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Effects of Medium Density Fiberboards (MDF) Recycling Methods on Fiber Dimensions and Some Reconstructed Board Properties

Učinci recikliranja srednje guste ploče vlaknatice (MDF) na dimenzije vlakana i na neka svojstva ploča od recikliranih vlakana

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ABSTRACT • *In this study, different methods, including acid hydrolysis (phosphoric and formic acid), thermo-hydrolysis, and microwave methods were tested for recycling of fiberboards made of 100 % beech and 70 % beech + 30 % pine wood fibers, which are widely sold in the market. The impacts of the using methods on the fibers were investigated with the help of a device that determines the fiber dimensions according to optical principles. In a laboratory setting, test boards were constructed using recycled fibers, and the changes in certain physical and mechanical qualities were studied. As a result, it was determined that recycled fibers obtained from microwave and thermo-hydrolysis fibers could be effectively used in fiberboard production. However, the proportion of fibers, longer than 1.24 mm, was decreased by about 30 % with the phosphoric acid method for MDF samples composed of 100 % beech fiber. The fiberboards could not be obtained from fibers recycled through acid hydrolysis except for phosphoric acid method with 100 % beech fibers.*

KEYWORDS: *waste MDF; recycling; recycled fibers; fiber properties; board strenght*

SAŽETAK • *U radu se istražuju različite metode recikliranja ploča vlaknatica kao što su kiselinska hidroliza (uz pomoć fosforne i mravlje kiseline), toplinska hidroliza i mikrovalne metode. Reciklirani su uzorci ploča vlaknatica izrađenih od 100 % vlakana drva bukve te ploča vlaknatica izrađenih od 70 % vlakana drva bukve i 30 % vlakana drva crnog bora. Ploče vlaknatice takvog sastava uvelike su zastupljene na tržištu. Utjecaj metoda recikliranja na vlakna istraživan je uz pomoć uređaja kojim se određuju dimenzije vlakana na optičkim načelima. Ploče od recikliranih vlakana izrađene su u laboratorijskim uvjetima i na njima su promatrane promjene određenih fizičkih i mehaničkih svojstava. Utvrđeno je da se reciklirana vlakna dobivena mikrovalnim metodama i toplinskom hidrolizom mogu učinkovito primjenjivati u proizvodnji ploča vlaknatica. Međutim, kiselinskom hidrolizom uz dodatak fosforne kiseline u uzorcima izrađenim od 100 % bukovih vlakana udio vlakana duljih od 1,24 mm smanjuje se za*

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oko 30 %. Ploče vlaknatice nisu se mogle proizvesti od recikliranih vlakana dobivenih kiselinskom hidrolizom. Za njihovu proizvodnju pogodna su se pokazala samo reciklirana vlakna od 100 % bukovih ploča vlaknatica srednje gustoće dobivena kiselinskom hidrolizom uz dodatak fosforne kiseline.

KLJUČNE RIJEČI: *otpadni MDF; recikliranje; reciklirana vlakna; svojstva vlakana; svojstva ploče*

1 INTRODUCTION
1. UVOD

Fiberboards, particularly medium-density fiberboards (MDF), have surpassed other wood-based boards as one of the most important raw materials in the furniture industry, owing to their more homogenous and superior surface structure (Moezzipour *et al.,* 2018). The total global production of MDF and high-density fiberboard (HDF) was 71 164 023 m^3 in 2010, and 104 095 018 m^3 in 2020, according to the 2021 statistical data released by the Food and Agriculture Organization of the United Nations (FAO). Turkey's overall production of MDF and HDF increased from 3 265 000 m^3 to 4 775 000 m^3 bet from 2010 to 2020 (FAOSTAT, 2021).

Rapid expansion in the fiberboard industry is putting strain on available forest resources. With the developments in other forest industry sectors, it is expected that the supply of raw wood materials will become constrained in the near future (Demirkır and Çolak, 2006). Additionally, like with other wood-based composites, leaving MDFs uncontrolled in landfills or burning them as fuel at the end of their lifecycle is expected to cause serious environmental problems (Demirkır and Çolak, 2006; Lykidis and Grigoriu, 2008; Nuryawan *et al.,* 2020). Burning of this kind of products releases toxic gases such as formaldehyde to the atmosphere as a result of the use of formaldehyde-based thermoset glue matrices such as urea-formaldehyde (UF), phenol-formaldehide and melamine-formaldehyde in their manufacture, as well as greenhouse gases such as methane and carbon dioxide (Lubis *et al.,* 2018a; Moezzipour *et al.,* 2017; Zeng *et al.,* 2018; Hagel *et al.,* 2021).

Recycling these waste boards into products and raw materials provides a significant solution to both solid waste management and raw material shortages in the relevant sectors (Demirkır and Çolak, 2006). In this context, mechanical, thermo-hydraulic, chemical, and other techniques for combining them have all been developed in recent years (Antov and Viktor, 2019). Thermo-hydrolysis recycling methods, which produce lignocellulosic fibers from fiberboards, are carried out by removing the polymer matrix established by the glues in the panel samples and generally by breaking the bonds between the polymer matrix and fiber using heat and water vapor (Lubis *et al.,* 2018a; Moezzipour *et al.,* 2018; Hagel *et al.,* 2021). Many different techniques for recycling wood fibers from composite panels have been developed based on this principle (Roffael and Hüster, 2012). Fiber/chip boards, to be smoothly recycled using the thermo-hydrolysis process with a chemical pre-treatment (WKI method), are first immersed in a solution containing a solution of urea, ammonia, or another chemical that dissolves the UF adhesive and then recycled in an autoclave at a suitable temperature (Michanickl and Boehme, 2002). Wan *et al.* (2004) reported that 0.5 % butane tetracarboxylic acid, together with heat treatment, successfully recycles particleboard and MDF samples made with UF. Lubis *et al.* (2018b) stated that alkaline hydrolysis removed 25 % of the UF polymer from waste MDF, while neutral hydrolysis removed 50 %, and acid hydrolysis removed 75 %. Additionally, a micro-release method has been developed with the purpose of generating atomic heat by activating the water and hydroxyl ions on the panel with microwave energy, specifically targeting to solve the bonds between fibers and also fiber adhesive (Demirkır and Çolak, 2006, Mitchell and Stevens, 2009).

Although numerous methods for recycling waste MDF panels have been developed, research on MDF recycling, the effect of recycling methods on fiber characteristics, and the qualities of boards made from recycled fibers are quite restricted. This study aims to:
- Compare some recycling methods for MDF samples produced from different fiber composition,
- Determine and compare the fiber and fiberboard properties for different MDF recycling methods,
- Analyze the effect of some studied recycling methods on fiber quality.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Material
2.1. Materijal

In this study, thermo-mechanical pulping (TMP) fibers, which are produced using 100 % *Fagus orientalis* (beech) and a *Fagus orientalis* (beech) - *Pinus nigra* (pine) mixture (70 % : 30 % w/w), and MDFs manufactured in the fiberboard production line from these fibers, were obtained from Kastamonu Entegre A.Ş. Kastamonu O.S.B. factory (Kastamonu, Turkey) according to the company production specifications. The MDF samples were cut into strips of 1 cm width and of appropriate length, using various cutting tools to prepare them for recycling, and then stored under room conditions.

Ammonium chloride, ammonium sulfate, formic acid, and phosphoric acid were provided in analytical purity for the recycling procedures used in the study. To manufacture boards from recycled fibers, urea-formaldehyde adhesive with 55 % solids content (urea/formaldehyde ratio of 1:1.17; pH 8.4; density 1.24 g/cm^3; viscosity 65 cps at 25 °C) was used, along with 10 % ammonium chloride solution as a hardener.

2.2 Recycling of fiberboards
2.2. Recikliranje ploča vlaknatica

The boards were recycled in accordance with the experimental design shown in Table 1. Samples separated for recycling by the micro release method were kept in boiling distilled water for 5 minutes before being processed for 5 minutes at medium wave frequency in an industrial microwave device. The MDF samples then swelled and lost their integrity, and their fibers were separated from each other. The fibers were dispersed manually and dried under room conditions (Mitchell and Stevens, 2009). The WKI method, which is a thermo hydraulic method, was modified and applied to the samples. Instead of urea or ammonia solutions, 25 % solutions of ammonium chloride (WKI 1) and ammonium sulfate (WKI 2) were used in the method. The presence of acid ions in the aqueous solutions of both solutions was a significant factor in the selection of ammonium chloride and ammonium sulfate. In addition, these chemicals are widely employed by wood-based board factories as a hardener for UF resin (Pizzi, 2003). The MDF samples immersed in 25 % ammonium salt solutions were then treated in an autoclave at 121 °C for 30 minutes. After the autoclave, the samples were washed with distilled water to separate and fibers were dried under room conditions before the MDF production. Formic acid (AH 1) and phosphoric acid (AH 2) were chosen for MDF recycling via acid hydrolysis. The properties that contributed to the selection of these two acids, found in the literature, were the ability of formic acid to dissolve cellulose even at high concentrations without abrasion (Hafızoğlu and Deniz, 2010) and the ability of phosphoric acid to catalyze the hydrolysis of UF adhesive (Lall *et al.*, 1982). The MDF samples to be recycled were heated and mixed in a 25 % acid solution until the fibers separated. After washing the acquired fibers with distilled water with the help of filter paper, they were left to dry under room conditions.

2.3 Investigation of changes in fiber morphologies
2.3. Istraživanje promjena u morfologiji vlakana

Dimensional analyses (length and width) of fiber samples taken prior to the production and recycling of the boards were performed using the Imal brand optical laboratory fiber scanner (Fibercam 100®, Imal Pal, Italy). The gadget, in which certain masses of the obtained fibers were placed, automatically determined the percent fiber amount in certain frequency ranges according to the total fiber measured optically.

2.4 Production of fiberboard from recycled fibers and determination of some properties
2.4. Proizvodnja ploča vlaknatica od recikliranih vlakana i određivanje nekih njihovih svojstava

The panels were manufactured from dried recycled wood fibers at a target density of 700 kg/m^3 and had dimensions of 0.360 m × 0.310 m × 0.011 m. A drum gluing mixer, with two-point injection, 100 lt sample volume, and 5 rpm rotating speed, was used in the gluing process of the recycled fibers in fiberboard production for 10 minutes. Samples were pressed with a laboratory press (SSP 125, Cemil Usta, Turkey) for 2 MPa at 190 °C for 8 min, including the warm-up time of the additional press plates used. However, some acid hydrolyzed fiber groups were deformed during hot pressing. After that, the undeformed fiberboards at the end of the hot press were conditioned in the air-condi-

Table 1 Experiment design of MDF recycling
Tablica 1. Eksperimentalni postupci recikliranja MDF-a

Board type *Vrsta ploče*	**Recycle method** *Metoda recikliranja*	**Applied chemical** *Upotrijebljene kemikalije*
100 % beech *100 % bukovina*	Micro release / *mikrootpuštanje*	Distilled water / *destilirana voda*
	AH 1	25 % Formic acid / *25 % mravlja kiselina*
	AH 2	25 % Phosphoric acid / *25 % fosforna kiselina*
	WKI 1	25 % Ammonium chloride / *25 % amonijev klorid*
	WKI 2	25 % Ammonium sulfate / *25 % amonjjev sulfat*
Beech - pine mixture (70 : 30 % w/w) *smjesa bukovine i borovine (70 : 30 % težine)*	Micro release / *mikrootpuštanje*	Distilled water / *destilirana voda*
	AH 1	25 % Formic acid / *25 % mravlja kiselina*
	AH 2	25 % Phosphoric acid / *25 % fosforna kiselina*
	WKI 1	25 % Ammonium chloride / *25 % amonijev klorid*
	WKI 2	25 % Ammonium sulfate / *25 % amonjjev sulfat*

tioned room. The following properties of the boards were determined according to related standards:
- Density (d: kg/m^3) (EN 323, 1993)
- Thickness swelling percent in 24 hours (TS: %) (EN 317, 1993)
- Water absorption percent in 24 hours (WA: %) (EN 317, 1993)
- Bending Strength (MOR: N/mm^2) (EN 310, 1993)
- Modulus of elasticity (MOE: N/mm^2) (EN 310, 1993).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Effect of recycling methods on fiber morphology
3.1. Utjecaj metoda recikliranja na morfologiju vlakana

The fibers obtained from the boards via the recycling methods were examined using an optical laboratory fiber scanner, and the fiber length analysis results obtained from the device are given in Table 2.

Table 2 shows that recycling procedures have a strong influence on the fiber lengths of 100 % beech fibers. Contrary to the raw fiber samples, the micro release technique had no effect on the rate of fine fibers. However, a considerable increase was observed in recycled fine fibers with modified WKI procedures. In addition, a certain amount of decrease is observed in fiber fractions with lengths greater than 1.24 mm, which can be classified as coarse fibers. This indicates that recycling processes have a negative effect on fiber lengths. Şahin (2014) stated that, in the recycling of paper fibers, there is generally a serious decrease in fiber length and strength until the 4th recycling of the fibers and that the recycled fibers are shorter than the fibers originally obtained from wood. In addition, in another study, fibers shorter than 0.09 mm were defined as fine fibers, and it was stated that the increase in the percentage of fine fibers caused a significant decrease in the elasticity modulus determination values of the sheets, especially in bending (Moezzipour *et al.,* 2018). Another study claimed that, with the addition of recycled fibers at different rates, the fiber size decreased in the long fraction (1.711 mm and above), and the percentage of the short fiber class (between 0.2-0.956 mm) increased (Klimczewski and Nicewicz, 2013). Hagel *et al.* (2021) concluded that the fibers recycled by the steam reactor are short and that these fibers are shortened with the application of the refinery process. The results obtained in this study are consistent with previous studies on fiber recycling in the literature (Hagel *et al.,* 2021).

Similar to results obtained using 100 % beech fibers, recycling methods have a negative effect on the fiber lengths of fibers produced from a mixture of 70 % beech and 30 % pine as shown in Table 2. In particular, a clear increase in the percentage of coarse and fine fibers was observed, whereas the coarse fiber fractions decreased (length 1.24 mm).

The results of the fiber width analysis of the recycled fibers using the optical fiber scanner device are shown in Table 3.

The negative effects of certain recycling methods on fiber width distributions are evident in Table 3. It

Table 2 Fiber length analysis results
Tablica 2. Rezultati analize duljine vlakana

Board type *Vrsta ploče*	**Recycle method** *Metoda recikliranja*	**Fiber sizes measuring ranges, mm** *Raspon mjerenja veličine vlakana,* mm										**Measured fiber count** *Broj izmjerenih vlakana*
		0.00 / 0.09	0.09 / 0.13	0.13 / 0.22	0.22 / 0.51	0.51 / 1.24	1.24 / 1.98	1.98 / 3.0	3.0 / 4.0	4.0 / 5.0	5.0 / 30.0	
100 % beech *100 % bukovina*	Raw fiber *sirova vlakna*	0.1*	1.6	4.1	18.7	36.1	18.2	11.6	4.6	2.3	2.6	139058
	Micro release *mikrootpuštanje*	0.1	1.7	3.9	18.5	39.1	19.1	9.8	4.1	2.2	1.6	335056
	AH 1	0.1	1.5	3.9	19.0	39.1	17.9	10.1	4.1	2.8	1.5	336228
	AH 2	0.3	2.8	5.9	24.6	39.3	15.1	7.5	2.4	1.4	0.8	305972
	WKI 1	0.3	2.6	5.1	20.7	38.8	17.6	9.1	3.3	1.6	1.0	396388
	WKI 2	0.2	2.3	4.8	20.3	37.7	16.7	9.9	4.1	2.1	2.0	367983
Beech - pine mixture (70 : 30 % w/w) *smjesa bukovina i borovine (70 : 30 % težine)*	Raw fiber *sirova vlakna*	0.1	1.7	4.0	18.4	33.4	16.9	12.1	5.2	3.6	4.7	137472
	Micro release *mikrootpuštanje*	0.1	1.5	3.7	17.1	35.3	18.2	11.9	5.4	3.4	3.4	300061
	AH 1	0.1	1.4	3.7	17.6	36.0	18.2	11.6	5.0	3.0	3.6	372036
	AH 2	0.1	1.1	3.1	16.4	35.2	20.0	12.2	5.2	5.0	1.8	53639
	WKI 1	0.2	2.1	4.7	19.4	35.9	16.9	10.9	4.8	3.0	2.8	254811
	WKI 2	0.2	2.4	5.1	20.8	35.2	16.0	9.9	4.0	2.3	3.3	332847

* The % value of the measured fiber amount and the number of fibers at the relevant frequency / *postotna vrijednost izmjerenih vlakana i broj vlakana pri relevantnoj frekvenciji*

Table 3 Fiber width analysis results
Tablica 3. Rezultati analize širine vlakana

Board type *Vrsta ploče*	**Recycle method** *Metoda recikliranja*	**Fiber sizes measuring ranges, mm** *Raspon mjerenja veličine vlakana,* mm							**Measured fiber count** *Broj izmjerenih vlakana*
		0 / 0.09	0.09 / 0.13	0.13 / 0.22	0.22 / 0.51	0.51 / 1.24	1.24 / 1.98	1.98 / 3.0	
100 % beech *100 % bukovina*	Raw fiber *sirova vlakna*	7.4*	20.2	37.0	26.5	9.0	-	-	139058
	Micro release *mikrootpuštanje*	8.4	22.0	39.0	25.7	5.0	-	-	335056
	AH 1	9.9	23.0	38.6	23.2	4.7	0.6	-	336228
	AH 2	10.8	26.3	39.5	19.8	3.6	-	-	305972
	WKI 1	8.0	21.2	38.3	27.9	4.6	-	-	396388
	WKI 2	9.7	23.0	37.5	24.1	5.4	0.3	-	367983
Beech - pine mixture (70 : 30 % w/w) *smjesa bukovine I borovine (70 : 30 % težine)*	Raw fiber *sirova vlakna*	9.6	22.3	37.9	21.1	9.1	-	-	137472
	Micro release *mikrootpuštanje*	7.9	21.5	39.4	24.3	6.9	-	-	300061
	AH 1	8.3	22.7	40.5	22.6	6.1	-	-	372036
	AH 2	6.3	20.7	40.6	22.5	7.7	2.1	-	53639
	WKI 1	10.0	24.0	38.5	21.2	6.3	-	-	254811
	WKI 2	8.6	22.7	39.3	22.9	6.5	-	-	332847

* The % value of the measured fiber amount and the number of fibers at the relevant frequency / *postotna vrijednost izmjerenih vlakana i broj vlakana pri relevantnoj frekvenciji*

was observed that some fibers were extremely thick, and there was a particularly significant increase in the ratio of fibers with a very small width (<0.22 mm). The primary reason for this is the glue and paraffin residues on the recycled fibers. These microscopic residues can remain on the surfaces of the recycled fibers and even reduce the bonding ability of the fibers as they bind to the –OH groups in the fibers (Zeng *et al.,* 2018). The increase in fine fiber fractions may be due to the fact that they damage the fibers while breaking off during recycling, and the optical fiber scanner (Fibercam 100 ®) probably classifies them as fines since they are separated from the fibers by breaking off a certain piece. Lubis *et al.* (2020) recycled fibers via hydrolysis with water and oxalic acid and observed that the amount of total nitrogen in the plate increased, although the amount of mass lost increased with the increase in the amount of recycled fiber in the final board production.

Similar to the results obtained using 100 % beech fibers, Table 3 shows that recycling methods have a negative effect on the fiber width of fibers produced from a mixture of 70 % beech and 30 % pine. In particular, an increase in the amount of fine and thin fibers was clearly observed, while there was a decrease in coarse fiber fractions (width ≥ 1.24 mm).

3.2 Characteristics of boards produced from recycled fibers
3.2. Svojstva ploča proizvedenih od recikliranih vlakana

Table 4 shows the performance of MDF panels made from recovered fibers via various recycling procedures from 100 % beech and 70 % beech + 30 % pine boards. In both types of boards, fibers recycled with formic acid and fibers recycled with phosphoric acid from 70 % beech + 30 % pine boards, deformation occurred in the fibers during hot pressing, compromising the board integrity. As a result, board manufacturing in these groups was less effective than in others. The acid hydrolysis process causes damage to the fibers, and the fact that the condensation processes of the UF resin are complete before the hot pressing process and are hydrolyzed during pressing with the impact of the remaining acid in the fibers, are the primary reasons for this (Lubis *et al.,* 2018b). By treating these fibers with high-concentrated acid pre-treatment, they can be assessed as raw materials for ethanol production (Zhao *et al.,* 2019).

The analysis of the densities of the recycled MDF panel samples, presented in Table 4, clearly shows that they met the goal density and that the obtained results were equivalent to those of the original fiberboard samples. Figure 1 was created according to the data in Table 4 to enable the comparison of the 24-hour water absorption. The water absorption performance of the recycled fibers was found to be quite poor. This is because the original MDF samples were sourced from a mill, and the majority of companies used additives to improve water absorption values. Additionally, the shrinkage of the fibers and the residual UF resin on the fibers hindered the fiber-resin-fiber bonds during gluing (Zeng *et al.,* 2018). Apart from the hydrolytic degradation of UF, the boards became more dimensionally unstable, a reaction that is likely to occur during the hot press process in both residual glue and newly added glue in the recycled

Table 4 Physical and mechanical properties of boards with standard deviations
Tablica 4. Fizička i mehanička svojstva ploča sa standardnim devijacijama

Board type *Vrsta ploče*	**Recycle method** *Metoda recikliranja*	**Density, kg/m³** *Gustoća, kg/m³*	**24 h WA, %**	**24 h TS, %**	***MOR*, N/mm²**	***MOE*, N/mm²**
100% beech *100 % bukovina*	Original fiberboard *originalna ploča vlaknatica*	720.17 (9.22)	29.31 (1.31)	5.05 (0.26)	31.10 (1.25)	3315.59 (52.94)
	Micro release *mikrootpuštanje*	733.69 (13.57)	107.05 (13.02)	36.88 (5.14)	6,79 (1.79)	1998.95 (407.60)
	AH 1	-*	-	-	-	-
	AH 2	706.02 (21.58)	75.97 (1.50)	8.72 (0.74)	3.19 (0.89)	2116.44 (802.34)
	WKI 1	711.97 (16.16)	59.65 (3.64)	21.54 (2.54)	5.18 (1.04)	3274.54 (727.87)
	WKI 2	713.15 (21.71)	96.68 (7.36)	16.29 (2.56)	8.94 (2.21)	5087.742 (1425.99)
Beech - pine mixture (70 : 30 % w/w) *bukovina – borovina (70 : 30 % težine)*	Original fiberboard *originalna ploča vlaknatica*	723.00 (8.27)	33.36 (1.48)	8.15 (1.71)	32,39 (1.76)	3260.64 (87.31)
	Micro release *mikrootpuštanje*	703.23 (24.56)	104.94 (8.41)	29.12 (6.79)	6.36 (1.59)	2536.91 (672.25)
	AH 1	-	-	-	-	-
	AH 2	-	-	-	-	-
	WKI 1	733.45 (13.19)	85.06 (6.98)	30.45 (4.01)	2.95 (0.64)	828.57 (347.12)
	WKI 2	715.46 (20.26)	97.48 (4.42)	27.30 (6.36)	5.80 (1.12)	1452.48 (344.26)

* not produced / *nije proizvedena*

boards (Nuryawan *et al.,* 2020). In general, the water uptake values of the sample groups, hydrolyzed by chemical treatment, were lower than those obtained for MDF samples via micro release method. The reason for this situation can be attributed to the high percentage of coarse fibers in the methods using chemicals compared to the micro-release method.

The swelling ratios, measured from the thickness of the MDF panel samples, after 24 hours, are showed in Figure 2, which was prepared according to the data in Table 4. Although the changes in swelling values are in parallel with the changes in water absorption values, the 100 % beech fiber recycled boards treated with phosphoric acid gave quite good results compared to the original fiberboard samples.

The results of bending strength tests on MDF panel products acquired through various recycling processes are shown in Figure 3. Bending strength data were found to be quite low compared to those of the original fiberboards. The reason for this can lie in the decrease in fiber lengths and also in the fact that the fiber-fiber and fiber-glue-fiber bonds are not formed efficiently in panel production and that solidified UF resin on the recycled fibers prevents fiber-fiber bonding ability (Zeng *et al.,* 2018; Bütün Buschalski and Mai, 2021). Moezzipour (2018) de-

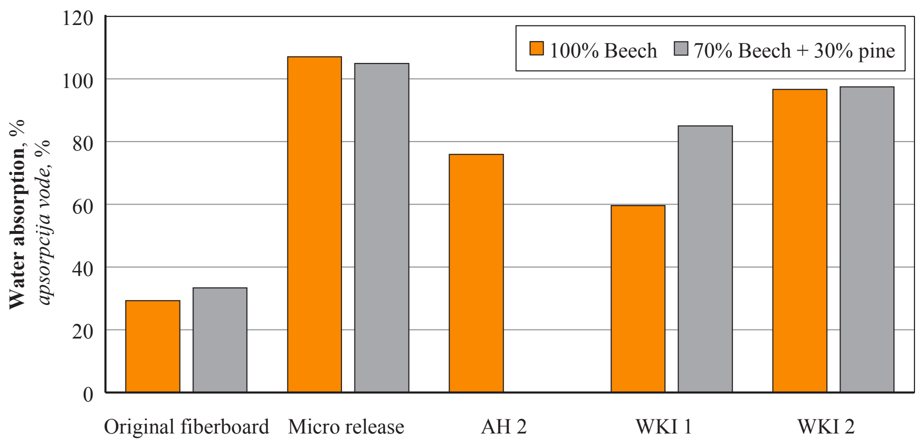

Figure 1 24 h water absorption values of tested boards
Slika 1. Vrijednosti apsorpcije vode ispitivanih ploča nakon 24 sata

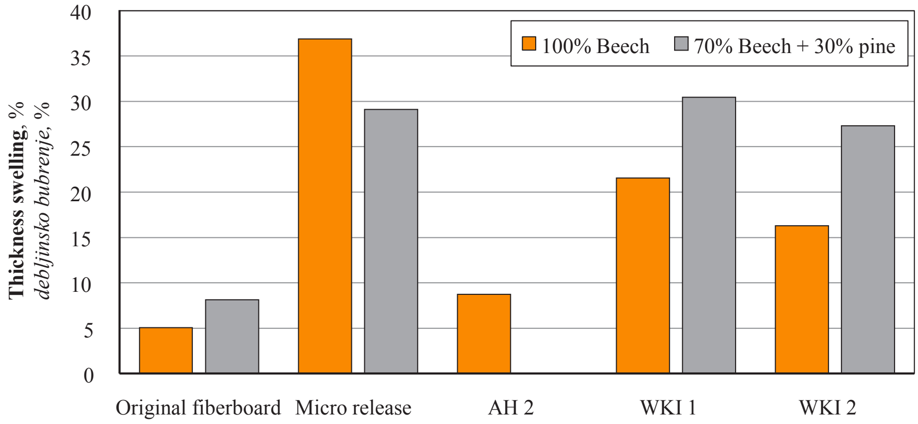

Figure 2 24 h thickness swelling values of tested boards
Slika 2. Vrijednosti debljinskog bubrenja ispitivanih ploča nakon 24 sata

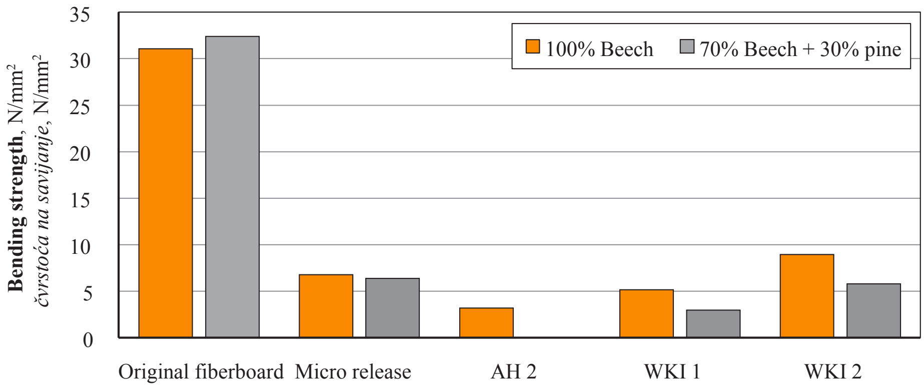

Figure 3 Bending strength values of tested boards
Slika 3. Vrijednosti čvrstoće ispitivanih ploča na savijanje

fined fibers shorter than 0.09 mm as fines and stated that the increase in the amount of fines, in particular, caused a noticeable decrease in the elasticity modulus values determined for the MDF panel samples.

When evaluating the modulus of elasticity in bending, the obtained MDF sample groups from 100 % beech fibers, treated with ammonium solutions, give more elastic boards than 70 % beech+30 % pine fiber mixture (Figure 4). In their study, Lykidis and Grigoriou (2008) demonstrated that the fiber elasticity increases with hydrothermal treatment. They stated that this situation was almost certainly the primary reason for the increase in the modulus of elasticity. Based on this, it can be said that the low modulus of elasticity of the fibers, obtained through the microwave method, results in more rigid fibers than the others. Microwave, defined as electromagnetic radiation, affects the hydroxyl groups and changes the felting properties of the fibers.

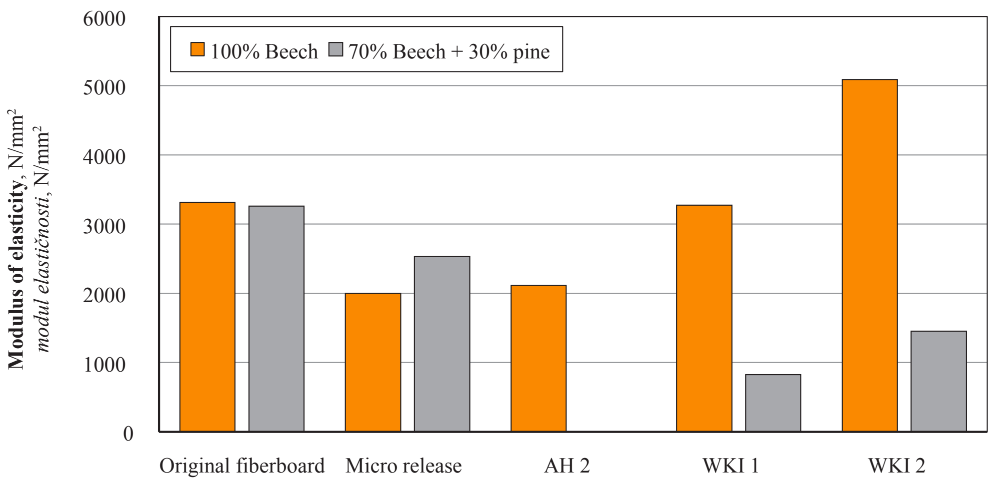

Figure 4 Modulus of elasticity values of tested boards
Slika 4. Vrijednosti modula elastičnosti ispitivanih ploča

In addition to this, the decrease in the bending strength and modulus of elasticity in the acid-treated group (AH 2) shows that the fibers are damaged during both processing and drying of recycled fibers.

4 CONCLUSIONS
4. ZAKLJUČAK

As a result of the study, it was observed that the fibers obtained by recycling waste boards could be reused in the fiberboard production industry.

It was observed that the recycling process has an absolute effect on the fiber dimensions and that these changes directly affect the physical and mechanical properties of the fiberboards.

The micro-release method provided better quality recycled fibers and boards according to the tested and evaluated characteristics.

Ammonium salts are more readily available in solid form than ammonia solution. The mild acidity of these solutions also prevents undesirable reactions during fiber recycling process. The type of ammonium salts, used percentages, and process factors, including temperature and time, will change this approach.

Acid hydrolysis seriously damaged fibers, should be more suitable for other applications such as bioethanol manufacturing.

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