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The effect of the addition of primary fibers on the papermaking ability of wastepaper

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Abstract: *The effect of the addition of primary fibers on the papermaking ability of wastepaper*.
The rapid increase in paper production and consumption at the end of the 20th century contributed to the increasing difficulties connected with assurance of required resources base for paper industry and the utilization of the growing amount of paper waste. The wastepaper salvage and application of secondary pulps for paper production make a significant contribution to solving these issues, and these activities are justified based on ecology and economy. It must be said, however, that the addition of certain amount of primary fibers is necessary to ensure strength and others usable properties of produced paper. The authors have set themselves the goal of the examination of primary fibers addition on papermaking ability of wastepaper. Studies have shown that the addition of primary fibers to wastepaper has a positive impact on all examined strength properties of paper.

Keywords: wastepaper, cellulosic pulp, wood, paper properties

INTRODUCTION

The rapid increase in paper production and consumption in industrialized countries caused a shortage of wood in many areas of the world in the second half of the 20th century, which is a serious problem, because the global demand for fibrous raw materials is still growing. At the beginning of the 20th century, the production of paper products in the world amounted to about 5 million tons [1], while in 2016, on a global scale, it reached the level of 410 million tons [2, 3], and it shows a constantly increasing trend [4] (Fig. 1). The consumption of paper products per capita is therefore around 57 kg per year [5].

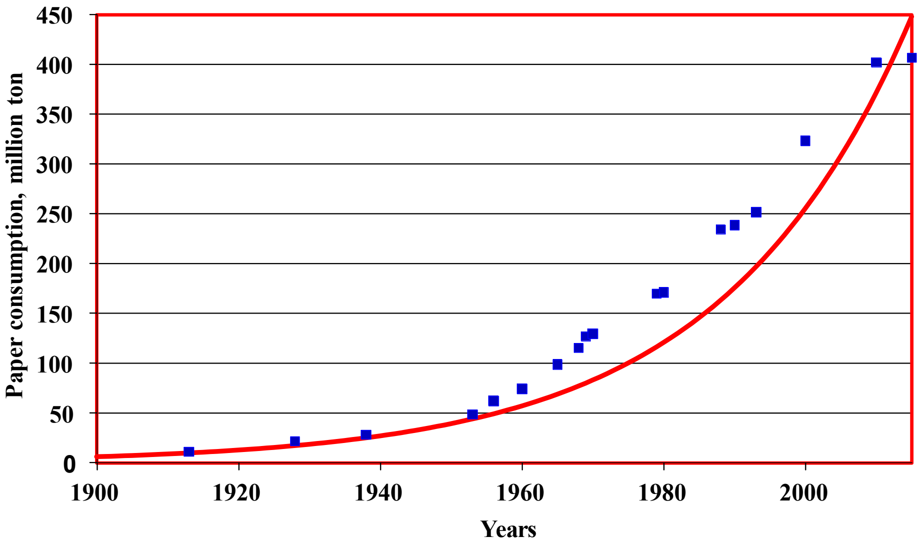

Figure 1. Graph of the paper consumption in the 20th and 21st century

The paper industry is therefore making efforts to expand its raw material base. The search for alternative raw materials for paper production is additionally fueled by the growing ecological awareness of society manifested in the protection of the natural environment, including forest resources, the pressure of ecologists concerned about the destruction of forest animal habitats, the rising prices of typical wood fiber materials and the possibilities of today's technology. Activities aimed at expanding the resource base of the paper industry include, among others, building plantations of fast-growing trees [6, 7], using non-wood fibrous raw materials [8, 9] and increased use of waste paper [10].

The secondary pulp currently accounts for 50% of the total amount of pulp used in the world [11], while in Europe the indicator is 40% [12]. They can be divided into recycled paper and dry broke produced in paper mills and paper processing plants. Recycled paper is the most commonly used secondary raw material. Secondary pulp is cheaper than the original one, so thanks to its use, the costs of paper production are reduced. The use of recycled paper in the paper production process significantly contributes to the expansion of the raw material base in the paper industry and to the utilization of the growing amount of paper waste [13]. Not only does it save space in rubbish dumps, but also an extremely valuable raw material for paper production - wood. Unfortunately in Poland, only 42% of wastepaper is recycled [14], while in Europe in 2014 this figure came up to about 70% [15].

Along with the increased use of recycled paper, the technology of converting it into secondary pulp is also developing. Depending on the type of recycled paper and its processing methods, we can obtain pulps with different characteristics. However, it should be taken into account that in order to ensure the strength and other properties of the produced paper, some primary fibers must be added. Therefore, this work examines the impact of adding recycled paper to virgin fibers on the papermaking potential of the produced paper.

MATERIALS AND METHODS

The following materials were selected for research:

- an industrial air-dried and bleached pine sulfate pulp in the form of sheets
- wastepaper:
  - mixed wastepaper composed of unsorted wastepaper; (ranked as 3.19 according to EN643 “List of European standard types waste paper”)
  - white wastepaper, including products made from bleached pulps; (ranked as 3.04 according to EN643 “List of European standard types of waste paper”).

The 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) that were subjected to disintegration using the laboratory JAC SHPD28D propeller pulp disintegrator (Danex, Katowice, Poland) at 23000 revolutions, according to ISO 5263-1 (2004). Additionally, the waste papers were screened using a membrane screener PS-114 (Danex, Katowice, Poland) equipped with 0.2 mm gap screen to remove impurities. The disintegrated pine pulps were concentrated to the dry weigh content of 10% and refined in a JAC PFID12X PFI mill under standard conditions, according to ISO 5264-2 (2011). After refining of pine pulps and screening of waste paper, the three mixtures were prepared from waste papers and pine pulps. The mixtures were prepared with the addition of 15%, 30% and 50% of the primary pine fibers. After preparing the mixtures, the following properties of the pulps were evaluated:

- The Schopper-Riegler freeness – the measurement of refining degree was performed using Schopper – Riegler apparatus (Danex, Katowice, Poland) in accordance with PN-EN ISO 5267-1 (2002).
- WRV(Water Retention Value) – the water retention within fibers was examined centrifugal method which was developed by Jayme and Rothamel, according to ISO 23714 (2014). According to this method, the pulp sample is subjected to centrifugation using the acceleration of 3,000g for 15min and determining ratio of water to weight of bone dry sample [16].

The next step was forming sheets of paper in the 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 basis weight of 80 g/m². Only sheets with a base weight that ranged from 79 to 81 g/m² were accepted for further investigation. Test sheets were conditioned for 24 h at 23 ± 1°C and 50 ± 2% relative humidity, according to ISO 187 (1990). The paper properties were examined as follows. The roughness and the air permeability were measured on a Bendtsen apparatus (Kontech, Lodz, Poland). Mechanical measurements were performed on a Zwick Roell Z005 TN ProLine tensile testing machine (Zwick-Roell, Ulm, Germany), according to PN-EN ISO 1924-2 (2010):

- 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].

RESULTS AND DISCUSSION

Properties of examined pulps are shown in Table 1. The Schopper-Riegler freeness determines the ability of the pulp to dehydration under standard conditions. A freeness is expressed in Schopper-Riegler degrees (°SR) on a scale from 0 to 100°SR [17]. The freeness of papers produced form mixed and white wastepaper was comparable. No significant differences have been observed between secondary pulps obtained from mixed and white wastepaper, but the freeness increases with the addition of primary fibers (Tab. 1).

Table 1. Properties of pulp

Raw material		Freeness	WRV (with fines)
		°SR	%
Mixed wastepaper	100% wastepaper	15	93
	15% pine pulp 85% wastepaper	15	111
	30% pine pulp 70% wastepaper	17	117
	50% pine pulp 50% wastepaper	17	130
White wastepaper	100% wastepaper	14	103
	15% pine pulp 85% wastepaper	14	116
	30% pine pulp 70% wastepaper	15	124
	50% pine pulp 50% wastepaper	17	135

The WRV indicator determines the amount of water retained in the pulp. The essence of this method is removing free water from the test pulp (contained between the fibers) and determining the content of stopped water (water contained inside the fibers) [18, 19]. The paper with the largest content of pine fibers achieved the highest value of WRV, for both mixed and white wastepaper (Tab. 1).

Figure 2 shows a comparison of breaking length of papers received from wastepaper with different addition of pine pulp. The indicator is one of the fundamental static tensile properties of paper. It is the length of paper strip, if suspended vertically from one end, would break by its own weight [20]. Breaking length is generally used in the paper trade to describe the inherent strength of paper. It constitutes a very good basis for comparing the strength of papers made from different materials and of different basis weight.

The breaking length is a widely used indicator, because it allows to estimate the usable properties of many products. This is particularly important for the evaluation of usefulness of packaging and newsprint papers.

The breaking length depends on the average fiber length, among other things, which explains why the papers with increased participation of pine fibers have higher strength (Fig. 2, Tab. 2). 50% addition of primary fibers caused the increase of breaking length level of 70% in relation to the paper made only from mixed wastepaper. In white wastepaper, the increase of indicator was 33%. The indicator for papers made from white wastepaper is 12 ÷ 43% higher than in the mixed wastepaper (Fig. 2). Also for other mechanical properties, the strength grew with increasing the addition of primary fibers, irrespective of the waste paper type (Tab. 2).

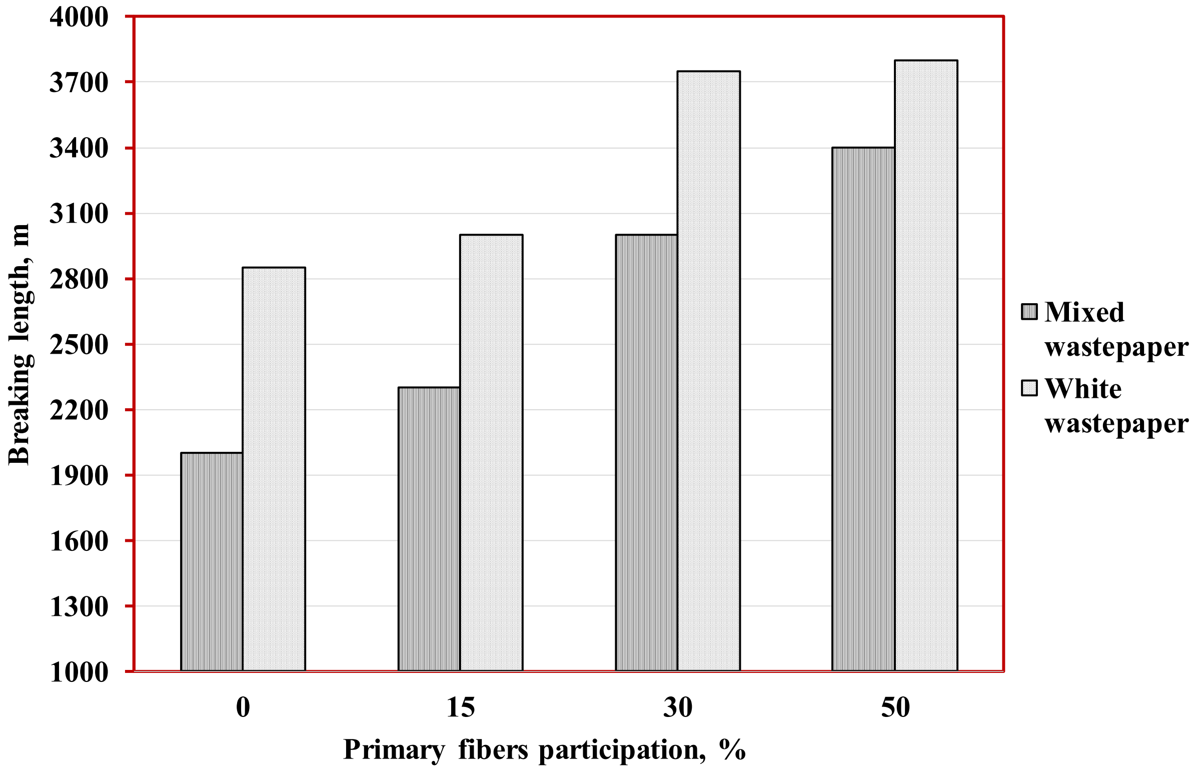

Figure 2. The effect of primary fibers addition for wastepaper on changes in the breaking length of paper.

Roughness of the paper (or its smoothness) is a very important usable property, because it determines the surface susceptibility to printing [21]. This property depends on, among others, the composition and properties of pulp or the papermaking process conditions.

The value of primary fibers addition did not show significant effects on the roughness of examined samples. The papers produced with mixed wastepaper showed higher roughness that ranged between 323 and 361 ml/min, probably due to the higher content of impurities in the pulp (Tab. 2).

The content of pine pulp also did not show significant effects on the air permeability of papers (Tab. 2). Air permeability is related to the porosity of the product and depends on the structure density. The measurement of air permeability is an important indicator of the production process control, because it indicates the porosity of the product and strength properties, absorbency of the product or dielectric properties associated with porosity [22]. High air permeability is a desirable property in dustproof cartons and filter papers. However, many wrapping paper, and especially food packaging paper, should have a very low air permeability.

The air permeability of papers made from mixed wastepaper ranged between 4712 and 4921 ml/min. The indicator greater than 5000 ml/min was unchanged for papers produced from white wastepaper (Tab. 2).

Table 2. Properties of paper

Pulp	The part of primary fibers	σ_T^b	σ_T^W	ε_T	W_T^b	W_T^W	E^b	E^w	E^*	F_{low}	F_B	R*	AP**
		N/m	Nm/g	%	J/m^2	J/g	N/m	Nm/g	MPa	N	N	ml/min	ml/min
Mixed wastepaper	0%	1584	19.62	1.56	16.23	0.20	257100	3185	2337	2.30	23.50	358	5000
	15%	1849	22.68	2.20	27.67	0.34	212600	2608	1932	1.38	27.62	323	4851
	30%	2372	29.55	2.77	43.68	0.54	281000	3502	2555	2.05	32.71	332	4712
	50%	2710	33.26	2.98	62.53	0.77	310500	3810	2821	2.35	38.36	361	4921
White wastepaper	0%	2189	27.92	1.93	27.87	0.36	309900	3957	2817	2.76	33.55	313	5000
	15%	2296	29.22	2.43	37.3	0.47	321400	4090	2922	2.85	33.22	297	5000
	30%	3021	36.71	2.83	58.15	0.71	353500	4289	3212	2.68	44.16	292	5000
	50%	2954	37.18	3.13	61.91	0.78	332800	4184	3026	2.82	44.33	301	5000

*R – roughness
*AP – air permeability

CONCLUSIONS

1. The addition of virgin fibers to wastepaper has a major influence on the strength properties of papers.
2. The addition of virgin pine pulp in secondary pulp does not significantly affect roughness and air permeability of paper, however, the smoothness and air permeability are higher for papers made form white wastepaper compared to mixed wastepaper.
3. The type of wastepaper does not significantly influence the pulp properties (freeness and WRV), but the fiber swelling degree is growing as the addition of primary fibers rises.
4. The availability of a constant, year-round supply of fiber is a primary concern for paper mills. It is right and necessary to permanent developing technology of the

wastepaper processing owing to the shortage of wood raw materials and the rising prices of typical wood fiber materials.

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Streszczenie: *Wpływ dodatku włókien pierwotnych na zdolność papierotwórczą makulatury*. Szybki wzrost produkcji i zużycia papieru przyczyniły się pod koniec XX wieku do narastających trudności związanych z zapewnieniem odpowiedniej bazy surowcowej dla przemysłu papierniczego oraz utylizacji rosnącej ilości odpadów papierowych. Odzyskanie makulatury i wykorzystanie wtórnych mas włóknistych do produkcji wytworów papierowych w znacznym stopniu przyczyniają się do rozwiązania tych trudności i są jak najbardziej uzasadnione względami ekologicznymi oraz ekonomicznymi. Należy jednak wziąć pod uwagę fakt, że w celu zapewnienia wytrzymałości i innych właściwości użytkowych wytwarzanego papieru konieczny jest dodatek pewnych ilości włókien pierwotnych. Za cel niniejszego artykułu autorzy postawili, zatem zbadanie wpływu dodatku włókien pierwotnych na zdolność papierotwórczą masy makulaturowej. Stwierdzono, że dodatek włókien pierwotnych do masy makulaturowej pozytywnie wpływa na wszystkie badane właściwości wytrzymałościowe papieru.

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