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PROPERTIES OF PARTICLEBOARDS PRODUCED WITH USE OF *SIDA HERMAPHRODITA* RUSBY

Rafał Czarnecki, Dorota Dziurka, Janina Łęcka

Faculty of Wood Technology
Poznań University of Life Sciences

SYNOPSIS. The paper investigates the possibility of applying pulverized stems of *Sida hermaphrodita* Rusby as a substitute for wood particles in the process of producing single-layer particleboards glued with UF, MUPF and PMDI resins. The investigations were conducted at two stages. At the first stage, the effect of the level of substitution (0, 10, 25, 50, 75 and 100%) was determined for the basic properties, i.e. bending strength, modulus of elasticity and internal bond before and after the boil test (only for MUPF and PMDI), swelling in thickness and formaldehyde content (only for UF and MUPF). The obtained results led to the conclusion that it is possible to entirely substitute particles of *Sida hermaphrodita* Rusby for wood particles in the process of producing particleboards glued with the above-mentioned resins. Based on these conclusions, the other stage of investigations was implemented, i.e. an attempt was made to determine the optimum resin level for the boards made entirely from this material. The selected resin levels were 10, 12 and 14% for UF and MUPF resins and 6, 8, 10 and 12% for PMDI resin. The produced boards were subjected to the same tests as at the first stage. The achieved results prove that the boards can be produced even with the lowest resin levels, which were applied in the investigation.

KEY WORDS: particleboard, *Sida hermaphrodita* Rusby, substitution

INTRODUCTION

For many years, the production and consumption of wood-based boards have been growing throughout the world. Due to the technical and utilitarian value of these materials, as well as their economic effectiveness, no noticeable reduction in their production has been observed, even in the periods of economic crisis. The development of this branch of industry is largely dependent upon the access to wood; yet its resources are limited in the global scale. What is more, owing to the constant deficiency of wood, as well as its growing price, soon it may be necessary to draw on reserves in order to fulfil the demand of wood-based industry for lignocellulose materials. At present, there is also strong competition for raw materials from pulp and paper industry and power engineering which uses biomass.

For a number of years researchers have been working on possible uses of annual plants in the production of particleboards and fibreboards, as the resources of these plants are much wider than the needs of wood-based industry. In spite of worse properties of these particles (greater content of mineral parts, shorter fibres, lower bending strength), they can be successfully applied in the production of boards with good mechanical properties.

Among numerous naturally occurring fibrous materials, cereal straw is of the greatest significance (Dalen 1999, Nicewicz et al. 2000, Grigoriou 2000, Onisko 2001, Bechta 2003). This material has been the most thoroughly investigated, yet it is not the only one to be applied. Boards can be produced from particles of annual and perennial plants, such as linen, hemp, colza, sugar cane, bamboo, sunflower, jute and cotton (Kozłowski et al. 2001, Papadopoulos et al. 2004, Guler and Ozen 2004, Dziurka et al. 2005, Dukarska et al. 2006, Frąckowiak 2007, Borysiuk and Mamiński 2008). Searching for an alternative for timber, researchers attempted at evaluating usability of such plants and materials as peanuts (Sosińska et al. 2000, Guler et al. 2008), almond shells (Gürü et al. 2006), oat hull (Czarnecki et al. 2001), tea leaves waste (Yalinkilic et al. 1998), pine needles (Nemli et al. 2008), palm betel (Lin et al. 2008), eggplant stems (Guntekin and Karakus 2008). Moreover, more attention is focused on fast-growing species used for energy purposes. One of promising plants, along with quite commonly widespread basket willow, topinambur, reed canary grass or miscanthus, is *Sida hemraphrodita* Rusby, which can be a potential material also in the production of wood-based boards.

Sida hermaphrodita Rusby has the form of a dense rooty bush with a few dozen of stems with the length of 400 cm and diameter of 5 to 35 cm. The plant is reproduced by means of root cuttings, stem cuttings or seeds. The plant is not very demanding in terms of soil and climate conditions, and it can be cultivated for 15-20 years. It is a plant of a great yielding potential and it has attracted interest of power industry. It is also considered to be very useful in land reclamation, it can be planted in idle lands as well as in roadsides so as to protect other plants from pollution (Borkowska and Styk 2006). *Sida* is also a valuable pharmaceutical material as it contains substances similar to those which are present in *Symphytum officinale* L. What is more, *Sida* can be used as nectar flow (it is in bloom till autumn frosts) and its stems can be applied in the cultivation of beans as poles. The plant can also be successfully applied in the production of pulp, which is used in pulp and paper industry (Mańko 1996, Bączyńska and Stanisławczyk 1988, Borkowska and Styk 2006). The pulp obtained from *Sida hermaphrodita* Rusby may be used as an insulating material and in the production of agglomerated materials (Mańko and Noskowiak 2002).

Putting the stems of *Sida hermaphrodita* Rusby into use may enrich the material resources and reduce the amount of the used timber. An average annual increment of a 25-year-old pine forest in the area of 1 ha in the habitat of stand quality class 3 can amount to 3.9 tons and for a 35-year-old spruce forest it is 5.1 tons. After 50 years it is possible to obtain respectively 122.4 tons of pine trunks and branches, 113.8 tons of spruce and 300-600 tons of *Sida hermaphrodita* Rusby (assuming low yielding level – 6-12 t/ha per year and establishing the plantation for three times). The discussed species may be, if not competitive, a complementary one even to agroforests with short use period (10-30 years), and annual production of 7-25 t/ha (Borkowska and Styk 2006).

Taking into consideration the great potential of *Sida hermaphrodita* Rusby and the growing deficiency of timber, the researchers from the Department of Wood--Based Materials of Poznań University of Life Sciences conducted investigation whose purpose was to explore the possibility of producing particleboards with use of this plant and with various kinds of resins.

MATERIALS AND METHODS

In order to produce the boards, pulverized stems of *Sida hermafrodita* Rusby were used as well as pine particles. The characteristics of the pine and *Sida* particles are presented in Table 1 and Figures 1 and 2.

Table 1. Moisture content and dimensions of the investigated pine and *Sida* particles

Investigated properties	Pine particles	*Sida* particles
Moisture content [%]	2.0	2.7
Average dimension [mm]	10.54 × 1.80 × 0.51	6.63 × 2.02 × 0.88

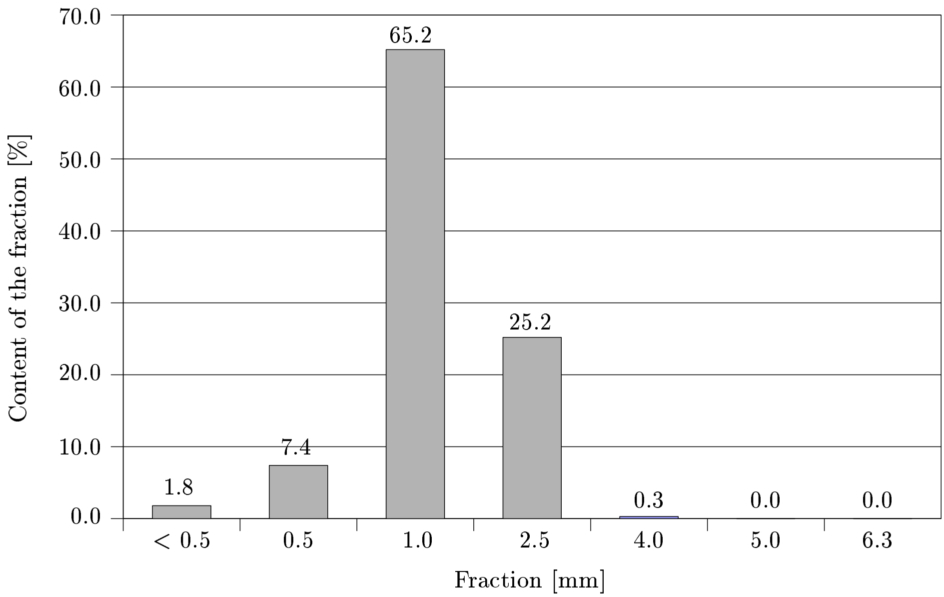

Fig. 1. Fractional composition of wood particles

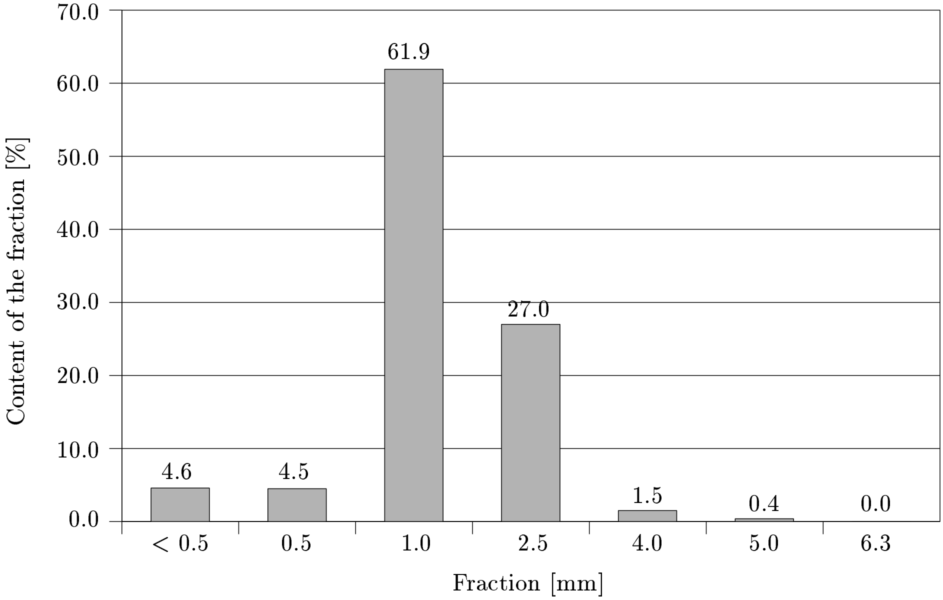

Fig. 2. Fractional composition of *Sida* particles

The boards were glued with UF, MUPF and PMDI resins. Their properties are shown in Table 2.

Table 2. Properties of resin adhesives used in experiments

Type of test	Unit	Properties of resin		
		UF	MUPF	PMDI
Density	[g/cm^3]	1.282	1.298	–
Viscosity	[mPa·s]	678	516	215
Apparent dry matter content	[%]	66	63.5	100
Miscibility with water	[–]	1.4	1.0	–
Gel time at 100°C	[s]	62	83	–
pH	[–]	8.21	9.35	–
Acid value	[mg/kg]	–	–	1 218
NCO group content	[%]	–	–	30.9

Single-layer particleboards were manufactured in laboratory conditions, with use of the following constant parameters:

- thickness of the boards: 12 mm
- density of the boards: 700 kg/m^3
- dimension of the boards: 600 × 500 mm
- pressing temperature: 200°C
- maximum unit pressure of pressing: 2.5 N/mm^2 (pressing schedule is shown in Figure 3)
- pressing time: 22 s per mm of the board thickness.

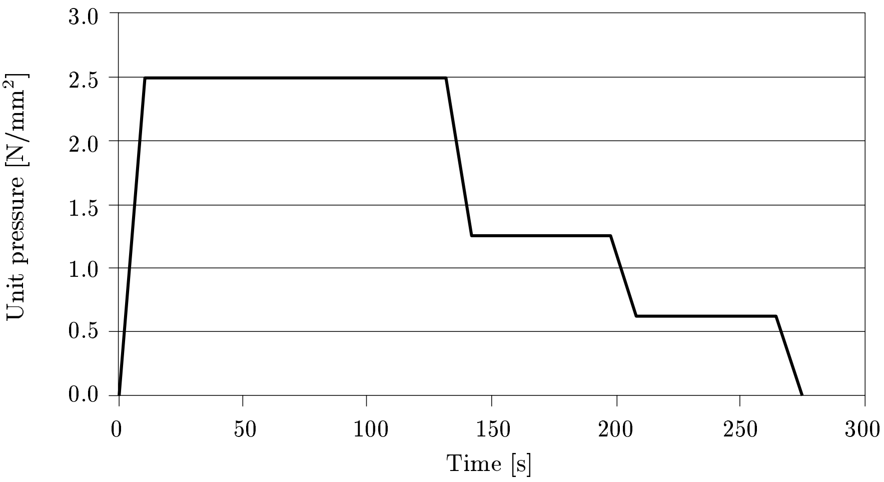

Fig. 3. Schedule of pressing the boards

After pressing, the boards were conditioned for 7 days.

The investigations were conducted at two stages. At the first stage, the effect of the level of substituting particles of *Sida* for wood particles (0, 10, 25, 50, 75 and 100%) was determined for the basic properties of the boards:

- bending strength and modulus of elasticity in bending according to EN 310
- internal bond according to EN 319
- internal bond after the boil test according to EN 1087-1 (only for MUPF and PMDI)
- swelling in thickness after 24 h according to EN 317
- formaldehyde content according to EN 120 (only for UF and MUPF).

The resin level for UF and MUPF resins was 12% and for PMDI it was 8%. In case of UF and MUPF resins, a curing agent NH4NO3 was used; it was added in the amount of 2% in relation to dry mass of the resin.

At the other stage of the investigations an attempt was made to determine the optimum resin level for the boards made entirely from *Sida hermaphrodita* Rusby and, for comparison reasons, from pine particles. The selected resin levels were 10, 12 and 14% for UF and MUPF resins and 6, 8, 10 and 12% for PMDI resin. The produced boards were subjected to the same tests as at the first stage.

RESULTS AND DISCUSSION

The results of the investigations upon mechanical properties of the boards produced with use of *Sida hermaphrodita* Rusby are shown in Table 3.

In terms of boards glued with UF and MUPF resins, a slight decrease in bending strength is observed, as the amount of *Sida* increases. The same can be noticed

Table 3. The influence of substituting *Sida hermaphrodita* Rusby for wood particles upon basic mechanical properties of the boards

Substitution degree [%]	Bending strength			Modulus of elasticity			Internal bond		
	N/mm^2								
	UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
0	15.5	18.2	23.7	3 160	3 010	3 220	0.78	1.09	1.41
	*0.8**	*1.6*	*3.1*	*342*	*268*	*455*	*0.09*	*0.15*	*0.29*
10	15.1	18.0	24.8	2 780	2 930	3 420	0.93	1.06	1.48
	1.6	*1.7*	*2.8*	*297*	*311*	*306*	*0.10*	*0.14*	*0.20*
25	14.5	17,6	25.2	2 580	2 880	3 630	0.88	1.05	1.50
	1.5	*2.3*	*3.8*	*222*	*299*	*451*	*0.09*	*0.13*	*0.26*
50	14.4	17.4	20.0	2 450	2 530	2 800	1.02	1.15	1.29
	0.7	*1.6*	*1.9*	*132*	*245*	*203*	*0.11*	*0.12*	*0.16*
75	13.8	17.4	19.0	2 140	2 630	2 690	1.12	1.11	1.21
	1.2	*1.0*	*2.5*	*168*	*43*	*307*	*0.06*	*0.14*	*0.12*
100	13.3	17.4	15.6	1 920	2 510	2 300	1.10	1.11	1.15
	1.3	*1.9*	*2.2*	*153*	*162*	*354*	*0.11*	*0.14*	*0.08*

*Standard deviation is given in italics.

as for modulus of elasticity; in this case, however, the decrease is more significant. It can be explained by the fact the structure of *Sida* particles is much more porous than that of wood particles and, therefore, the bonds between the resin and particles can be more easily broken in the process of bending the boards. Yet, the results of tests on internal bond are much different. As the amount of *Sida* particles grows, the value of the parameter increases. It can be assumed that due to lower density of *Sida* particles they are closer to one another, which favourably affects the value of internal bond.

In case of the boards glued with PMDI resin, the effect of substituting *Sida hermaphrodita* Rusby for wood particles is more ambiguous. The boards with small amount of *Sida* (10 and 25%) show the increase of the investigated values in relation to boards made only from wood particles. However, for the boards with larger amount of *Sida* (50, 75 and 100%), the values are much lower. This phenomenon may occur due to the fact that the two lignocellulose materials are characterised by a different structure. In a certain range, a small amount of smaller and more dense *Sida* particles, may enable a better arrangement in a board. As a result, by means of increasing the contact surface, the chemical bonds between the lignocellulose material and PMDI resin are more easily created.

The results of investigations upon the resistance to the action of water are presented in Table 4. For boards made with use of UF resin only swelling in thickness after 24 h was determined; its value deteriorated significantly as the amount of *Sida* increased. A similar effect was observed in case of MUPF and PMDI resins, however, quite expectedly, they show much more favourable influence upon the values of swelling in thickness than UF resin.

As for the boil test of the boards glued with PMDI resin, their resistance decreased considerably as the amount of *Sida* grew: from 1.2 N/mm^2 (board made

Table 4. The influence of substituting *Sida hermaphrodita* Rusby for wood particles upon resistance properties and formaldehyde content

Substitution degree [%]	Internal bond after boil test			Swelling in thickness			Formaldehyde content		
	N/mm^2			%			mg CH_2O/100 g d.m.b.		
	UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
0	–	0.20	1.21	34.8	24.2	18.8	4.42	4.93	–
	–	*0.03**	*0.19*	*2.8*	*2.7*	*1.9*	–	–	–
10	–	0.21	1.14	38.4	25.8	21.8	4.61	5.08	–
	–	*0.04*	*0.17*	*3.8*	*3.3*	*2.0*	–	–	–
25	–	0.22	0.68	37.8	26.1	21.1	4.23	5.61	–
	–	*0.05*	*0.10*	*2.2*	*4.0*	*4.3*	–	–	–
50	–	0.24	0.52	39.1	28.1	19.0	5.42	6.08	–
	–	*0.05*	*0.07*	*2.7*	*3.5*	*3.7*	–	–	–
75	–	0.19	0.27	48.8	29.3	21.5	4.29	7.08	–
		0.03	*0.03*	*2.5*	*4.7*	*1.9*	–	–	–
100	–	0.23	0.21	53.3	31.9	25.4	5.89	7.20	–
	–	*0.04*	*0.03*	*2.7*	*2.4*	*4.9*	–	–	–

*Standard deviation is given in italics.

entirely from pine particles) down to 0.2 N/mm^2 (board made entirely from *Sida* particles). Such significant differences do not occur in case of boards made with use of MUPF resin. All the determined values, regardless of the substitution degree, oscillate around 0.2 N/mm^2.

The use of *Sida hermaphrodita* Rusby as a substitute for wood particles, does not significantly affect the formaldehyde content in the boards (Table 4, only UF and MUPF). Although a slight growing tendency can be observed (especially for MUPF resin) as the amount of *Sida* increases, the obtained values are always below 8 mg CH_2O/100 g of dry mass of the board.

The results of the other stage of the investigations were meant to determine the optimum resin level for the boards made entirely from *Sida hemafrodita* Rusby; they are shown in Tables 5 and 6.

The data presented in Table 5 indicate that the increase of the resin level results in the improvement of the resistance properties. They also show that, regardless of the resin level of the boards made entirely from *Sida hemaphrodita* Rusby with use of UF, MUPF and PMDI resins, the values of bending strength and modulus of elasticity in bending deteriorate in comparison with the boards made from pine particles. Similarly to the first stage of the research, it results from worse geometry of *Sida* particles and their less porous structure. Analogously to Table 3, the values of modulus of elasticity decrease more dynamically than those of bending strength and there is no unfavourable influence of *Sida* particles upon the values of internal bond for any of the applied resin.

As the resin level increases, the values of properties related to resistance to the action of water improve (Table 6). The results of tests on the internal bond of the boards glued with PMDI resin show that in terms of boards made entirely from

Table 5. Mechanical properties of the boards made from wood and *Sida hermaphrodita* Rusby particles depending on the kind and amount of a bonding agent

Kind of material	R** [%]	Bending strength			Modulus of elasticity			Internal bond		
		N/mm^2								
		UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
Pine particles	6	–	–	18.4	–	–	2 850	–	–	1.20
		–	–	*1.3**	–	–	*421*	–	–	*0.13*
	8	–	–	21.7	–	–	2 900	–	–	1.24
		–	–	*1.9*	–	–	*277*	–	–	*0.12*
	10	12.4	16.4	30.2	2 700	2 900	4 120	0.64	0.90	1.58
		1.0	*1.4*	*2.7*	*187*	*238*	*385*	*0.04*	*0.08*	*0.29*
	12	15.5	18.1	31.1	3 160	3 270	4 130	0.78	1.12	2.03
		0.8	*1.6*	*2.6*	*342*	*394*	*408*	*0.08*	*0.11*	*0.22*
	14	15.9	18.3	–	3 010	3 320	–	0.80	1.18	–
		1.3	*1.6*	–	*392*	*437*	–	*0.07*	*0.11*	–
Sida particles	6	–	–	12.8	–	–	1 990	–	–	1.11
		–	–	*1.2*	–	–	*266*	–	–	*0.11*
	8	–	–	14.3	–	–	2 160	–	–	1.13
		–	–	*1.3*	–	–	*161*	–	–	*0.09*
	10	10.1	15.7	16.1	1 490	2 290	2 360	0.68	1.17	1.26
		0.7	*1.4*	*1.2*	*81*	*193*	*398*	*0.14*	*0.11*	*0.11*
	12	11.5	16.9	18.1	1 860	2 300	2 520	0.68	1.26	1.29
		1.1	*1.6*	*1.5*	*96*	*265*	*190*	*0.06*	*0.13*	*0.17*
	14	13.0	17.5	–	1 410	2 430	–	0.72	1.34	–
		0.5	*1.9*	–	*85*	*287*	–	*0.07*	*0.22*	–

*Standard deviation is given in italics.
**Resin level.

Sida, the value is considerably deteriorated; no such an effect is observed in case of boards glued with MUPF resin. This situation is also analogous with the first part of the investigations, just as the analysis of the results obtained for swelling in thickness. The most favourable results are achieved for the boards made with use of PMDI resin, next for MUPF resin; the worst values are obtained for UF resin. In each case, the attained results are worse for the boards made from *Sida* than for those made from pine particles.

The investigations upon formaldehyde content (Table 6) show that, quite obviously, the value increases as the resin level grows. In case of UF resin, the use of *Sida* does not affect formaldehyde content. However, in terms of MUPF the presence of *Sida* influences the formaldehyde content, which is also indicated in Table 4. Yet, the values are always below 8 mg CH_2O/100 g of dry mass of the board.

Table. 6. Resistance properties of the boards and formaldehyde content, depending on the kind and amount of a bonding agent

Kind of material	R** [%]	Internal bond after boil test			Swelling in thickness			Formaldehyde content		
		N/mm^2			%			mg CH_2O/ /100 g d.m.b.		
		UF	MUPF	PMDI	UF	MUPF	PMDI	UF	MUPF	PMDI
Pine particles	6	–	–	0.99	–	–	23.1	–	–	–
		–	–	*0.13**	–	–	*1.1*	–	–	–
	8	–	–	*1.05*	–	–	19.2	–	–	–
		–	–	0.19	–	–	*1.0*	–	–	–
	10	–	0.17	1.69	51.5	29.5	14.1	3.90	2.92	–
		–	*0.06*	*0.22*	*1.8*	*4.8*	*2.2*	–	–	–
	12	–	0.20	1.68	34.8	23.6	10.4	4.42	3.73	–
		–	*0.09*	*0.05*	*2.8*	*3.4*	*1.5*	–	–	–
	14	–	0.26	–	32.6	20.8	–	4.08	4.21	–
		–	*1.1*	–	*1.6*	*2.4*	–	–	–	–
Sida particles	6	–	–	0.15	–	–	29.1	–	–	–
		–	–	*0.03*	–	–	*4.7*	–	–	–
	8	–	–	0.21	–	–	26.2	–	–	–
		–	–	*0.03*	–	–	*3.1*	–	–	–
	10	–	0.17	0.34	61.2	39.4	21.8	3.63	6.54	–
		–	*0.05*	*0.06*	*2.8*	*2.6*	*2.6*	–	–	–
	12	–	0.21	0.28	53.5	31.8	19.7	4.73	6.82	–
		–	*0.07*	*0.05*	*1.7*	*1.9*	*1.8*	–	–	–
	14	–	0.30	–	50.9	23.7	–	4.44	7.32	–
		–	*0.05*	–	*2.3*	*2.1*	–	–	–	–

*Standard deviation is given in italics.
**Resin level.

CONCLUSIONS

1. The conducted investigations show that, as the amount of *Sida hermaphrodita* Rusby grows in boards glued with UF and MUPF resin, a slight decrease in bending strength and a more distinct decrease in modulus of elasticity are observed; yet, the values of internal bond slightly increase. The scope of these changes leads to the conclusion that it is possible to manufacture particleboards even with 100% substitution of *Sida* and the lowest investigated resin level of 10%.

2. In case of boards glued with UF resin, *Sida hermaphrodita* Rusby considerably deteriorates resistance to the action of water measured by swelling in thickness after 24 h. In terms of bards glued with MUPF the deterioration is not that significant. However, the use of *Sida* does not affect the resistance of the boards after the boil test. Therefore, we can conclude that, in spite of a more distinct negative effect of *Sida* upon the resistance properties than upon the mechanical ones, it is still possible to produce particleboards with 100% substitution of *Sida* and the lowest investigated resin level of 10%.
3. In terms of all the particleboards produced with use of *Sida* and glued with UF and MUPF resin, the formaldehyde content is within the permissible limits. Yet, the increase in the amount of *Sida* results in the growth of this value in case of boards glued with MUPF resin.
4. The properties of boards made with use of PMDI resin are significantly different from those glued with UF and MUPF. We can actually conclude that the use of *Sida* in the amount of up to 25% does not result in any deterioration of their properties, and in case of most of them an improvement is observed. A further increase in the amount ranging from 25 to 50%, sets them on the level relevant to that of boards made from pine particles (apart from resistance after boil test). When the amount of *Sida* exceeds 50%, all the properties considerably deteriorate; yet, this can be compensated by the increase of the resin level.
5. As the resin level increases, all the mechanical and resistance properties improve.
6. *Sida hermaphrodita* Rusby can be considered a full-value material purposed for manufacturing of particleboards.

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Author's address:
Prof. Janina Łęcka
Dr. Dorota Dziurka
Dr. Rafał Czarnecki
Department of Wood-Based Materials
Faculty of Wood Technology
Poznań University of Life Sciences
ul. Wojska Polskiego 38/42
60-627 Poznań
Poland