boards (in case of boards wetted starting from 10%) might have had a significant effect on such a distribution of properties of these boards. Starting from the moisture content of 10%, PMDI reacted not only with directly with functional groups of wood components, but to a large degree reactions took place of chain elongation and resin cross-linking through its polyurea structures, formed as a result of a reaction with water found on particle surface. A slight deterioration in bending strength and tensile strength of boards at higher mat moisture contents may be explained by increasing amounts of formed polyurea systems in relation to reactive isocyanate groups capable of entering into reactions with them. Such an interpretation of results seems to be justified by the lowering of internal bond values in boards produced from particles with a 25% moisture content, indicating a distinctly lower number of chemical resin-wood bonds.

In turn, Table 4 presents mechanical properties of particleboards which were produced 7 days after the application of water on the surface of particles in order to obtain assumed moisture contents (it pertains to moisture content ≥10%). It results from the presented data that also in this case properties of boards are dependent on the moisture content of the particle mat. However, the differences are not particularly significant, and generally for the 15-25% range of particle moisture content both bending strength and modulus of elasticity have similar values. Such results indicate that uniform distribution of water in particles is more advantageous for the process of resin cross-linking and its adhesion to wood; it strongly suggests that it prevents the transition of excessive amounts of polyisocyanate into polyureas.

Table 4. Mechanical properties of particleboards produced from particles subjected to air-conditioning for 7 days prior to their resination with PMDI

Particles moisture content	MOR		MOE		IB	
%	MPa	V*, %	MPa	V, %	MPa	V, %
2	14.8	*11.3*	2940	*14.8*	1.15	*8.8*
5	17.0	*8.9*	2930	*13.5*	1.17	*9.0*
10	18.3	*11.8*	3290	*9.7*	1.09	*15.2*
15	26.3	*13.2*	4070	*11.3*	1.31	*7.0*
20	26.1	*7.1*	4130	*8.4*	1.18	*7.1*
25	26.1	*7.2*	4200	*7.4*	1.18	*8.0*

* Variation coefficient

While comparing mechanical properties of boards in terms of the time which passed since the moment appropriate amounts of water were applied on their surface it needs to be stated that generally better mechanical properties are found for boards produced from particles which were air-conditioned for 7 days after the application of water.

The effect of particle moisture content on water resistance of boards

Table 5 presents results of water resistance tests conducted for boards, in which particles with an assumed moisture content had been air-conditioned for 1 h before production, measured using the swelling in thickness after 24 h soaking in water and internal bond after the boiling test. It may generally be stated that swelling is slightly lower only for boards produced form particles with the lowest moisture content (2%). It most probably results from the fact that under these conditions a considerable amount of resin reacted primarily with hydroxyl groups contained in wood components, in this way making the produced board "hydrophobic". On the other hand, internal bond after the boiling test was very high in the produced boards and no distinct dependency was found on the moisture content in the mat of pressed particles. Analogous dependencies were observed for particleboards produced from particles air-conditioned prior to their resination with PMDI for the period of 7 days (Table 5), while these boards exhibit slightly higher internal bond after the boiling test.

Table 5. Water resistance of particleboards produced from particles subjected to air-conditioning for 1 h or 7 days prior to their resination with PMDI

Particles moisture content	Swelling in thickness after 24 h		V 100	
	after 1 h air-conditioning particles	after 7 days air-conditioning particles	after 1 h air-conditioning particles	after 7 days air-conditioning particles
	%			
2	12.6 *10.0**	12.6 *10.0*	0.91 *11.3*	0.91 *11.3*
5	15.1 *7.8*	15.1 *7.8*	1.10 *8.9*	1.10 *8.9*
10	17.0 *7.6*	15.2 *4.7*	0.88 *20.7*	1.08 *9.8*
15	15.6 *8.2*	14.9 *9.8*	0.94 *8.6*	1.04 *8.0*
20	14.9 *5.9*	14.2 *4.4*	0.78 *11.3*	0.98 *11.4*
25	14.7 *6.8*	13.5 *4.6*	0.79 *7.9*	0.83 *10.9*

* Variation coefficient

CONCLUSION

1. Moisture content of the particle mat has a significant effect on the course of temperature in the middle layer during the pressing process of particleboards resinated with PMDI. The highest temperatures in this layer are obtained for boards with the lowest moisture content, although along with the increase in particle moisture content in the initial period of the pressing process the overheating of the particle mat occurs faster.
2. The best mechanical properties were found for boards produced from particles with the moisture content of 15%, which after applying additional amounts of water were air-conditioned prior to production for 7 days.
3. A slightly higher water resistance measured by swelling in thickness after 24h of soaking in water was found for boards which were produced using particles with low moisture contents. However, internal bond after the boiling test did not show a direct dependency on the moisture content in the mat of pressed particles.
4. Uniform distribution of moisture content in pine particles (longer air-conditioning after the application of water on their surface) makes it possible to obtain particleboards with better mechanical properties and improved water resistance.

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