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Effect of Resin and Wax on Mechanical and Physical Properties of Harboard From Air-Laid Mats

Ujtecaj smole i voska na mehanička i fizikalna svojstva tvrdih vlaknatica proizvedenih suhim postupkom

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ABSTRACT • *Wax has long been used to improve physical and dimensional stability properties of hardboard. However, the value of adding wax to a composite must also consider the level of resin used. In this study, two levels of resin (6.5 % and 11%) and three levels of wax (0%, 0.8%, and 1.6%) were applied to hemlock fiber. The fiber was converted into mats made on a nonwoven, airformed line. For all mats, the wood fiber was blended with 10% polyester fiber to provide strength. The mats were pressed into 3-mm-thick panels, cut into specimens, and tested for mechanical and physical properties. The results showed that increasing the levels of resin and wax had little effect on mechanical properties but did improve physical properties.*

Key words: *wood fiber, polyester fiber, composites, dry-process, harboard, phenolic resin, wax, dimensional stability, mechanical properties, physical properties*

SAŽETAK • *Vosak se već dugo koristi za poboljšanje fizičkih svojstava i dimenzijske stabilnosti tvrdih vlaknatica. Povoljnost dodavanja voska, međutim, treba razmatrati uzimajući u obzir i količinu upotrijebljene smole. U ovom ispitivanju dva su iznosa količine dodane smole (6.5 % i 11 %) kombinirana s tri vrijednosti dodatka voska (0 %, 0,8 % i 1,6 %) vlakancima čugovine (engl.*

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hemlock, Tsuga heterophylla). Vlakanca su nataložena u tepihe na zračnoj liniji. Svi su tepisi obogaćeni dodatkom 10 % poliesterskih vlakanaca radi postizanja veće čvrstoće. Tepisi su stiješnjeni u 3 mm debele ploče, od kojih su izrađeni uzorci za ispitivanje mehaničkih i fizikalnih svojstava. Rezultati pokazuju da povećanje dodatka smole i voska ima samo mali utjecaj na mehanička svojstva ali da se time poboljšavaju fizikalna svojstva.

Ključne riječi: *drvna vlakanca, poliesterska vlakanca, suhi proces izrade vlaknatica, tvrde vlaknatice, fenolna smola, vosak, dimenzijska stabilnost, mehanička svojstva, fizikalna svojstva*

1. INTRODUCTION
1. Uvod

Water repellency - the ability to repel liquid water and water vapor - is essential for the service life of structures sheathed with various types of wood-based panels. Poor water repellency may lead to dimensional instability, as measured by thickness swell and linear expansion. Poor dimensional stability, in turn, can eventually lead to a reduction in strength properties.

Wax has been used to improve the water repellency of wood-based and other composite products. The addition of up to 2% wax improves the water repellency of particleboard, hardboard, waferboard, and oriented strandboard. Wax has also been used in the manufacture of nonwoven wood fiber-plastic fiber composites. Covering the surfaces of individual fibers with wax reduces the surface energy of the fiber, making it more hydrophobic and less susceptible to the influences of moisture in high humidity conditions. The ability of wax to repel liquid water and water vapor is related to wax chemical composition, physical properties (melting poing, viscosity, and oil content) that affect application with conventional spray technology, and application rate (Clad 1985, Hsu et al. 1990).

In studying the effect of wax on the dimensional stability of particleboard as influenced by test methodology, Heebink (1967) concluded that equilibration of specimens at low and high (30% and 90%) relative humidities is more useful than short-time water-soak procedures for evaluating thickness swell. Suzuki and others (1976) studied the effect of six resin and two wax levels on the ability of dry process fiberboard to absorb water. They concluded that water absorption and thickness swelling tend to decrease with an increase in resin, an increase in panel density, and the addition of paraffin. The effect of paraffin on water absorbability gradually decreased with an increase in soak time. In studying the effect of wax content on waferboard properties, Hsu et al. (1990) reported that addition of wax lowered thickness swelling and tended to improve mechanical properties, but the effect did not increase proportionately with wax content. Youngquist and others (1990) reported that for the 24-h water- soak test, increased resin and wax content generally decreased water absorption and thickness swell of hardboards prepared with two levels of resin and wax. However, the addition of wax decreased bending properties.

Winistorfer and others (1992) evaluated the influence of 10 wax products and 3 wax application rates (0.5%, 1.0%, and 1.5%, based on ovendry furnish weight) on the properties of oriented strandboard. The results for internal bond suggest that the application of any wax in any of the three amounts studied reduces bond quality, but higher application rates reduce water absorption, thickness swell, and linear expansion.

Air-laid web composites provide options for balancing performance properties and costs, depending upon the application under consideration. However, the use of airlaid products is limited by the poor dimensional stability resulting from the hygroscopic nature of wood fibers. To improve dimensional stability properties, the wood fiber can be modified with a wax. The dimensional stability of panel products made from modified fibers is better than that of panels made from unmodified fibers.

The purpose of our research was to determine the mechanical and physical properties of composite panels made from various combinations of wood fiber, resin, wax, and textile fiber.

2. EXPERIMENTAL DESIGN AND ANALYSIS
2. Pokus i analiza

The experiment was an incomplete factorial test of two sets of panels with 1.0 g/cm^3 density. In the first set, wood fibers

Table 2.
Effect of resin content on mechanical and physical properties of hardboards • Utjecaj sadržaja smole na mehanička i fizikalna svojstva vlaknatica

Property Svojstvo	ANSI A135.4 tempered hardboard uljem obogaćena vlaknatica	83.5% hemlock fiber 6.5% phenolic resin 0% wax 1 0% polyester	79.0% hemlock fiber 11.0% phenolic resin 08% wax 10% polyester	**Postotno učešće** - vlakanaca čugovine - fenolne smole - voska - poliestera
Static bending MOR (MPa) Modul loma kod statičkog savijanja (MPa)	41.4	49.8	53.5	
Static bending MOE (GPa) Modul elastičnosti kod statičkog savijanja (GPa)	N/A	4.85	4.95	
Tensile strength (MPa) Vlačna čvrstoća (MPa)	20.7	26.9	31.2	
Tensile MOE (GPa) Vlačni modul elastičnosti (GPa)	N/A	5.15	5.36	
Impact energy (J) Energija kod udara (J)	N/A	34.8	29.6	
Thickness swell 24-h (%) Debljinsko bubrenje 24 h (%)	20	20.7	13.1	
Water absorption 24-h (%) Upijanje vode 24 h (%)	25	43.4	34.9	
Linear expansion (%) Linearno izduženje (%)				
30% RH (r.v.z.)	N/A	0.17	0.18	
65% RH (r.v.z.)	N/A	0.37	0.38	
90% RH (r.v.z.)	N/A	0.58	0.57	

a Values connected by solid line are not statistically different at 0.05 significance level.
a Vrijednosti spojene punom linijom nisu statistički signifikantno različite na nivou 0,05.

pansion test specimens were of the size specified in ASTM D1037. Length was measured at equilibrium at 30%, and 90% RH at 27 °C. Specimens were then oven-dried, and length was measured. Linear expansion values were calculated over the following ranges: ovendry to 30% RH, ovendry to 65% RH, and ovedry to 90% RH.

4. RESULTS AND DISCUSSION
4. Rezultati i diskusija

Mechanical and physical properties of composite panels are presented in Tables 2 and 3; data include results of multiple comparisons.

Static Bending Properties

Effect of resin - Panels made with 11 % resin had the higher bending MOR value (53.5 MPa); MOR was 49.8 MPa for panels made with 6.5% resin. A pattern similar to that found for MOR values was noted for bending MOE values; panels containing 11% resin exhibited slightly higer MOE. No statistically significant differences were observed for MOR and MOE bending properties at either resin level.

The minimum required MOR value in the American National Standards Institute-American Hardboard Association (ANSI-AHA) A135.4 standard is 41.4 MPa for tempered hardboard (AHA 1995). In our study, all boards met this minimum property requirement.

Effect of wax - In general, no statistically significant differences were observed for both MOR and MOE bending properties at all tested wax levels.

Tensile Strength Properties

Effect of resin - For the panels with 11% resin, tensile strength was 31.2 MPa, 16% greater than the tensile strength of panels with 6.5% resin. Thus, tensile strength values were significantly different for these two formulations. In contrast, tensile modulus MOE values were very close to each other. Therefore, the higher resin level did not significantly influence tensile MOE values. The minimum tensile strength parallel to panel surface as specied in the ANSI-AHA standard is 20.7 MPa for tempered hardboard. Treatments at all resin and wax levels

Hemlock fiber (%) Vlakanca čugovine (%)	Phenolic resin (%) Fenolna smola (%)	Wax (%) Vosak (%)	Resinated wood fiber to polyester fiber (%) Omjer učešća smolom oblijepljenih drvenih vlakanaca i poliesterskih vlakanaca (%)
93.5	6.5	0	90/10
89.0	11.0	0	90/10
82.2	11.0	0.8	90/10
87.4	11.0	1.6	90/10

Table 1. *Experimental design • Sastav pokusnih ploča*

were treated with 6.5% or 11% resin; in the second set, wood fibers were treated with 11% resin and 0, 0.8%, or 1.6% wax (Table 1). Polyester fiber was used to provide mat strength and integrity. The ratio of resinated wood fiber to polyester was 9:1.

Approximately 26 panels were produced for each formulation. Six panels were used for impact testing; each remaining panel was cut into one linear expansion specimen, two tensile specimens, two bending specimens, and two water-soak specimens.

No outlying data were found in this experiment. Each data set was tested for normality at the 5% significance level using Shapiro- Wilk statistical analysis. Nonparametric methods of analysis were used for those properties that showed non-normality. For both the normal and non-normal cases, means were compared at a 0.05% significance level using Tukey's method of multiple comparisons.

3. MATERIALS AND METHODS
3. Materijal i metode

The amount of resin and wax was determined by Canadian Forest Products Ltd. (CANFOR, Vancouver, BC), who were interested in the mechanical and physical properties of composite panels as preliminary data for a full-scale mat production line. Resin and wax were applied to western hemlock (*Tsuga heterophylla*) fibers at the CANFOR facility before the material was shipped to the Forest Products Laboratory in Madison, Wisconsin.

Wood fibers were produced from 100% pulp-grade chips, steamed for 2 min at 0.759 MPa, fiberized in a pressurized disk refiner, and flash dried at 160 °C in a tube dryer. This processing sequence produced fibrous strands made of individual fibers, pieces of fiber, and fiber bundles. In this report, these fibrous strands are referred to as fibers. The phenolic resin had a solids content of 48%, viscosity of 0.1 Pa•s at 25 °C, and pH of 9.5. The resin was applied to the fiber in the blow line after it exited from the refiner. The petroleum slack wax, which had a solids content of 100% and melting point of 62 °C, was applied to the wood chips prior to the refining process. The polyester fiber was obtained from DuPont de Nemours, Inc. (Wilmington, DE); the fiber had 5.5 denier (6.1 x 10^{-7} kg/m), was 38 mm long and crimped, and had a bonding temperature >215 °C.

The wood and polyester fibers were mixed by passing them through a 305-mm wide, laboratory-scale Rando-Webber nonwoven web-forming machine. Webs measuring 305 by 305 mm were weighed and selected into various weight categories. Appropriate webs were then selectively stacked to arrive at the target panel basis weight. Webs with any type of defect were discarded.

The 305- by 305-mm mats were stacked so as to construct a multi- layer mattress to produce a density of 1.0 g/cm^3 per panel. Panels were pressed in a manually controlled, steam-heated press at 195 °C for 4 min, with no cooling procedure. A digital thickness-measuring gauge was used to determine platen closing to produce 3.2-mm-thick panels. After pressing, panels were trimmed to a final size of 279 by 279 mm.

For each wax-resin formulation, panels were tested for mechanical and physical properties, including dimensional stability. Prior to tests at room temperature (about 23 °C), specimens were conditioned at 65% relative humidity (RH) and 20 °C. Specimens had minimal exposure to ambient humidity during testing.

Three-point static bending modulus of rupture (MOR) and modulus of elasticity (MOE), tensile strength, and tensile MOE parallel to panel surface were evaluated in conformance with ASTM D1037 (ASTM 1994) using an Instron testing machine. Impact energy was measured in conformance with TAPPI standard T803 om-88 (TAPPI 1989). Thickness swell and water absorption measurements were made by immersing specimens in water horizontally for 24 h at ambient temperature. Testing for thickness swell-water absorption was conducted in conformance to ASTM D1037. Linear ex-

Table 3. *Effect of wax content on mechanical and physical properties of hardboards • Utjecaj sadržaja voska na mehanička i fizikalna svojstva vlaknatica*

Property Svojstvo	ANSI A135.4 tempered hardboard uljem obogaćena vlaknatica	79.0% hemlock fiber 11.0% phenolic resin 0% wax 10% polyester	78.2% hemlock fiber 11.0% phenolic resin 08% wax 10% polyester	77.4% helock fiber 11.0% phenolic resin 1.6% wax 10% polyester	**Postotno učešće** - vlakanaca čugovine - fenolne smole - voska - poliestera
Static bending MOR (MPa) Modul loma kod statičkog savijanja (MPa)	41.4	53.5	51.7	50.7	
Static bending MOE (GPa) Modul elastičnosti kod statičkog savijanja (GPa)	N/A	4.95	5.98	4.75	
Tensile strength (MPa) Vlačna čvrstoća (MPa)	20.7	31.2	30.7	30.0	
Tensile MOE (GPa) Vlačni modul elastičnosti (GPa)	N/A	5.36	5.48	5.45	
Impact energy (J) Energija kod udara (J)	N/A	29.6	34.9	33.0	
Thickness swell 24-h (%) Debljinsko bubrenje 24 h (%)	20	13.1	12.6	10.1	
Water absorption 24-h (%) Upijanje vode 24 h (%)	25	34.9	24.1	23.4	
Linear expansion (%) Linearno izduženje (%)					
0-30% RH (r.v.z.)c	N/A	0.18	0.17	0.21	
			(b)		
0-65% RH (r.v.z.)	N/A	0.38	0.38	0.40	
0-90% RH (r.v.z.)	N/A	0.57	0.57	0.59	

a) Values connected by solid line are not statistically different (p = 0.05).
b) The 0.18% and 0.21% linear expansion values are not statistically different.
a) Vrijednosti spojene punom linijom nisu statistički signifikantno različite (p = 0,05)
b) Vrijednosti lienarnog izduženja od 0,18% i 0,21% nisu statistički signifikantno različite.
c) r.v.z. = relativna vlažnost zraka

exceeded this minimum value.

Effect of wax - Tensile modulus MOE values were nearly equal for the three wax formualtions; no significant differences were noted.

Impact Energy

Effect of resin - The 11% resin level produced statistically significant reduction in impact energy - this property was 15% below that of panels made with 6.5% resin. Clegg and Collyer (1986) suggest that the higher impact energy of panels with 6.5% resin may reflect a bonding condition between the wood and polyester fibers. Although polyester fibers act as reinforcing fibers and wood fibers form the matrix, Clegg and Collyer's theory suggests that panels with 6.5% resin may have minimal bonding between wood and polyester fibers, which allows polyester fibers to be pulled from the wood fiber matrix without breaking. This withdrawal of polyester fibers from the matrix could cause an increase in energy absorption during the impact test. In the case of panels made with 11% resin, the bond between wood and polyester fibers may be strong enough to cause the polyester fibers to break during the impact test rather than be witdrawn from the matrix fibers. In this situation, the energy required to break the fibers is less than that required to withdraw them.

Effect of wax - For the 0.8% was level, imapct energy was increased by about 18% compared with that of the control panel, a statistically significant difference. However, test results showed no clear pattern or significant difference between the 0.8% and 1.6% wax application rates. It is possible that other sources of variation not accounted for by this test procedure caused the difference in impact properties between wax application rates.

Thickness Swell and Water Absorption

The ANSI-AHA maximum property standards for tempered hardboard are 20% for thickness swell and 25% for water absorption.

Effect of resin - As expected, thickness swelling decreased by 36% for the higher level of resin. Thickness swell values at 6.5% resin were almost equal to those allowed by the standard and at 11% resin, much lower than allowable values. Results similar to thickness swell data were observed for the water absorption values, which were 20% lower for panels with 11% resin compared to those with 6.5% resin. Nevertheless, water abosprtion of panels without wax was higher than the allowed maximum of 25% at both resin levels. It was particularly noticeable that the higher resin level significantly influenced water-soak properties. These results are in agreement with other research on natural fiber- polymer composites (Youngquist and others, 1992, Krzysik and others, 1993).

Effect of wax - The amount of wax had little influence on thickness swell and water absorption values. Incorporating 0.8% wax did not significantly influence thickness swell; 1.6% wax produced a small but statistically significant improvement. One noteworthy observation from this test is that hese properties were very close - 10.1% to 13.1% - for all tested wax levels and well below the maximum specified in the standard.

The pattern for water absorption was different from that for thickness swell. Water absorption values of panels made with 0.8% and 1.6% wax were not significantly different; values ranged from 24.1% to 23.4%. The 1.6% level of wax decreased water absorption properties by about 33%. For both thickness swell and water absorption, additional benefits obtained from increasing wax content from 0.8% to 1.6% were small. Panels containing 1.6% wax exhibited the lowest thickness swell and water absorption values (10.1% and 23.4%, respectively).

Nevertheless, some improvements in these properties were statistically signficant, and values at both wax levels were slightly below the maximum allowable values. Winistorfer and others (1992) reported similar results in water-resistant properties of orineted strandboard with increase in wax application rate.

Linear Expansion

Effect of resin - For both resin levels, linear expansion values at 30%, 65%, and 90% RH were very similar and statistically equivalent.

Effect of wax - For all wax levels, linear expansion values at 30% RH ranged from 0.17% to 0.21% and results were not consistent. At 65% and 90% RH, no significant differences were noted among all wax levels. The relationship of linear expansion to wax application rates appears to depend on the RH at which length is measured. Apparently, the phenomena that determine linear expansion during changes of RH for different wax application rates are more complicated than those that determine thickness swell or water absorption.

5. CONCLUDING REMARKS
5. Zaključci

1. In general, nearly all property values exceeded requirements specified in the ANSI-AHA standard for tempered hardboard.

2. Most mechanical properties were not significantly influenced by increasing the resin level, whereas physical properties for the water-soak tests did show significant improvement.

3. Mechanical properties were not sig-

nificantly influenced by the addition of wax, except for impact energy. On the other hand, wax improved water-soak properties significantly, depending on the level added.

4. Linear expansion was not affected by resin or wax level.

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