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THE EFFECT OF THERMAL MODIFICATION OF ASH WOOD ON GRANULARITY AND HOMOGENEITY OF SAWDUST IN THE SAWING PROCESS ON A SASH GANG SAW PRW 15-M IN VIEW OF ITS TECHNOLOGICAL USEFULNESS

This paper presents the results of granulometric analyses of sawdust of unmodified and thermally- modified ash wood (Fraxinus exelsior L.) sawed on a narrow-kerf sash gang saw. The sawdust of dry thermally-modified ash produced in the sawing process on a frame sawing machine PRW15-M at a feed speed in the range of 0.36-1.67 m·min^{-1} has chip granularity ranging from 33.5 μm to 9.9 mm; whereas unmodified ash wood sawdust consists of chips in a granularity range from 35.6 μm to 13.8 mm. It was observed that thermally-modified ash sawdust is finer, with a distinctly larger share of the fraction in the granularity range a = 125-500 μm and a slightly increased share of the fraction in the range a = 32-125 μm. Changes in mechanical characteristics of modified wood were also observed in the technological usefulness of a part of dry sawdust chip in the granularity range a = 250 μm-2.4 mm. While the homogenous share of chips in sawdust produced in the process of sawing of dry ash wood was $HSCh_a$ = 81-84 %, the demonstrated homogenous share of chips in ash sawdust formed in the process of sawing of dry thermally-modified wood was lower by 4-6 %.

Keywords: ash wood, thermal modification, frame sawing machine, granulometric analysis, granularity

Introduction

During the sawing process of wood, chip sawdust is produced together with the main product. The shape, dimensions and amount of chips depend on the form, physical and mechanical properties of the sawed wood, as well as on the shape, dimensions, and sharpness of the cutting blade, and technical and technological

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conditions of the sawing process [Prokeš 1978; Goglia 1994; Lisičan et al. 1996; Wasielewski 1999; Orłowski 2003; Kopecký, Rousek 2007; Klement, Detvaj 2007; Dzurenda 2007].

Sawdust is characterised as poly-dispersion bulk material consisting of coarse and medium- coarse fractions [Hejma et al. 1981; Dzurenda 2009], i.e. bulk material with dimensions of grain over 0.3 mm, while the share of fine fractions with smaller dimensions of chips is not excluded. According to the classification parameters of bulk material described in STN 26 0070 standard, sawdust is classified as B-45UX, i.e. bulk material of fine granularity (0.5-3.5 mm), hygroscopic, low crisp and abrasive material with a tendency to crowd.

As a secondary raw material, sawdust has miscellaneous applications. For example, sawdust is one of the base materials utilised in the production of agglomerated chip materials in the range of granularity 0.25-2.4 mm [Drouet 1992; Štefka 1997] and also in chemical processing of wood. Moreover, it is a valuable raw material for energy use by way of direct combustion, and possibly also for the production of dimensionally and energetically homogenised fuel, for instance briquettes (type RUF Klasik with dimensions 155×65×95 mm) and industrial type pellets (with a cylindrical shape of Ø6-8 mm in diameter and a length of 25-30 mm) [Dzurenda, Slovak 2001; Pastorek, Kara, Jevič 2004; Šooš 2005; Dobrowolska et al. 2010].

In recent years, the increasing interest in sawdust as a secondary raw material, has created the need for a proper specification of the following physical properties: granularity, geometric shapes and dimensions of sawdust chips. The aim of this work is to analyse the effect of the thermal treatment of ash wood (*Fraxinus excelsior* L.) on sawdust granularity in the sawing process conducted on a frame sawing machine (sash gang saw) PRW15-M, and its technological advantages in the production of agglomerated chip materials and bio-fuel (pellets and briquets).

Material and methods

The thermal modification of ash was performed in overheated steam in a high temperature steam dry kiln PW-10 [Hamech 2011] using a technology similar to ThermoWood technology, in the following conditions presented in fig. 1:

– intense heating of ash wood up to the temperature of t = 110ºC joined with drying with wet atmospheric air,
– overheating of wood in an environment of superheated steam at atmospheric pressure at a temperature corresponding to conditions of modifications, with lower intensity than in phase 1., and wood drying,
– proper process of thermal modification of ash wood at a constant temperature of t = 197ºC in an environment of superheated steam at atmospheric pressure, process duration: 4 hours,

– timber cooling to approximately 80ºC and humidifying by means of water spraying in order to dampen the atmospheric air,
– further timber cooling to a final temperature of the process of wood thermal modification and air conditioning in humid atmospheric air.

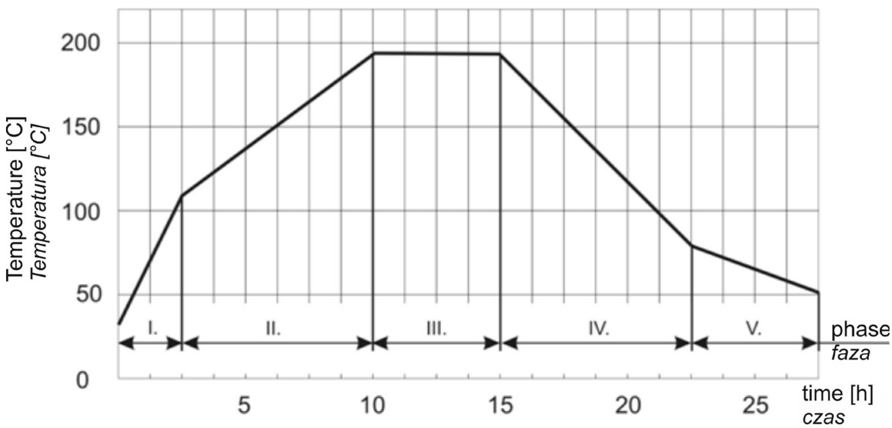


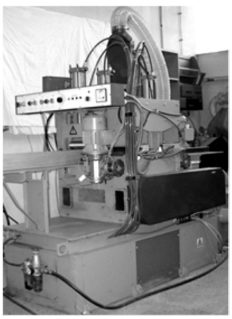
Fig. 1. Conditions of thermal modification of ash wood samples
Rys. 1. Warunki modyfikacji termicznej próbek drewna jesionowego

The above described process of thermal modification was similar to the process of oak wood (*Quercus robur* L.) modification described in the work by Dzurenda et al. [2010].

For granulometric analyses, samples of dry ash sawdust (natural, unmodified) and dry sawdust from thermally-modified ash were taken isokinetically from the exhaust pipe of a frame sawing machine PRW-15 in accordance with STN ISO 9096 (Manual determination of mass concentration of particulate matter) during the sawing of modified and unmodified ash wood. Square timber blocks of the after-planning dimensions of 59.5´59.5´500 mm were sawed at feed speeds of v_1 = 0.36 m·min^{-1} and v_2 = 1.67 m·min^{-1} on a frame sawing machine PRW15-M (table 1) in a laboratory of the Faculty of Mechanical Engineering at Gdansk University of Technology. The moisture content of ash sawdust w_{ash} = 8.3% and thermally-modified ash wood sawdust $w_{ash\text{-}M}$ = 8.5% was determined by the weight method. The technical and technological conditions of sawing are presented in table 1.

The basic granulometric analyses were done by screening sawdust on a set of sieves with mesh sizes of 2 mm, 1 mm, 0.50 mm, 0.25 mm, 0.125 mm, 0.080 mm, 0.063 mm, and 0.032 mm, during the time of t = 15 min on an automatic vibration sieving machine AS 200 (f. RETSCH). The weights of fractions on the sieves were determined on a set of laboratory scales EP 200 (f. BOSCH) with a weighting accuracy of 0.001 g.

Table 1. Technical data of a frame sawing machine PRW15-M and cutting conditions during sampling of sawdust
Tabela 1. Dane techniczne pilarki ramowej PRW15-M i warunki skrawania podczas pobierania próbek trocin

Narrow-kerf frame sawing machine PRW15–M *Pilarka ramowa wielpiłowa PRW15–M*			
	Span of the saw frame *Prześwit ramy piłowej*	mm	170
	Stroke of the saw sash *Skok ramy piłowej*	mm	160
	Max. height of sawn material *Wysokość maksymalna przedmiotu*	mm	150
	Min. height of sawn material *Wysokość minimalna przedmiotu*	mm	30
	Number of saw blades in the gang during tests *Liczba pił w sprzęgu podczas prób*	–	5
	Overall set (kerf) of the saw blades *Rozwarcie całkowite (rzaz) ostrzy*	mm	2
	Cutting edge material *Materiał ostrza skrawajacego*	stellit	
	Feed speed *Prędkość posuwu*	$m \cdot min^{-1}$ 1.67	0.36 1.67

With a view to specifying details concerning the size of the smallest particles of fine fraction of dry ash sawdust, a microscopic analysis of granules of dry ash sawdust fraction was performed. An additional analysis of dry ash sawdust was carried out by the optical method, i.e. an analysis of the a picture taken under the microscope Nikon Optiphot-2 with an objective Nikon 4× at the Biometric Laboratory FLD MZLU in Brno. The granules of sawdust were scanned by 3D TV CCD camera HITACHI HV-C20 (RGB 752×582 pixels), with a horizontal resolution of 700 TV lines, and evaluated using LUCIA-G 4.0 software (Laboratory Universal Computer Image Analysis), installed on a PC equipped with a Pentium 90 processor (RAM 32 MB) and a graphic card VGA Matrox Magic, working under the operating system Windows NT 4.0 Workstation. The software LUCIA-G for image analyses enabled us to identify individual particles of disintegrated wood material, perform quantitative determination of individual particles placed in the analysed picture and gain basic information, such as the width and length of the particles, and their circularity, i.e. roundness expressing the degree of deviation of projection-plane of existing grain shape from a projection-plane of round shape according to the formula:

$$\psi = \frac{4 \cdot \pi \cdot S}{O^2} \tag{1}$$

where: S is a particle area (m^2), and O is a particle perimeter (m).

The share of the technologically-useful part of sawdust chips in the range of granularity equalling a = 250 μm-2.4 mm, according to the methodology for the determination of homogenous share of chips (HSCh) in sawdust [Dzurenda, Kučerka 2009], is defined by the points of intersection of the lower and upper limit of the homogenous share of chips on the curve of remainders Z_a (fig. 2).

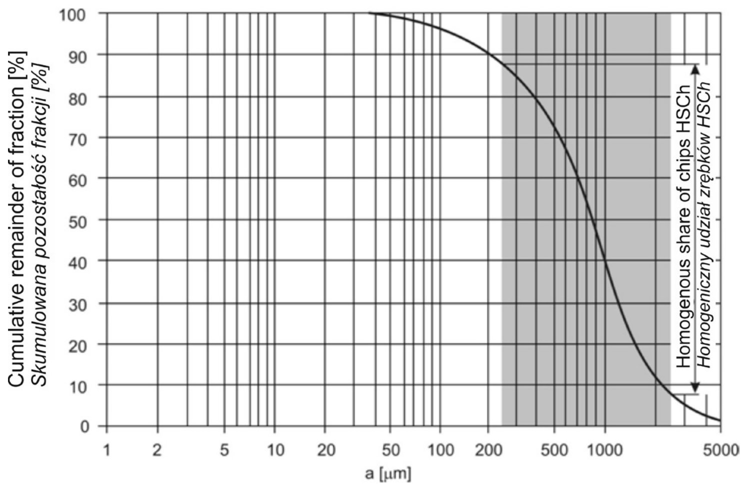


Fig. 2. Determination of the share of homogenous granularity of sawdust
Rys. 2. Określanie udziału trocin o jednorodnej ziarnistości (rozdrobnieniu)

Results and discussion

The results of sieve analyses, i.e. granulometric composition of dry sawdust of unmodified and thermally-modified ash, are presented in tables from 2 to 5.

The granulometric composition of ash sawdust from a frame saw PRW15-M obtained during cutting at a feed speed of v_1 = 0.36 m·min^{-1} is given in table 2.

Table 2. Granulometric composition of ash sawdust from a frame saw PRW15-M obtained while cutting at a feed speed of v_1 = 0.36 m·min^{-1}
Tabela 2. Skład granulometryczny trocin jesionowych uzyskanych na pilarce ramowej PRW15-M podczas przecinania z prędkością posuwu v_1 = 0.36 m·min^{-1}

MSM [mm]	MoF	Representation of the fractions in dry ash sawdust [%] *Procentowa reprezentacja frakcji w trocinach jesionowych [%]*							
		Natural wood (unmodified) *Drewno naturalne (niemodyfikowane)*				Thermally-modified wood *Drewno modyfikowane termicznie*			
		S1	S2	S3	Av.	S1	S2	S3	Av.
2.000	coarse *gruba*	3.17	3.21	3.08	3.15	1.91	1.97	1.71	1.86
1.000		7.15	7.45	6.74	7.11	1.68	1.77	2.16	1.87

Table 2. Continued
Tabela 2. Ciąg dalszy

0.500	medium coarse *średnio gruba*	35.83	36.15	35.48	35.82	18.13	19.09	18.73	18.65
0.250		37.06	35.69	36.68	36.48	55.95	54.98	55.28	55.40
0.125	fine *miałka*	13.10	12.82	13.81	13.24	18.94	17.68	17.51	18.05
0.080		2.79	2.88	2.68	2.78	2.48	2.94	3.14	2.86
0.063		0.71	0.94	0.92	0.86	0.70	1.04	0.99	0.91
0.032		0.20	0.86	0.61	0.56	0.21	0.52	0.48	0.40
<0.032		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Legend: MSM – measure of sieve mesh, *MoF* – mark of fraction, *S1* – sample #1, *S2* – sample #2, *S3* – sample #3, *Av.* – average value
Legenda: MSM – wymiar oczka sita, MoF – rodzaj frakcji, S1 – próbka nr 1, S2 – próbka nr 2, S3 – próbka nr 3, Av. – wartość średnia

The largest and the smallest dimensions of particles recognized in dry ash sawdust from natural (unmodified) and thermally modified ash wood obtained during sawing on a narrow-kerf frame sawing machine PRW15-M at a feed speed of v_1 = 0.36 m·min^{-1} are presented in table 3.

Table 3. Areal dimensions of the largest and the smallest chips in examined ash sawdust after sawing at a feed speed of v_1 = 0.36 m·min^{-1}
Tabela 3. Wymiary powierzchniowe największych i najmniejszych wiórów w badanych trocinach jesionowych po przecinaniu z prędkością posuwu v_1 = 0.36 m·min^{-1}

Timber *Drewno*	Dimensions of maximal chips [mm] *Wymiary maksymalnych zrębków [mm]*			Dimensions of minimal chips [µm] *Wymiary minimalnych zrębków [mm]*		
	S1	S2	S3	S1	S2	S3
Unmodified ash *Jesion niemodyfikowany*	3.8 × 12.1	4.1 × 12.4	4.2 × 11.6	35.1 × 35.6	35.8 × 35.9	36.7 × 37.3
	3.1 × 11.7	3.9 × 11.2	3.3 × 10.8	35.6 × 36.3	37.8 × 39.2	37.1 × 38.9
	2.8 × 8.6	3.5 × 10.9	2.6 × 9.8	36.2 × 37.8	38.2 × 39.6	37.7 × 41.2
Thermally- modified ash *Jesion modyfikowany termicznie*	3,2 × 8.5	3.6 × 8.3	4.9 × 7.9	33.1 × 33.6	33.5 × 33.5	33.7 × 34.3
	2.8 × 7.9	3.2 × 7.7	4.7 × 6.9	33.6 × 35.3	37.8 × 39.2	34.1 × 34.9
	2.7 × 7.3	2.8 × 6.3	2.2 × 5.7	33.2 × 36.8	38.4 × 39.9	34.7 × 35.2

Table 4 presents the results of sieve analyses concerning granulometric composition of dry sawdust of unmodified and thermally-modified ash after sawing at a feed speed of v_2 = 1.67 m·min^{-1}. Furthermore, the largest and the smallest dimensions of particles found in dry ash sawdust from natural (unmodified) and thermally-modified ash wood obtained while sawing on a narrow-kerf frame sawing machine PRW15-M at a feed speed of v_2 = 1.67 m·min^{-1} are given in table 5.

Table 4. Granulometric composition of ash sawdust from a frame saw PRW15-M obtained while cutting at a feed speed of v_1 = 1.67 m·min^{-1}
Tabela 4. Skład granulometryczny trocin jesionowych uzyskanych na pilarce ramowej PRW15-M podczas przecinania z prędkością posuwu v_1 = 1.67 m·min^{-1}

MSM [mm]	MoF	Representation of the fractions in dry ash sawdust [%] *Procentowa reprezentacja frakcji w trocinach jesionowych [%]*							
		Natural wood (unmodified) *Drewno naturalne (niemodyfikowane)*				Thermally-modified wood *Drewno modyfikowane termicznie*			
		S1	S2	S3	Av.	S1	S2	S3	Av.
2.000	coarse *gruba*	2.46	2.90	2.89	2.75	2.41	2.41	2.47	2.43
1.000		12.21	11.75	12.05	12.00	3.65	4.37	4.99	4.00
0.500	medium coarse *średnio gruba*	39.62	41.55	38.74	39.97	38.90	42.64	40.78	40.77
0.250		34.00	31.63	33.15	32.93	36.46	33.16	32.97	34.20
0.125	fine *miałka*	9.56	9.43	9,99	9.66	12.47	11.20	13.12	12.26
0.080		1.45	1.81	2.18	1.82	5.15	4.97	5.30	5.14
0.063		0.51	0.67	0.77	0.65	0.67	0.82	0.99	0,83
0.032		0.19	0.25	0.23	0.22	0.29	0.43	0.38	0.37
<0.032		0.00	0.00	0,00	0.00	0.00	0.00	0.00	0,00
Legend: MSM – measure of sieve mesh, *MoF* – mark of fraction, *S1* – sample #1, *S2* – sample #2, *S3* – sample #3, *Av.* – average value *Legenda: MSM – wymiar oczka sita, MoF – rodzaj frakcji, S1 – próbka nr 1, S2 – próbka nr 2, S3 – próbka nr 3, Av. – wartość średnia*									

Table 5. Areal dimensions of the largest and the smallest chips in examined ash sawdust after sawing at a feed speed of v_1 = 1.67 m·min^{-1}
Tabela 5. Wymiary powierzchniowe największych i najmniejszych wiórów w badanych trocinach jesionowych po przecinaniu z prędkością posuwu v_1 = 1.67 m·min^{-1}

Timber *Drewno*	Dimensions of maximal chips [mm] *Wymiary maksymalnych zrębków [mm]*			Dimensions of minimal chips [µm] *Wymiary minimalnych zrębków [mm]*		
	S1	S2	S3	S1	S2	S3
Unmodified ash *Jesion niemodyfikowany*	4.2 × 13.8	5.1 × 13.3	3.9 × 12.9	34.5 × 35.8	33.7 × 35.8	35.7 × 36.2
	3.3 × 13.5	3.8 × 13.6	4.2 × 12.4	35.6 × 37.3	38.8 × 39.9	36.6 × 37.3
	2.4 × 10.2	2,9 × 12.3	3.1 × 11.8	38.8 × 41.3	39.9 × 43.6	37.7 × 39.3
Thermally-modified ash *Jesion modyfikowany termicznie*	4.2 × 9.9	2.9 × 13.6	3.8 × 8.3	33.3 × 33.8	33.5 × 33.8	33.3 × 34.1
	3.8 × 9.6	2.7 × 8.1	4.2 × 8.1	33.4 × 34.6	33.7 × 33.9	35.1 × 36.2
	1.6 × 8.9	2.5 × 7.8	2.4 × 6.9	34.8 × 35.5	36.7 × 37.1	35.5 × 36.4

Based on the analyses carried out, it can be concluded that the sawdust of dry thermally modified ash produced in the sawing process on a frame sawing machine PRW15-M at a feed speed in the range of v = 0.36-1.67 m·min^{-1} consists of chips of granularity in the range of a = 0.0335-9.9 mm; whereas unmodified ash wood sawdust consists of chips in the granularity range of a = 0.0356-13.8 mm.

The analyses of size and shape of particles of dry sawdust of both unmodified and thermally- modified ash demonstrate that most chips fall into the category of polydispersive fibrils with a strong extension in one dimension. Chips of other fractions are largely within the category of isometric particles, i.e. particles with the same dimensions in all three dimensions. The above conclusions result from the fact that the plan view of chips determined by an optical method is square-shaped and has the value of circularity in the interval of Ψ = 0.7-1.0, and work under the assumption that the third measure of freely-scattered three-dimensional objects on a horizontal surface is lower than its largest measure.

The same information on the shape of particles was given by Dzurenda et al.[2006] in the analysis of pine sawdust particles produced during the sawing process of dry pine on a frame sawing machine PRW15-M at a feed speed of v = 0.5-1.5 m·min^{-1}, as well as in the work of Dzurenda et al. [2010] in the case of the sawing of dry oak and thermally-modified oak wood on a frame sawing machine PRW-15M.

Fig. 3 presents granularity plots of sawdust obtained during the sawing process of thermally- modified (course a) and unmodified ash wood (course b), with the highlighted parts of technologically-useful fractions of sawdust chips in the range from 250 μm to 2.4 mm.

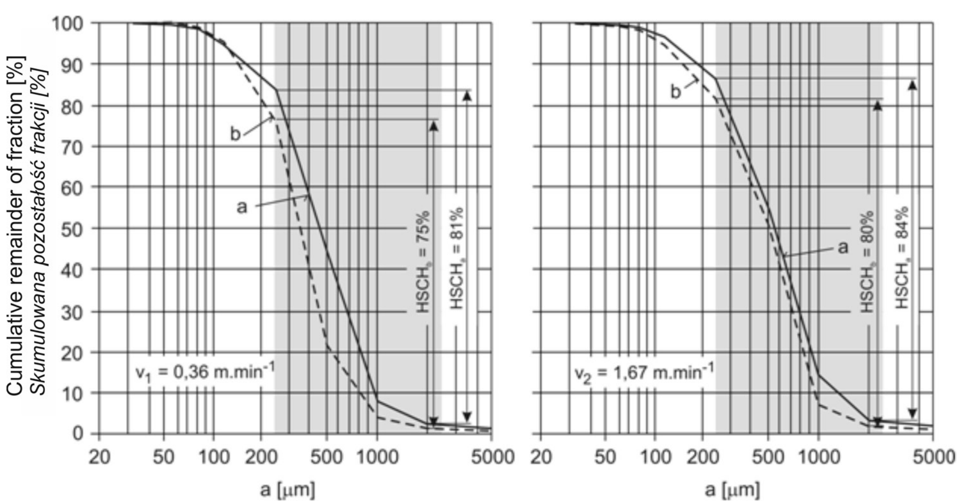


Fig. 3. Residue courses of dry sawdust obtained while sawing on a frame sawing machine PRW15-M, where: a – unmodified ash, b – thermally-modified ash

Rys. 3. Wykresy pozostałości suchych trocin uzyskanych podczas piłowania na pilarce ramowej PRW15-M, gdzie: a – jesion naturalny (niemodyfikowany), b – jesion termicznie modyfikowany

The residue courses (fig. 3) and also the sieve analyses results for sawdust from the sawing processes of unmodified and modified ash wood (tables 2, 4) prove that the sawdust obtained in the sawing process of dry thermally-modified ash is finer (see that course b is shifted to the left, fig. 3) than the sawdust from unmodified ash. In the sawdust of the thermally-modified wood, the share of moderate coarse fractions in the range of a = 125-500 µm increased sharply. Furthermore, there is an increase in the share of fine fraction in the range of granularity a = 32-125 µm at the expense of the fraction a = 0.5-2.0 mm. This fact can be attributed to the increased fragility of thermally-modified ash wood [Mayes, Oksanen 2002; Reinprecht, Vidholdová 2008]. Similar results, i.e. refinement of chip granularity, were observed during the milling process of thermally-modified beech wood [Beljo Lučic et al. 2009].

The comparison of dimensional homogeneity allows the observation that the directly technologically-useful part of sawdust chips in the range of granularity a = 250 µm-2.4 mm, originating from the sawing process of dry ash wood, was $HSCh_a$ = 81-84 % (homogenous share of chips in sawdust); whereas in the case of sawdust chips originating from the sawing process of dry modified ash wood that value was lower by 4-6 %.

Conclusions

Based on the analyses carried out, it can be concluded that:

- firstly, the sawdust of the dry thermally-modified ash, created in the sawing process on a frame sawing machine PRW15-M at a feed speed of v = 0.36-1.67 $m \cdot min^{-1}$, consists of chips of granularity ranging from 33.5 µm to 9.9 mm; whereas unmodified ash wood sawdust consists of chips in the granularity range from 35.6 µm to 13.8 mm; in both cases, polydispersive fibrils with a strong extension in one dimension were observed,
- secondly, in terms of particle shape, the chips of the largest fraction fall into the category of fibril bulk materials; whereas the chips of the fine fraction are in the category of isometric particles,
- thirdly, thermally-modified ash sawdust is finer, with a distinctly larger share of the fraction in the granularity range a = 125-500 µm, and a slightly increased share of the fraction in the range a = 32-125 µm, at the expense of the fraction a = 0.5-2.0 mm,
- finally, some technological usefulness of sawdust obtained during the sawing process on a frame sawing machine PRW15-M of both thermally-modified and unmodified ash wood in the range of granularity a = 250 µm-2.4 mm was observed; the homogenous share of chips in dry ash sawdust was $HSCh_a$ = 81-84 %; whereas in ash sawdust produced in the sawing of dry thermally-modified wood, the share was lower by 4-6 %.

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WPŁYW MODYFIKACJI TERMICZNEJ DREWNA JESIONOWEGO NA ZIARNISTOŚĆ I JEDNORODNOŚĆ TROCIN Z PROCESU PRZECINANIA NA PILARCE RAMOWEJ WIELOPIŁOWEJ PRW15-M W ASPEKCIE ICH PRZYDATNOŚCI TECHNOLOGICZNEJ

Streszczenie

Przedstawiono wyniki analiz granulometrycznych trocin, drewna jesionowego niemodyfikowanego (*Fraxinus exelsior* L.) i modyfikowanego termicznie, otrzymanych w procesie przecinania drewna na pilarce ramowej wielopiłowej PRW15-M. Przecinanie drewna prowadzono dla dwu prędkości posuwu 0,36 $m \cdot min^{-1}$ oraz 1,67 $m \cdot min^{-1}$. Ziarnistość powstających trocin dla drewna jesionowego modyfikowanego termicznie zawierała się w przedziale od 33,5 µm do 9,9 mm, podczas gdy dla drewna niemodyfikowanego ziarnistość trocin mieściła się w przedziale od 35,6 µm do 13,8 mm. Stwierdzono, iż trociny otrzymywane z drewna modyfikowanego termicznie są bardziej miałkie, z większym udziałem frakcji o ziarnistości w przedziale a = 125 – 500 µm, z nieznacznie większym udziałem frakcji z zakresu a = 32 – 125 µm. Zaobserwowano również, że przydatność technologiczna trocin mieszczących się w zakresie ziarnistości a = 250 µm – 2.4 mm dla drewna jesionowego niemodyfikowanego termicznie zawiera się w przedziale 81 – 84 %, zaś dla drewna jesionowego modyfikowanego termicznie jest mniejsza o około 4 – 6%.

Słowa kluczowe: drewno jesionowe, modyfikacja termiczna, pilarka ramowa wielopiłowa, analiza granulometryczna, ziarnistość