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INVESTIGATION OF THE FIBER COMPOSITION EFFECT UPON SACK PAPER PROPERTIES

The article presents data on production volumes of sack paper, which is produced by the world's leading companies. The main raw material for the manufacture of this product is unbleached softwood sulphate pulp having a high cost. In the present research work the fiber composition effect upon sack paper properties was investigated. This makes it possible to determine the optimal mass ratio of unbleached kraft primary fibers (kraft pulp) and secondary fibers (waste paper) for the manufacture of sack paper. *D*-optimal continuous design (Kono, 1962) for the estimating second order polynomial full models was used as the experiment design for the optimization of the pulp fiber composition. Considering the restrictions on the quality parameters specified in GOST 2228–81 "Sack paper. Specifications" the analysis of the obtained experimental data using the search function in Microsoft Excel 2007 gave the following results on the sack paper fiber composition: kraft pulp content (X_1) – 43.30% of a. d. s.; polyacrylonitrile fibers content (X_2) – 0.15% of a. d. s.; waste paper content – 56.55% of a. d. s.

During the experiment it was found that an increase of polyacrylonitrile fibers content from 0.05 to 0.20% in the kraft pulp structure leads to the increase of sack paper tensile strength by 25–28% (breaking length increased from 5,700 to 7,300 m). But paper whiteness at the same time decreased by 9.7%. This made possible to reduce the content of expensive kraft pulp in the composition of sack paper by 27% (taking into account the 30,000 t/year production of sack paper, saving of kraft pulp can reach 8,000 t/year).

Key words: sack paper, fiber composition, kraft pulp, waste paper, polyacrylonitrile, tensile strength, whiteness, tensile elongation, ternary plot.

Introduction. Nowadays the main world paper producers (Mondi Group, CJSC "Investlesprom", BillerudKorsnäs AB and Smurfit Kappa Group) produce more than 2 mln tons of sack paper per year. At the same time about 87% of the aforementioned number belongs to the products obtained from the expensive unbleached softwood kraft pulp [1].

In the Republic of Belarus sack paper is produced according to GOST 2228–81 "Sack paper. Specifications" (reissued in 2004) where is indicated that along with unbleached softwood kraft pulp "the use of cellulose from hard wood at the amount up to 10% is allowed on the conditions of the conformity of paper parameters" [2].

Many domestic manufacturers in order to save the primary softwood fiber produce paper in compliance with the technical specifications and extend the mass ration of the recycled fiber (waste paper) in the composition of sack paper up to 30%. But to our opinion this composition is not optimal as there are reserves for the primary softwood fiber economy.

Main part. According to the common terminology sack paper is the paper designed for the production of bags, including water resistant, saturated and cast-coated bags. Usually paper is produced with the mass of one square meter equal to 70–100 g. Sack paper shall have high tear strength, tensile elongation, folding resistance, bursting strength and has high hydrophobic properties [3, 4]. According to GOST 2228–81 four kinds of sack paper brand marks are produced: untreated (M-70A, M-79B, M-78A, M-78B, M-78C), water resistant (W-70, W-78), saturated (S-70, S-78) and polyethylene coated (P) [2].

Sack paper as a wide-scale kind of paper product is produced on technological lines equipped with high-capacity machinery. The technology of sack paper production has been constantly improving in compliance with the requirements of consumer market.

All the new technical solutions applicable to sack paper technology are based on theoretical researches aimed at the achievement of some contrast paper properties such as high strength of bags and high porosity in combination with additional functional properties – good printability on such paper, release properties (antiadhesion ability), water resistance, wet-strength, vapor-impermeability, etc.

In the world practice the most common index of sack paper strength is TEA (*tensile energy absorption*). The TEA is the work done when a specimen is stressed to rupture in tension under pre-

scribed conditions as measured by the integral of the tensile strength over the range of tensile strain from zero to maximum strain. The TEA is expressed as energy per unit area (test span × width) that is absorbed by the test paper specimen in the process of its elongation until rupture [5].

The validity of this index is confirmed by the results of correlation analysis of the relation between paper material TEA index and strength of the bag manufactured of sack paper (strength index of bags was expressed by the number of impact until tear after their throwing from a certain height) [6, 7].

Important technological factor for the provision of the optimal ratio of such contrast properties of sack paper as air permeability (porosity) and mechanical strength is based on the addition of auxiliary chemical components such as cationic starches and water-soluble polymers.

It is well known that the increase of air permeability (porosity) is achieved mostly by the reduction of the freeness value of paper-pulp; however this causes the reduction of paper mechanical strength. Cationic starches in the combination with other chemical additives which regulate the fibers and fines microflocculation as well as the dehydration of paper furnish can compensate this disadvantage.

At the same time the usage of auxiliary chemical components causes the increase of the materials-output ratio of paper products and does not allow reducing the production costs of the sack paper.

Scientific and practical interest was in the determination of usage capability of unbleached softwood kraft pulp obtained in the process of kraft pulping together with addition of polyacrylonitrile fibers in the composition of sack paper. As the abovementioned kraft pulp has enhanced strength so we can suppose that mass ratio of fiber materials can be moved to increased waste paper share and primary pulp savings.

Goal of work lies in the study of the effect of sack paper composition on the paper properties and in the determination of the possibility of kraft pulp mass ratio reduction in the furnish composition of sack paper.

The research had the following tasks:

– in vitro manufacturing the sack paper samples and study their properties;

– determination of the optimal fiber composition of sack paper containing waste paper and kraft pulp obtained in the process of kraft pulping together with addition of polyacrylonitrile fibers.

Previously [10] it was reveal that polyacrylonitrile fibers in conditions of pulping process are subjected to alkaline hydrolysis and transform to small particles with 0.5–2.0 μm diameter.

The test subjects were the sack paper samples with weight of (78 ± 2) g/m^2 manufactured from analyzed kraft pulp with increased strength properties and waste paper of marks МС-5Б and МС-6Б according to GOST 10700–97 (1.01–1.05, 4.01–4.08, 5.04 according to EN 643). The standard methodology that is widely applied in the paper industry was used during the research [8].

The conditions of the paper samples (handsheets) preparing conformed to GOST 2228–81 “Sack paper. Specifications”. The pulp freeness was 60°ShR. The laboratory valley beater with the adjustable clamping force of the grinding drum bars against a smooth bed was used for the fiber materials refining.

The sack paper handsheets were tested for the following quality parameters: strength properties were determined on the tensile testing machine SE 062/064 Lorentzen & Wettre (GOST ISO 1924-1-96), tear strength on the Elmendorf tear strength tester (GOST 11208, ISO 1974), whiteness on the Kolir tester (ISO 2470, GOST 30113) and folding endurance on the Schopper double fold tester (ISO 5626). At least five samples were manufactured and tested at each experimental point [9].

On the first stage of the research in the laboratory of Department of chemical processing of wood preliminary experiments were carried out for the preparation of sack paper fiber composition. Softwood kraft pulp with increased strength was used in the present experiment. Such fiber material was obtained earlier in the kraft pulping process of coniferous chips together with polyacrylonitrile (PAN) fibers. It was found that increase of the PAN-fibers consumption from 0.05 to 0.20 wt % of oven-dry wood results in the increase of pulp strength by 15–18% (breaking length raised from 8,480 up to 9,990 m, breaking strength when dry – from 93.8 up to 109.5 N). Also whiteness of the pulp was reduced by 10% which may be due to the formation of chromophoric compounds of residual lignin and ammonia released by polyacrylonitrile hydrolysis [10].

Table 1 shows the data on the influence of fiber composition of pulp on the properties of sack paper.

It is well known that waste paper maintenance in pulp composition reduces strength and special properties of paper. However during the study it was revealed that negative effect of waste paper on strength of sack paper can be avoided by PAN adding in to the pulp composition even in a minor amount.

Thus the mass ratio of waste paper in the composition of sack paper can be increased up to 60% at the 0.15% content of the PAN. At the same time the basic properties remain within the limits specified in the standard (GOST 2228–81).

The tensile elongation of paper handsheets at abovementioned fiber mass ratio was less than 3.9% due to the fact that the samples were not subjected to microcreping (process of imparting special elastic properties to sack paper).

Table 1

Quality parameters of sack paper depending on the fiber composition

PAN consumption, % of a. d. s.	Mass ratio of softwood kraft pulp, %	Mass ratio of waste paper (МС-6Б grade), %	Breaking length, m	Tear strength, mN	Breaking strength when dry, N	Tensile elongation, %
0	70	30	5,550	1,150	62.6	1.9
0.05	60	40	5,900	960	64.5	1.7
0.10	50	50	6,450	840	72.2	2.4
0.15	**40**	**60**	**6,050**	**790**	**68.4**	**2.0**
0.20	30	70	5,200	720	56.8	1.7
Quality parameters for sack paper of M-78A grade in conformity with GOST 2228–81			Not less than 4,300	Not less than 770	Not less than 45.0	Not less than 3.9

On the second stage of the research the optimal fiber mass ratio of sack paper stock was determined using *D*-optimal continuous design (Kono, 1962 [11]) for the estimating second order polynomial full models (Table 2).

As X_1 the softwood kraft pulp mass ratio (%) in the sack paper composition was defined and as X_2 the PAN fiber consumption (wt % of oven-dry wood) was defined [12].

Table 2

Kono design for the estimating second order polynomial full models

Test	X_1, %	X_2, % of oven-dry wood
1	70	0.2
2	30	0.2
3	30	0
4	70	0
5	70	0.1
6	50	0.2
7	30	0.1
8	50	0
9	50	0.1

Considering the restrictions on the quality parameters, specified in GOST 2228–81 “Sack paper. Specifications”, the analysis of the obtained experimental data using the search function in Microsoft Excel 2007 gave the following results on the sack paper fiber composition: kraft pulp content (X_1) – 43.30% of a. d. s., polyacrylonitrile fibers content (X_2) – 0.15% of a. d. s. and correspondingly waste paper content – 56.55% of a. d. s. This confirms the correctness of conclusions that was made after preliminary tests of the samples of sack paper. Thus there can be achieved 27% economy of the primary wood pulp (kraft pulp).

Fig. 1 demonstrates the mass ratio of the fiber components of sack paper before optimization (*a*) and after (*b*) then kraft pulp with increased strength (by PAN fibers) was used.

The proposed method of paper production allows saving of about 100 US dollars per ton of sack paper. However the abovementioned value can be decreased because of bigger mass ratio of waste paper in the paper stock will require additional outlay for purchase and installation of special cleaning equipment such as centrifugal cleaners and vortex cleaners for the pulp cleaning from impurities contained in waste paper and flotation unit for the cleaning of circulating and waste water in the production line.

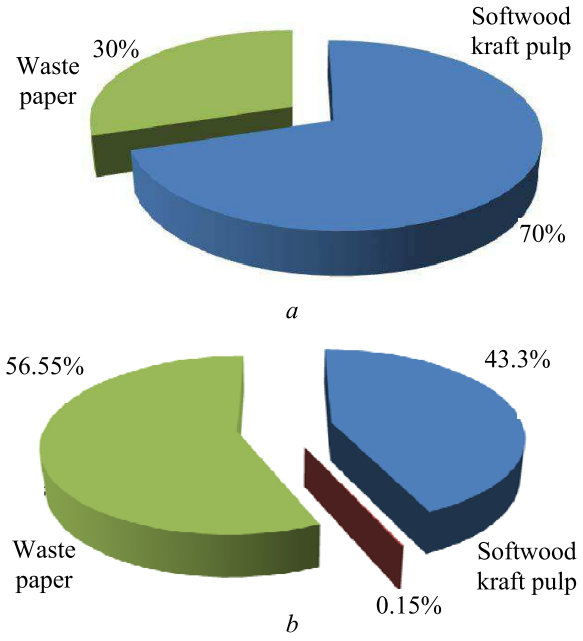

Fig. 1. Mass ratio of fiber components in the structure of sack paper: the existing production method (*a*) and the proposed method (*b*)

On the third stage of the research with the use of Statistica 6.0 software the 3D ternary plots (designs of Scheffé [13]) was created that clearly demonstrate the negative effect of waste paper on sack paper strength properties (Fig. 2, *a*–*c*).

At the same time the application of PAN in the structure of paper prevents from the reduction of sack paper strength.

The analysis of ternary plots demonstrates that the increase of waste paper mass ratio in the com-

position of sack paper leads to the reduction of breaking length from 7,300 to 5,000 m and breaking strength when dry from 73 to 54 N.

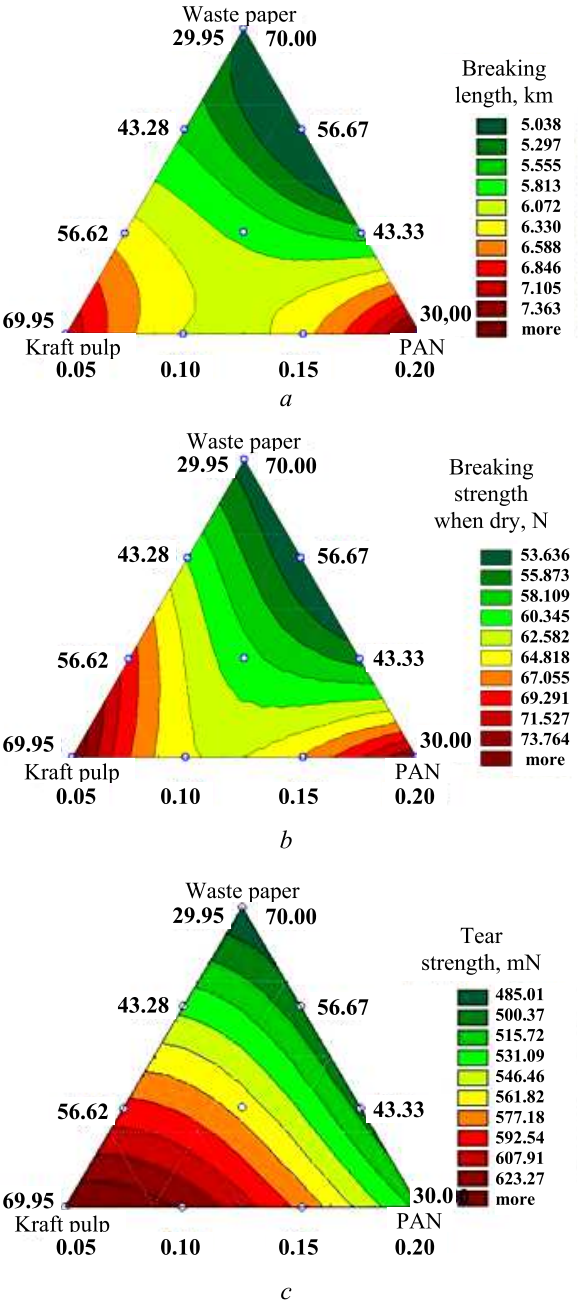

Fig. 2. 3D ternary plots of the influence of fiber composition of sack paper on the breaking length (*a*), breaking strength (*b*) and tear strength (*c*)

It was also determined that tear strength of sack paper was more effected by the kraft pulp content in the composition of sack paper compared with waste paper content. This may be explained by the action of PAN particles which were distributed on the surface of cellulose fibers during the refining process and provided together with hydrogen bonds additional interaction between fiber microfibrils through the cohesion.

With the help of optical microscope with camera adapter and Optika Vision Pro 4.1 software it was reviled that acrylonitrile particles of spherical shape (particles 0.5–2.0 μm in diameter) were held on the surface of pulp fiber and promoted their bonding by cohesion force (Fig. 3).

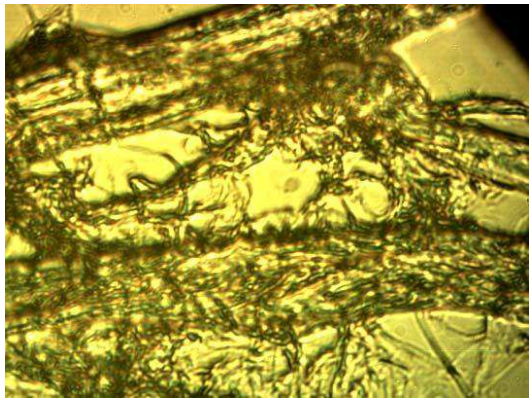

Fig. 3. Micrographs of pulp fibers and particles obtained from PAN in interfiber space

This is confirmed by the literature data saying that under temperature of about 120°C that corresponds the paper sheet drying process the softening of acrylonitrile takes place (glass transition temperature of acrylonitrile is 85–90°C) [14].

Conclusion. During the research it was found that:

– optimal mass ratio of sack paper fiber composition includes 43.30% of kraft pulp with increased strength containing 0.15% of particles from polyacrylonitrile subjected to sulfate pulping process and 56.55% of waste paper of МС-6Б grade according to GOST 10700–97 (1.01–1.05, 4.01–4.08, 5.04 according to EN 643);

– with the increase of PAN consumption rate from 0.05 to 0.20% of oven dry wood the strength of sack paper increases by 25–28% and whiteness reduces by 9.7%.

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