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THE EFFECT OF WOOD CHIP SUBSTITUTION WITH EVENING PRIMROSE WASTE ON PROPERTIES OF PARTICLEBOARDS DEPENDING ON THE TYPE OF BINDING AGENT

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ABSTRACT

Within the framework of the presented study properties of particleboards manufactured with a proportion of evening primrose straw were investigated depending on the type of the applied binding agent. Straw of evening primrose was used as a substitute of wood chips in the core of boards at 0, 5, 10, 15, 25, 50, 75 and 100% chip weight. UF, MUPF and PMDI resins were used as binding agents. Tests showed that depending on the applied binding agent total or partial substitution of wood chips with particles of evening primrose straw is feasible in the process of particleboard manufacture.

Key words: lignocellulose board, binding agents, evening primrose straw

INTRODUCTION

The development of particleboard industry, caused by an increased demand for these boards in such sectors as furniture industry and the construction business, as well as the deficit of wood supplies observed worldwide and its high prices encourage board producers to search for alternative non-wood lignocellulose raw materials of plant origin. Studies on the substitution of wood chips with particles of annual plants and agricultural waste products, particularly cereal straw, have been conducted for many years [1, 2, 3, 4, 5, 10, 11, 12]. Taking into consideration the volume of straw production worldwide it seems to be the most important raw material in board production, especially in countries with low afforestation rates. Chemical composition and morphology of these plants differ from the composition and structure of wood, which results in certain problems with their processing. A major difficulty in the application of straw in board industry is the seasonality of its supply - straw is harvested during only 4 - 6 weeks in a year. Providing its reserves for the entire year of production would require considerable warehousing space and optimal storage conditions, e.g. humidity at 10 - 12%, in order to limit microbial development and biodegradation [13]. When searching for a solution to this problem the authors of this study focused on the residue of herbaceous plants, frequently harvested after cereal harvest time. Waste of herbaceous and meadow plants such as hemp and flax shives were already used in the initial period of particleboard production and they were applied both in furniture industry and construction engineering [7]. At present both in Poland and other European countries a markedly increased interest has been observed in the cultivation of this type of plants (alternative plants) and in products of their processing. This has been caused by an enhanced interest of the public in products of natural origin and in the fact that their cultivation in view of food overproduction in most European countries offers new potential use for fallow land and a chance to increase revenue from farms [8]. It is estimated that in Poland the area covered by herb growing is at present approx. 35 000 ha, while in the EU it is approx. 70 000 ha, mainly in France and Spain [9]. Approximately 100 000 ton herbs are harvested and processed annually. In view of the growing demand for processed herbal products it may be assumed that in the nearest future the area of herb growing is going to increase considerably and herb processing will be transformed into modern pharmaceutical industry [6]. For this reason quantities of cultivation minor elements will also increase, which may be used in further processing, e.g. as an alternative lignocellulose raw material in board industry. Such an innovative material for board manufacture may be straw of an evening primrose species *(Oenothera paradoxa Hudziok)*, which is harvested in September and its considerable annual growth increment (100 – 150 cm) suggests a potential industrial application. Cultivation of evening primrose is easy, as the species yields well on weak and sandy soils and it is drought resistant. Evening primrose is a medicinal plant. Oil made from its seeds, due to its high content of g-linolenic acid (GLA), is widely used in the cosmetics industry and in medicine. For this reason for several years now a growing interest in this plant has been observed and the area of its cultivation has been increasing.

Thus the aim of this study was to investigate feasibility of wood chip substitution with evening primrose straw in the process of particleboard manufacture using binding agents commonly applied in board industry.

MATERIALS AND METHODS

Boards were manufactured using pine wood chips and particles of evening primrose straw with the following resins as binding agents: urea–formaldehyde (UF), melamine-urea-phenol–formaldehyde (MUPF) and isocyanate (PMDI) resins. Characteristics of resin adhesives used in these experiments are presented in Table 1.

Table 1. Properties of resin adhesives used in experiments

Type of test	Unit	Properties of resin		
		UF	MUPF	PMDI
Density	g/cm^3	1.316	1.298	-
Viscosity	mPa·s	748	516	250
Apparent dry matter content	%	72	63.5	100
Miscibility with water	-	1.6	1.0	-
Gel time at $100^{\circ}C$	s	90	83	-
pH	-	8.00	9.35	-
Acid value	mg/kg	-	-	1218
NCO group content	%	-	-	30.9

In order to determine the effect of wood chip substitution with particles of evening primrose straw, three-layer particleboards with a thickness of 19 mm and density of 700 kg/m^3 were manufactured on a semi-commercial scale, applying the following parameters:

- the rate of wood chip substitution in the core layer of boards with evening primrose straw: 0, 5, 10, 15, 25, 50 and 100% chip weight
- resination rate depending on the type of binding agent:
    - UF and MUPF resins – in outer layers at 12%, in the core at 8%
    - PMDI resin - in outer layers at 8%, in the core at 6%
- pressing conditions:
    - temperature 200°C

- pressure 2.5 N/mm^2
- pressing time 23 s/mm board thickness.

Manufactured boards were tested in terms of their physical and mechanical properties in accordance with respective standards:

- modulus of rigidity (MOR) and modulus of elasticity (MOE) according to EN 310,
- internal bond (IB) according to EN 319,
- internal bond after the boiling test V – 100 according to EN 1087-1 (for MUPF and PMDI resins),
- swelling in thickness after 24h soaking in water (G_t) according to EN 317 and additionally absorbability also after 24 h soaking in water (W_n)
- formaldehyde content using the perforation method according to EN 120 (for UF and MUPF resins)

DISCUSSION AND RESULTS

Testing results concerning mechanical properties of manufactured straw–chip boards are presented in Table 2.

Table 2. The effect of wood chip substitution with evening primrose straw in the core layer of particleboards on their mechanical properties, depending on the type of binding agent

Evening primrose fraction %	MOR			MOE			IB		
	N/mm^2								
	UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
0	13.9	16.6	22.1	2740	3040	3420	0.46	0.70	1.13
	1.43	*1.40*	*1.81*	*221*	*172*	*240*	*0.02*	*0.09*	*0.05*
5	13.4	16.4	22.0	2720	3020	3320	0.45	0.65	1.11
	0.64	*1.48*	*2.26*	*93*	*113*	*310*	*0.03*	*0.04*	*0.04*
10	12.8	16.4	22.0	2710	3020	3390	0.44	0.61	1.01
	1.28	*0.63*	*1.57*	*139*	*109*	*250*	*0.03*	*0.03*	*0.07*
15	11.8	16.4	21.7	2540	2970	3360	0.43	0.60	0.97
	0.49	*0.97*	*2.20*	*69*	*175*	*290*	*0.02*	*0.06*	*0.03*
25	11.6	16.2	21.1	2510	2970	3360	0.42	0.57	0.88
	0.54	*1.57*	*2.64*	*139*	*226*	*510*	*0.01*	*0.05*	*0.05*
50	11.7	16.0	20.3	2440	2840	3110	0.42	0.54	0.86
	1.25	*1.55*	*2.25*	*191*	*228*	*320*	*0.01*	*0.03*	*0.06*
75	11.5	15.8	19.4	2320	2810	2830	0.40	0.54	0.84
	0.25	*1.05*	*2.36*	*181*	*120*	*210*	*0.02*	*0.04*	*0.08*
100	11.6	15.5	18.6	2160	2680	2800	0.38	0.56	0.79
	0.38	*1.68*	*1.69*	*126*	*197*	*150*	*0.03*	*0.03*	*0.06*

It results from the analysis of data that with an increase in the wood chip substitution rate with evening primrose straw, for each tested type of binding agent, a slight decrease is observed in bending strength and modulus of elasticity of manufactured boards. A reduction of bending strength for boards with the core made entirely from evening primrose straw is 15% for UF and PMDI resins and 7% for MUPF resin. Results of board rigidity testing exhibit an analogous trend. Values of the modulus of elasticity decreased by a maximum of 15% for boards from evening primrose straw resinated with UF and PMDI and by 10% for MUPF resin. However, it needs to be stressed here that despite such a significant drop in this value for boards resinated with PMDI, even for boards manufactured solely from straw, it is higher than for boards manufactured from wood chips and resinated with the other resins, particularly UF (by approx. 25%). It needs to be assumed that it is caused by a much higher adhesion of PMDI to the surface of straw particles than the other types of resin. Thus it may be stated that irrespective of the type of binding agent used in the tests with an increase in the proportion of evening primrose straw particles in the core of boards their strength properties deteriorated, reaching the lowest values for boards made entirely from straw particles, with the highest strength at a given substitution rate found for boards resinated with PMDI. Recorded values of bending strength as well as internal bond of boards manufactured even in 100% from evening primrose straw and resinated with UF adhesive showed that they meet the requirements of standard EN-312 for general purpose boards used under dry conditions (type P1) and in case of a 10% substitution for boards used in interior design, including furniture (type P2). In case of MUPF resin, strength parameters of boards containing up to 50% straw particles meet the requirements for board bearing loads, used under humid conditions, i.e. boards type P5. In order to manufacture boards solely from evening primrose straw exhibiting strength required for board type P5, it is necessary to apply PMDI as the binding agent. Its use, at a 50% wood chip substitution with evening primrose particles, makes it possible to manufacture boards with an enhanced capacity to bear loads, to be used under humid conditions (type P7).

The effect of substitution rate of wood chips with evening primrose straw particles on water resistance of manufactured boards was defined by measuring their swelling in thickness and absorbability after 24 h soaking in water, and for MUPF and PMDI resin by determining their internal bond after the boiling test. It results from data given in Table 3 that in case of condensation resins the introduction of evening primrose straw particles to the core of boards has an adverse effect on their hydrophobicity as defined by swelling in thickness and absorbability.

Table 3. The effect of wood chip substitution with evening primrose straw in the core layer of particleboards on their water resistance, depending on the type of binding agent

Evening primrose fraction %	Swelling in thickness after 24 h			Absorbability after 24h			V -100		
	%						N/mm^2		
	UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
0	23.6	18.0	17.0	93.9	76.0	69.8	-	0.04	0.52
	1.87	*0.87*	*0.7*	*6.76*	*1.63*	*2.60*		*0.01*	*0.04*
5	24.0	18.1	16.8	91.9	76.0	68.2	-	0.04	0.47
	1.26	*1.13*	*0.3*	*5.68*	*3.20*	*2.10*		*0.01*	*0.03*
10	25.0	18.5	16.5	90.0	75.2	68.1	-	0.03	0.32
	1.08	*1.04*	*1.0*	*3.88*	*2.03*	*0.31*		*0.00*	*0.03*
15	25.3	19.1	16.4	87.6	75.8	68.0	-	0.03	0.28
	2.56	*0.71*	*0.7*	*3.03*	*2.37*	*1.62*		*0.01*	*0.01*
25	27.5	19.5	16.5	87.2	75.0	63.4	-	0.03	0.24
	2.00	*0.65*	*0.7*	*4.61*	*1.65*	*9.41*		*0.01*	*0.02*
50	28.9	21.2	14.1	86.9	74.9	47.6	-	0.03	0.16
	2.03	*1.43*	*1.0*	*6.62*	*2.83*	*2.19*		*0.00*	*0.02*
75	29.5	21.2	8.6	86.0	73.4	45.2	-	0.02	0.07
	4.31	*0.74*	*1.4*	*5.77*	*1.63*	*5.77*		*0.01*	*0.01*
100	30.3	21.8	7.5	85.7	71.5	37.1	-	0.02	0.06
	1.81	*0.55*	*0.7*	*5.06*	*0.76*	*3.71*		*0.01*	*0.01*

It was observed that in comparison to chip boards a long-term action of water results in an increase of swelling in thickness of boards manufactured solely from straw particles, amounting to 20% for UF and 28% for MUPF. In turn, a different trend was found for swelling in thickness for boards, in which PMDI was used as the binding agent. In this case a total replacement of wood chips with particles of evening primrose straw results in a reduction of swelling by approx. 50%. Such a significant downward trend was also recorded for absorbability of these boards. For boards resinated with UF and MUPF resins such a marked effect of the presence of straw particles on board absorbability was not found. Such a behaviour of boards resinated with PMDI in comparison to the other binding agents probably results from the chemical affinity of this resin in relation to functional groups found on the surface of evening primrose particles, stability and water resistance of glue lines, which at the simultaneous increase in cohesion of boards with an increase in straw content results in a reduction of their swelling in thickness and absorbability. Conducted analyses of internal bond after the boiling test also showed that the application of PMDI makes it possible to manufacture chip-straw boards containing up to 50% particles of evening primrose straw and exhibiting water resistance required by standard EN 312 for board type P5. In turn, in order to maintain water resistance required for P7 boards the threshold value of wood chip substitution is 25%. When considering the results of tests in this respect for boards resinated with MUPF resin it turned out rather unexpectedly that the recorded values of internal bond after the boiling test, even for boards manufactured solely from wood chips, do not meet the requirements of the above mentioned standard (the value required for P3 board of 0.08 N/mm^2). It probably results from the fact that hydrophobic agents were not used when manufacturing these boards. However, for this type of resin adhesive it may be stated that the presence of evening primrose straw in the core layer of the tested boards does not have a significant effect on the value of this parameter.

Results of tests concerning free formaldehyde content in boards manufactured using UF and MUPF resins, determined by the perforation method, are given in Fig. 1. The obtained high level of formaldehyde content in the investigated boards, especially those produced entirely from wood particles, exceeding the acceptable value 8,0 mg/100 g of board dry mass, undoubtedly results from the fact that the boards were produced without the use of formaldehyde-bonding agents commonly used in the commercial scale of the production process. Nevertheless, it was observed that the proportion of evening primrose straw particles in particleboards has an advantageous effect on the hygienic standard. Total substitution of wood chips in the core layer of boards results in a reduction of formaldehyde content by even as much as 45% in case of UF resin and by 30% for MUPF.

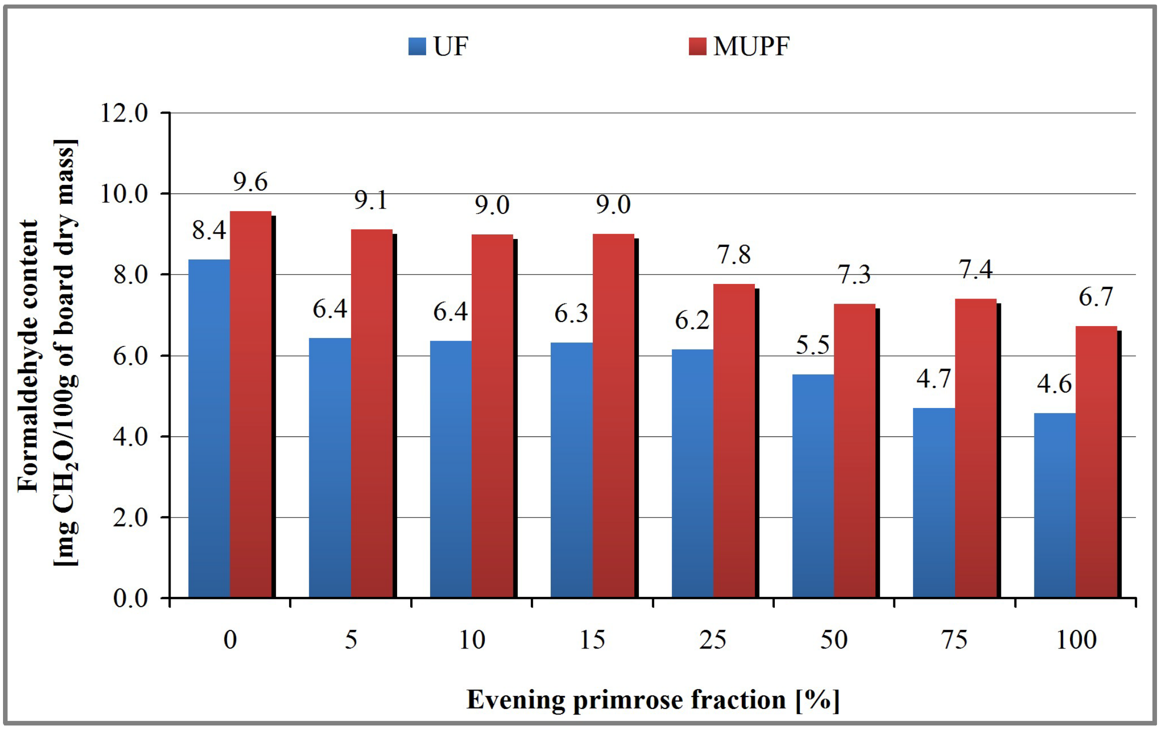

Fig.1. Formaldehyde content in boards depending on the level of wood chip substitution with evening primrose straw and the type of binding agent

CONCLUDING REMARKS

Conducted analyses showed that board strength decreases with an increase in the proportion of evening primrose straw particles in the core of particleboards, although it is still possible to manufacture boards with parameters required by standard EN - 312 applying a total or partial wood chip substitution, depending on the binding agent:

- when UF resin is applied as the binding agent it is possible to manufacture boards solely from evening primrose straw and meeting the requirements of standard EN-312 for board type P1, i.e. general purpose board used under dry conditions. In the production of boards for interior design purposes including furniture (type P2), due to the low bending strength a 10% substitution of wood chips is only possible
- it is possible to manufacture boards with a proportion of evening primrose particles resinated with MUPF resin with mechanical properties meeting requirements of standard EN-312 for boards bearing load to be used under humid conditions (type P5) if the content of evening primrose straw in the core layer of boards does not exceed 50%. However, the proportion of more than 25% straw in the board causes a slight increase

in swelling in thickness after 24h soaking in water, whereas no marked changes are observed in water resistance determined by absorbability and the V-100 test

- the application of PMDI resin makes it possible to manufacture boards with a 100% share of evening primrose straw, which strength parameters exceed the requirements of standard EN-312 for board type P5; however, a decrease in the value of internal bond after the boiling test limits the substitution level to 50%. In order to manufacture boards meeting the requirements for board P7, the threshold value for wood chip substitution with evening primrose particles in terms of strength is 50%, while for water resistance it is 25%.

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