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The influence of screening process parameters on paper properties produced from wastepaper

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Abstract: *The influence of screening process parameters on paper properties produced from wastepaper*. Wastepaper processing is of pivotal importance for environmental protection; it is also crucial for the economy and the management of raw materials. Not only does recycling save space at landfills, it also saves an extremely valuable raw material used for paper production, i.e. wood. Unlike primary pulps, however, wastepaper contains much more than just cellulose fibres and fillers. The fact that recycled paper contains many contaminants, such as metal staples, paper clips, plastic film, glass fragments, and others, makes it necessary to develop a much more complex pulp preparation systems compared to the ones used for primary pulps. Contaminants affect not only the usable quality of paper made of wastepaper, but also cause the wear and tear of paper processing equipment. Thus, the purifying and screening of secondary pulps for further processing is very important. Considering the above, the authors' objective was to study the impact of the width of screen slots on paper properties if produced from screened wastepaper pulp. Paper strength and paper surface properties were used as the main evaluation criteria. White and mixed wastepaper was used as research material. Based on the tests, the screen slot width was found not to have any significant impact on either paper mechanical strength or paper surface properties.

Keywords: membrane screener, screening, wastepaper, fibrous pulp, paper properties, papermaking ability

INTRODUCTION

Fibrous raw materials obtained from paper products have been long used for secondary pulp production. For several centuries, any products of inadequate quality, unsuitable for further use or dry broke have been used as the input materials. With a growing demand for paper, the processing of used paper products called wastepaper received increasing significance to obtain fibrous raw materials.

Nowadays, pulp and paper industry uses secondary pulps an indispensable production input material. Wastepaper accounts for about 50% of global (Godlewska K., Jastrzębski M., 2016) and for 40% of Europe's (Holik H., 2013) total fibre consumption.

Wastepaper should be properly sorted in order for it to be rationally used as the input material. The commonly used wastepaper classification comprises the following 4 grades:

- OCC wastepaper – unbleached (brown) wastepaper, used paper and paper-board;
- white wastepaper – includes wastepaper, used paper and paper-board made of bleached chemical pulp, uncoloured;
- newspapers and magazines – wastepaper, used paper and paper-board, mainly made of paper pulp;
- mixed wastepaper – the least valuable wastepaper, composed of other wastepaper types, used paper and paper-board, unsorted and unscreened waste included (PN-EN 643:2004).

The amount of processed wastepaper has increased over time, which stimulated continuous development of paper-to-pulp conversion technologies. The removal of contaminants contained in the wastepaper and papermaking ability regeneration are the main goals of the wastepaper processing into secondary pulp. The selection of the technological operations and their sequence depends on the type of processed wastepaper, the wastepaper pulp required properties and designed usage. Now, wastepaper processing includes the following basic technological operations: slushing, defibration, cleaning, screening, fractionation, flotation, inks dispersion, mineral contaminates removal and bleaching (Przybysz P., 2011, Jakucewicz S., 2014).

In the case of wastepaper pulps, sorting and screening process is one of the preliminary, yet extremely important, technological operations. This is particularly important in the case of mixed wastepaper (grade 3.19 according to EN643 "List of European standard types waste paper"). Thus, this paper focuses upon this process. Wastepaper pulp screening consists in contaminate separation with the use of perforated sorting plates; contaminates sizes and shapes differ from fibres sizes and shapes (Jakucewicz S., 2014). Pieces of plastic film, foamed polystyrene, threads, clips, etc. may negatively impact pulp properties and thus the paper optical qualities and strength. Contaminants may also damage the paper machine wire. Equipment with various screen aperture sizes (round or slotted) and various devices types are generally used. Regular screening devices, such as flat oscillating screens and pressure screens, are used for processing. Wastepaper pulp screening is also included in as a process step in various multifunctional devices (defibering and screening, cleaning and screening devices). Multi-stage pulp cleaning systems are commonly used in order to obtain adequate wastepaper pulp purity as well as to reduce fine fibres loss (Przybysz P., 2011).

Considering the screening process' pivotal importance for wastepaper processing, the authors resolved to analyze the screen slot width impact on paper properties.

MATERIALS AND METHODS

The following materials were selected for research:

- mixed wastepaper composed of unsorted wastepaper; (ranked as 3.19 according to the EN643 "List of European standard types waste paper")
- white wastepaper, including products made from bleached pulps; (ranked as 3.04 according to the EN643 "List of European standard types of waste paper").

Figure 1. Membrane screener PS-114

Sheets of paper were produced in laboratory conditions from rewetted all pulp samples (22,5 g d. w. samples were soaked in water for 24 h) which were subjected to disintegration with the use of a laboratory JAC SHPD28D propeller pulp disintegrator (Danex, Poland) at 23000 revolutions, in accordance with ISO 5263-1 (2004). Non-defibred substances versus the fibres and water were removed with the use of a membrane screener PS-114 (Danex, Poland) (Fig. 1). The installation was equipped with gap screens with different gap widths: 0.10, 0.12, 0.15, 0.20, 0.30, 0.40 and 0.50 mm. The pulps were screened in sequence on each of the screens.

The next step was forming sheets of paper in a Rapid-Koethen apparatus. The formation of paper sheets was performed in accordance with PN-EN ISO 5269-2 (2007). Each laboratory paper sheet was described by a basis weight of 80 g/m². Only sheets with their base weight ranging from 79 to 81 g/m² were accepted for further examination. The test sheets were conditioned for 24 h at 23 ± 1°C and 50 ± 2% relative humidity, in accordance with ISO 187 (1990).

Mechanical measurements were performed on a Zwick Roell Z005 TN ProLine tensile testing machine (Zwick-Roell, Germany), in accordance with PN-EN ISO 1924-2 (2010). The examined tensile properties of paper were as follows:

- I_B – breaking length [m];
- σ_T^b – width related force with break [N/m];
- σ_T^W – force at break index [Nm/g];
- ε_T – strain at break [%];
- W_T^b – energy absorption [J/m^2];
- W_T^W – energy absorption index [J/g];
- E^b – tensile stiffness [N/m];
- E^w – tensile stiffness index [Nm/g];
- E^* – Young’s modulus [MPa];
- F_{low} – being of Young’s modulus [N];
- F_B – tensile force at break [N].

Roughness and air permeability were measured with the use of a Bendtsen apparatus (Kontech, Poland). The contaminants assessment on the tested papers’ surface was carried out with the use of a Keyence VHX-6000 microscope (Keyence, Belgium) equipped with a VH-Z20UT lens (20 ÷ 200x magnification). An OP-72402 adapter (ring shape) was used for sample illumination. The microscope software made it possible to carry out the image-analysis based measurements of elements. A microscope was also used to test samples’ surface texture in accordance with the ISO 25178: 2016 Geometrical Product Specifications (GPS) – Surface texture.

A detailed statistical analysis was performed for individual research series, determining the basic indicators – arithmetic mean, extended deviation and percentage relative error.

RESULTS AND DISCUSSION

Breaking length is one of the fundamental static tensile properties of paper (Przybysz K., 2007). This indicator is generally used in the paper trade to describe the inherent strength of paper. Breaking length constitutes a very good basis for comparing the strength of different types of paper made from various materials. The breaking length also allows to estimate the usable properties of many products. This is particularly important for the evaluation of the usefulness of packaging and newsprint paper.

Table 1 shows a breaking length comparison of papers produced from screened wastepaper. This indicator of the papers made from mixed wastepaper screened on various screens ranging between of 1750 ÷ 2400 m, different gap width did not have any significant impact on paper properties. Similarly the papers produced from white wastepaper, where the breaking length ranged between 2600 ÷ 3700 m.

Table 1. Tensile properties of paper

Pulp	Screen gap width [mm]	I_B	σ_T^b	σ_T^W	ε_T	W_T^b	W_T^W	E^b	E^w	E^*	F_{low}	F_B
		m	N/m	Nm/g	%	J/m^2	J/g	N/m	Nm/g	MPa	N	N
Mixed wastepaper	0.10	1950 (298)	1501 (222)	18.89 (2.46)	1.35 (0.32)	12.96 (3.04)	0.16 (0.02)	236400 (14304)	2979 (180)	2151 (132)	2.11 (0.18)	22.32 (3.36)
	0.12	1750 (294)	1372 (216)	17.01 (2.70)	1.25 (0.20)	10.47 (2.32)	0.13 (0.00)	241200 (37450)	2987 (464)	2192 (340)	2.19 (0.34)	20.35 (3.52)
	0.15	1800 (308)	1412 (234)	17.76 (3.16)	1.36 (0.16)	12.13 (2.38)	0.15 (0.02)	223300 (42012)	2810 (546)	2031 (372)	2.03 (0.40)	20.88 (3.38)
	0.20	2000 (300)	1584 (238)	19.62 (2.92)	1.56 (0.28)	16.23 (2.62)	0.20 (0.02)	257100 (34544)	3185 (422)	2337 (310)	2.30 (0.30)	23.50 (3.66)
	0.30	1850 (236)	1483 (190)	18.34 (2.30)	1.32 (0.22)	13.36 (2.50)	0.17 (0.02)	244200 (33464)	3020 (416)	2222 (302)	2.21 (0.28)	22.03 (2.76)
	0.40	1850 (342)	1453 (290)	17.55 (3.18)	1.29 (0.18)	11.30 (2.32)	0.14 (0.02)	239200 (40390)	2995 (560)	2174 (202)	2.16 (0.36)	20.76 (3.46)
	0.50	2400 (308)	1904 (248)	23.55 (3.00)	1.48 (0.22)	18.56 (3.48)	0.23 (0.02)	288400 (34152)	3566 (482)	2622 (316)	2.51 (0.32)	28.97 (3.68)
White wastepaper	0.10	2850 (292)	2232 (232)	27.74 (2.84)	1.49 (0.20)	22.96 (5.06)	0.29 (0.04)	352000 (25872)	4315 (322)	3158 (234)	3.11 (0.48)	33,11 (3.78)
	0.12	2650 (466)	2092 (360)	26.21 (4.02)	1.45 (0.22)	19.61 (3.12)	0.25 (0.02)	326600 (53370)	4090 (702)	2969 (458)	2.97 (0.50)	30.91 (4.42)
	0.15	2600 (272)	2011 (208)	25.42 (2.66)	1.39 (0.22)	19.43 (2.72)	0.25 (0.02)	321700 (26248)	4065 (324)	2923 (236)	2.86 (0.18)	29.26 (3.12)
	0.20	2850 (422)	2189 (420)	27.92 (3.96)	1.93 (0.22)	27.87 (5.08)	0.36 (0.06)	309900 (55372)	3957 (700)	2817 (498)	2.76 (0.46)	33.55 (6.02)
	0,30	3400 (414)	2667 (324)	33.39 (4.06)	1.72 (0.24)	30.97 (4.54)	0.39 (0.04)	384900 (13114)	4819 (170)	3498 (124)	3.25 (0.40)	39.22 (5.34)
	0,40	3150 (320)	2454 (250)	30.80 (3.12)	1.91 (0.20)	32.48 (6.16)	0.41 (0.06)	325700 (28566)	4086 (362)	2962 (256)	2.97 (0.32)	35.41 (3.12)
	0,50	3700 (622)	2872 (482)	36.36 (6.24)	1.87 (0.62)	36.64 (5.38)	0.46 (0.04)	379300 (63482)	4796 (808)	3448 (438)	3.25 (0.32)	41.22 (6.42)

Note: Extended deviations are given in brackets.

Besides breaking length, energy absorption is one of the most important strength properties. Energy absorption represents a compromise between width-related tensile force at break and strain at break (Przybysz K., 1997). The parameter ranged from 10.47 to 18.56 J/m^2 and 19.43 to 36.64 J/m^2 for paper from mixed and white wastepaper, respectively. In order to characterize the strength properties of the tested papers in greater detail, measurements of width-related force at break were also made. The parameter ranged from 1372 ÷ 1904 N/m for mixed wastepaper and 2011 ÷ 2872 N/m for white wastepaper. Force at break index values ranged from about 17 to 24 Nm/g and 25 to 36 Nm/g for papers from mixed and white wastepaper, respectively. Strain at break did not exceed 2% in both kinds of wastepaper. The range of tensile stiffness value for paper produced from mixed wastepaper was 223300 ÷ 288400 N/m, while for the paper obtained from white wastepaper – 309900 ÷ 379300 N/m. Young's modulus was also determined in the study, reaching 2031 ÷ 2622 and 2817 ÷ 3448 MPa for the paper from mixed and white wastepaper, respectively. The tested paper was characterized with low values of tensile force at break not exceeding 29 N for mixed wastepaper and 42 N for white wastepaper.

To summarize the tensile properties analysis, there was no significant effect of the slot width of the screens on tensile properties of the paper obtained from screened wastepaper. Also interesting is the fact that the highest values of the tensile properties were obtained for the paper produced from pulp screened on a screen with 0.50 mm gap width. The paper produced from mixed wastepaper showed lower tensile properties, probably due to a higher contaminant content in the pulp (Tab. 1).

The next stage of research was a microscopic analysis of paper surface and measurements of roughness in order to evaluate the surface properties of the tested papers. Additionally, air permeability of paper was examined. The air permeability and roughness were performed using the Bendtsen method.

The degree of porosity (air permeability) is an extremely important property, which greatly contributes to the functional properties of paper. It is also an important indicator for the production process control because it indicates the porosity of the product, its tensile properties, absorbency or dielectric properties (Przybysz K., 2007, 1997). All the tested types of paper were characterized by very high air permeability values. With all screens used in the study, the indicator value of the tested paper exceeded the measuring range of the device (5000 ml/min).

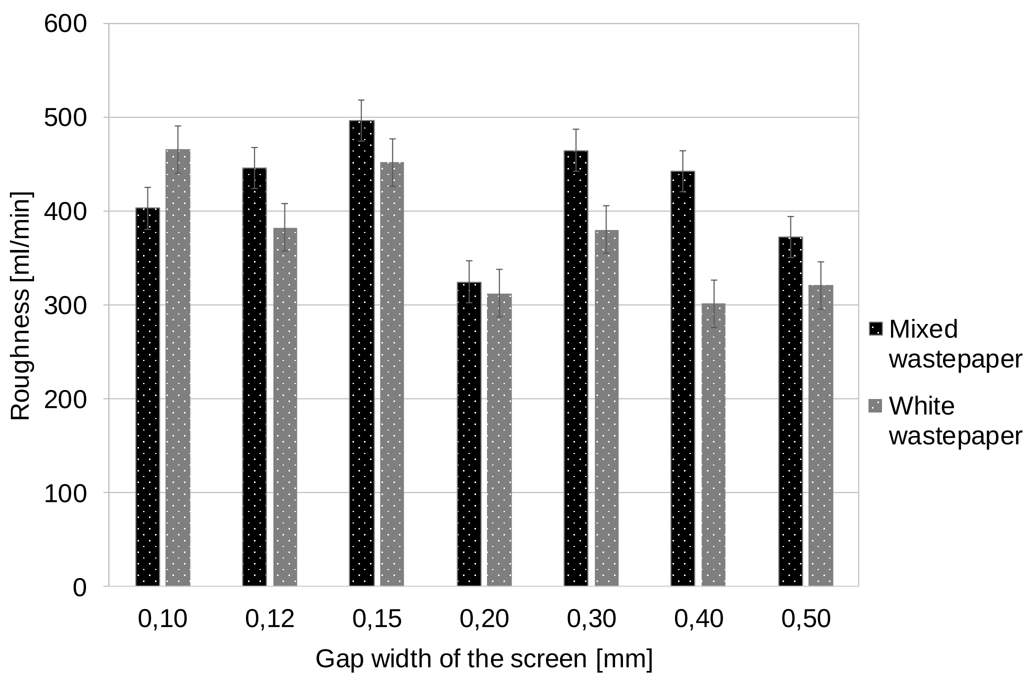


Figure 2. The effect of the screen gap width on changes in the roughness of paper

Roughness (or smoothness) of paper is another key property; it allows to determine micro- and macrostructure of paper surface and, therefore, the surface suitability for print application (Klein R., Schulze U., 2007). This property depends on, inter alia, the composition and properties of pulp or the papermaking process conditions. However, the results of the analysis showed that a change of the screening process parameters had no significant impact on the surface structure of the tested paper. In most samples, the paper produced from mixed wastepaper showed higher roughness ranging between 325 and 497 ml/min, probably due to a higher content of impurities in the pulp. In white wastepaper, the value of paper roughness ranged from 301 ÷ 465 ml/min (Fig. 2).

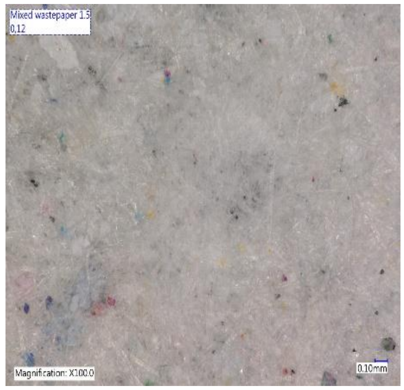
Roughness/smoothness was also determined with the use of a microscopic method. For this purpose, 3D images were made with the use of a Keyence VHX-6000 microscope. Then the images were processed to obtain linear roughness (S_a) and surface roughness (S_z) profiles. The S_a parameter indicates the average deviation of points in the sample from the plane which is the average height of the sample. The S_z parameter specifies the difference between the highest and the lowest point of the sample surface in the Z direction (the axis perpendicular to the sample surface). Numerical values of linear and surface roughness obtained from this measurement are presented in table (Tab. 2). Linear roughness (S_a) ranged from 3.83 ÷ 4.83 μm for mixed wastepaper and 3.76 ÷ 7.68 μm for white wastepaper. The range of surface roughness (S_z) value for the paper produced from mixed wastepaper was 36.71 ÷ 59.40 μm, while for the paper obtained from white wastepaper – 45.30 ÷ 66.56 μm. Variations in the screening screen did not show any clear tendency to change the roughness parameters of the paper from screened pulp, either in mixed or white wastepaper.

Table 2. Linear (S_a) and surface roughness (S_z) of the tested paper

Pulp	**Screen gap width [mm]**	**S_a [μm]**	**S_z [μm]**
Mixed wastepaper	0.10	4.34	59.40
	0.12	4.83	54.43
	0.15	4.67	57.74
	0.20	4.05	50.93
	0.30	4.46	56.62
	0.40	3.83	36.71
	0.50	4.37	43.02
White wastepaper	0.10	3.82	46.28
	0.12	6.19	52.45
	0.15	7.68	66.56
	0.20	3.76	45.30
	0.30	6.02	61.61
	0.40	4.38	50.08
	0.50	4.88	55.41

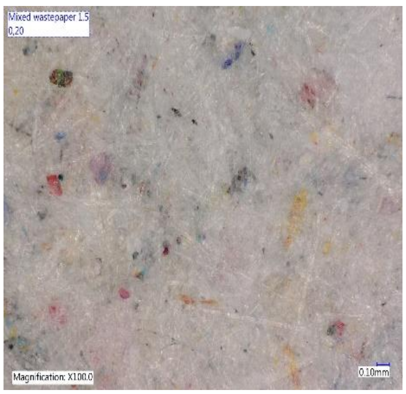
The microscopic analysis of impurities on the surface of the tested paper is presented in the figures (Fig. 3, 4) below. Significant amounts of impurities on the surface of papers produced from mixed wastepaper were observed due to a higher content of impurities in the pulp (Fig. 3). However, the gap width of the screen no significant affects the amount of these impurities both for mixed and white wastepaper.

0.10 gap screen

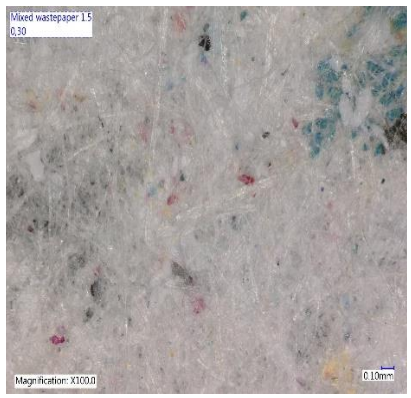


0.12 gap screen

0.15 gap screen

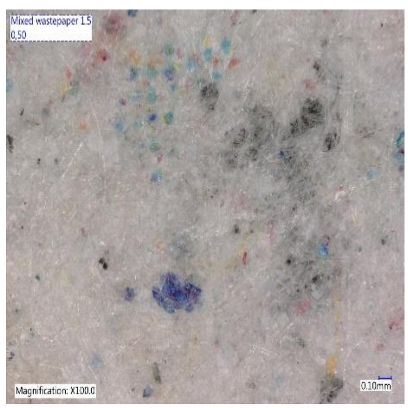


0.20 gap screen



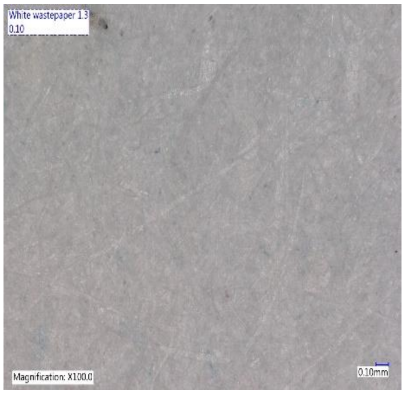
0.30 gap screen

0.40 gap screen



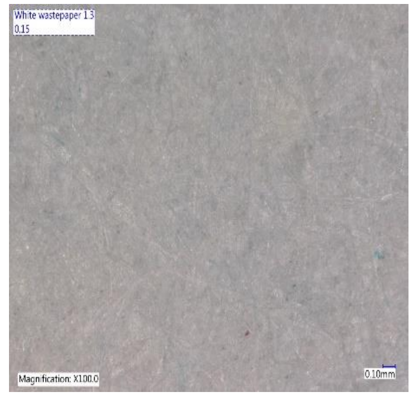
0.50 gap screen

Figure 3. Microscopic images of the paper surface for mixed wastepaper

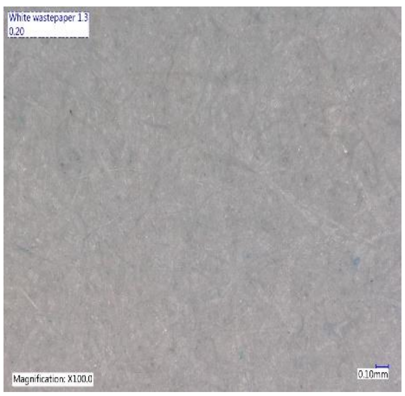


0.10 gap screen

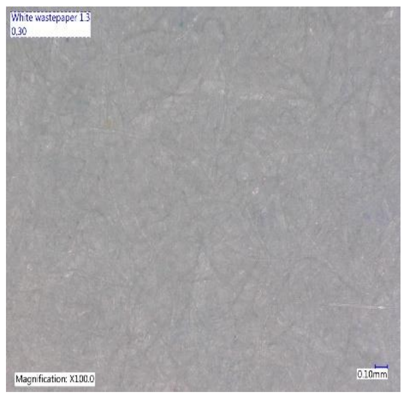
0.12 gap screen



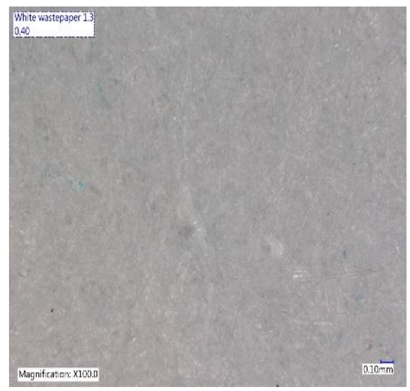
0.15 gap screen



0.20 gap screen



0.30 gap screen



0.40 gap screen

0.50 gap screen

Figure 4. Microscopic images of the paper surface for white wastepaper

CONCLUSIONS

The authors have studied and analysed the impact of screen slot widths on the strength and surface properties of paper produced from screened wastepaper pulps. The examinations were carried out in laboratory conditions. No effect of screen slot widths on either paper strength or its roughness and air permeability has been discovered. The microscopic images did not reveal an increased amount of contaminants on the paper surface for the product made of wastepaper screened pulp, screened with the use of a sieve with the largest screen slot width. Thus, the article indicates the need for further, in-depth research on the wastepaper screening process and the impact of the structural elements of screening devices on secondary pulps properties.

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Streszczenie: *Wpływ parametrów procesu sortowania na właściwości papieru wytworzonego z masy makulaturowej.* Proces przerobu makulatury jest bardzo ważny ze względu na ochronę środowiska, jak też na ekonomię i gospodarkę surowcami. Przerób mas wtórnych oszczędza miejsce nie tylko na wysypiskach śmieci, ale również niezwykle cenny surowiec do produkcji papieru, jakim jest drewno. Jednakże, w przeciwieństwie do mas pierwotnych, przetwarzana makulatura zawiera znacznie więcej niż tylko włókna celulozowe i wypełniacze. Udział zanieczyszczeń w postaci metalowych zszywek, spinaczy, kawałków folii, szkła i innych wymusza opracowanie znacznie bardziej złożonych układów przygotowania masy niż w przypadku mas pierwotnych. Zanieczyszczenia te, bowiem wpływają nie tylko na jakość użytkową wyprodukowanego papieru ale również powodują zużycie elementów wewnątrz urządzeń procesowych. Stąd tak ważny jest proces oczyszczania i sortowania w procesie przerobu mas wtórnych. Za cel pracy autorzy postawili, zatem zbadanie wpływu szerokości szczeliny sita sortowniczego na właściwości papieru otrzymanego z przesortowanej masy makulaturowej. Głównymi kryteriami oceny były właściwości wytrzymałościowe oraz właściwości powierzchni papieru. Jako materiał do badań wykorzystano makulaturę białą oraz mieszaną. Na podstawie wykonanych badań stwierdzono, że szerokość szczeliny sita nie wywiera istotnego wpływu zarówno na wytrzymałość mechaniczną papieru, jak i na właściwości jego powierzchni.

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