DOI 10.1007/s10692-019-10073-w
Fibre Chemistry, Vol. 51, No. 3, September, 2019 (Russian Original No. 3, May-June, 2019)

INFLUENCE OF FIBER LENGTH ON MECHANICAL PROPERTIES OF PAPER BASED ON HEAT RESISTANT AND FIRE-RESISTANT POLYMER FIBERS

I. O. Tsybuk and A. A. Lysenko

UDC 677.499

Information on industrial paper obtained from special purpose heat-resistant and fire-resistant fibers by the method of fiber swelling is presented. Results of a study of the effect of fiber cutting length on the mechanical properties the paper are presented. Corresponding dependencies are established.

Paper is a sheet material, usually consisting of plant fibers, suitably processed and joined into a thin sheet, in which the fibers are interconnected by surface adhesion forces.

The properties of paper depend on the fibrous composition, the nature of plant fibers, the nature of their processing, the content of filler, sizing, and the forming and finishing technology. But first of all, the properties of the final composition depend on the fibrous raw material.

In addition to plant fibers, in the production of special types of paper, synthetic and organic fibers as well as mineral ones are increasingly used: aramid, carbon, ceramic, metal, and others. The choice of raw materials for the production of paper with special properties is based on the chemical and physical properties of the polymer used for fiber production [1-3].

The areas of application of paper vary widely, from modern rocket science and aircraft, to nuclear, electrical, chemical and, finally, printing industries. The fields of application of synthetic fibers are expanding every year, which indicates the stability of the raw material base for obtaining paper based on such fibers. Paper from synthetic fibers, due to its unique properties, can not only compete with traditional types of paper made from plant fibers, but also partially replace them [4].

Among synthetic fibers, fibers with special properties play an important role, in particular heat-resistant fibers with exclusive indicators of strength, elastic modulus, and operability at temperatures up to 300 °C and above.

Particularly of interest is the technology of polyoxadiazole (POD) fibers, which are now available under the brand name “Arselon”. The values of thermal and thermo-oxidative stability for POD fibers were found to be quite close [5-7].

Arselon and products made from it can be used for a long time (up to three years) at high temperature, up to 250 °C, including during short-term (in the seconds) thermal shock of up to 400 °C. The temperature of the beginning of thermal destruction is about 500 °Ñ. The fiber does not melt. Arselon-based products are not burned when hit by hot particles with a temperature of 600-700 °C [7]. The industrial production of Arselon fiber has been established at the “Khimvolokno” Production Association in Svetlogorsk (Belarus). The structural formula of an elementary structural unit of POD is shown in Fig. 1 [7].

Another special purpose fiber should be noted – heterocyclic aramid fiber based on poly(amidobenzimidazole) (PABI), produced under the name CBM. It is known [7] that most products from aramid fibers are quite effective fireproof textile materials that retain fire protection regardless of the number of washings, dry cleanings and duration of use. In combination with a long service life of products, these properties, as well as good heat resistance, make it possible to consider these fibers as a promising precursor for the production of special purpose paper.

The main producers of aramid fibers and yarns in Russia are JSC Kamenskvolokno (Kamensk-Shakhtinsky) and research and production enterprise NPP Termoteks (Mytishchi). Having the most powerful production, JSC Kamenskvolokno produces over 20 tons per year of heterocyclic aramid fibers CBM, Arus, Artek, Ruslan, AuTx and

St. Petersburg State University of Industrial Technologies and Design, St. Petersburg, Russia. Translated from *Khimicheskie Volokna*, No. 3, pp. 43 – 46, May – June, 2019.

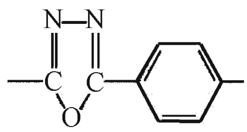

Fig. 1.

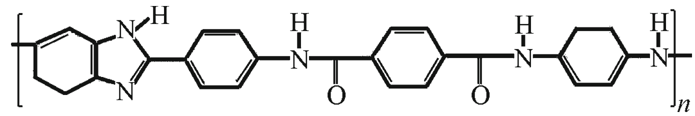

Fig. 2.

Fig. 1. Structural formula of an elementary unit of POD [8].

Fig. 2. Structural formula of an elementary unit of CBM aramid fiber.

products made from them, which are used to make personal protective equipment, composite materials, cable products, rubber products, and heat-resistant protective clothing.

CBM fiber has a unique set of properties that justifies a wide range of its applications. The crystalline nature of the polymer provides high thermal stability, and the presence of aromatic rings in the structure of the macromolecule determines its chemical stability [8–11]. The structural formula of an elementary unit of CBM aramid fiber is presented in Fig. 2.

In the global production of heat-resistant aramid paper, technologies using fiber-film materials (fibrids) of the same nature as aramid fibers prevail as a binder. By their nature, fibrids are a product of incomplete polymerization, obtained from solutions in the hydrodynamic field of the precipitator. In contrast to fibers, in addition to a highly developed surface, they have a lower degree of crystallinity and a lower melting point. This allows combining fibrids with dimensionally cut fibers to obtain durable heat-resistant paper from aqueous dispersions after press-finishing on a hot calender [12-14].

At the same time, paper with a 30-50% fibrid content has a number of disadvantages, the main of which are low tear resistance and difficulties in impregnating with epoxy diane binders to create honeycomb structures.

Previously, the ability of anisotropic polymers to swell [14] in aqueous solutions of lyophilic inorganic salts was revealed. Such salts belong to the class of aprotic acids that cause surface swelling of fibers and their bonding during the formation of paper canvas [2, 15].

From a practical point of view, this method of producing paper is notable in that the paper contains only fiber used to produce it, and the properties of the paper depend only on the properties of the precursor fiber, and not on the properties of the binders used. In addition, by reducing the number of technological stages, the complexity of the process of obtaining paper is reduced.

Since for the manufacture of paper, textile elongated highly oriented high-strength fibers are usually used, they bear the main strength load. However, it is known [16, 17] that with increasing binder content in paper, its strength indicators (tearing resistance, bursting strength, and tensile strength) increase, reaching a maximum at a binder content of 20-30%, and then decrease.

Important factors affecting the strength of the sheet are the cutting length and thickness of the fibers used. If the paper is obtained without the use of a binder, then these are the determining factors.

The presence of long fibers in the composition of paper provides significant advantages compared to traditional paper. Paper with a fiber length of more than 3 mm is called long-fiber paper. Some of its most notable advantages include significantly greater tearing resistance, folding endurance, higher tensile strength, greater porosity and permeability.

Long-fiber paper is obtained either by the wet or dry paper-making method usually using special forming devices (inclined-mesh or round-mesh paper machines) due to the fact that in an aqueous medium long fibers tend to aggregate.

Both wet and dry forming methods make it possible to obtain long-fiber paper weighing from 6-10 to 300 g/m^2. Depending on the composition and technology used, long-fiber paper can have the structure of low-density, well-permeable non-woven materials, in composites they form a strong reinforcing structure.

The process of obtaining paper based on selected fibers begins with the preparation of a dispersion of dimensionally cut fibers in an aqueous medium. The length of fiber cutting does not exceed 4-5 mm, which is an important condition for obtaining a uniform suspension of fiber in water and eventually a uniform fibrous cover. After the stages of casting and drying, the finished fibrous layer undergoes impregnation in an aqueous solution of a system of lyophilic salts for 5 min, it is dried and subjected to hot pressing at a temperature of 200-220 °C and a pressure of

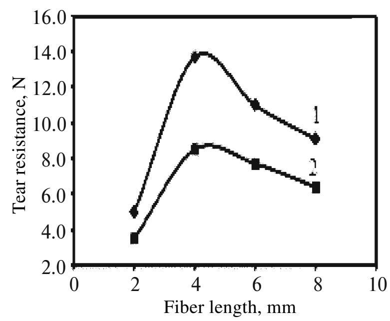

Fig. 3.

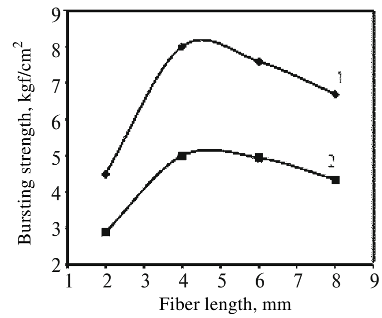

Fig. 4.

Fig. 3. Tear resistance of paper as a function of the fiber cutting length of CBM (*1*) and Arselon fibers (*2*).

Fig. 4. Burst resistance of paper as a function of the fiber cutting length of CBM (*1*) and Arselon fibers (*2*).

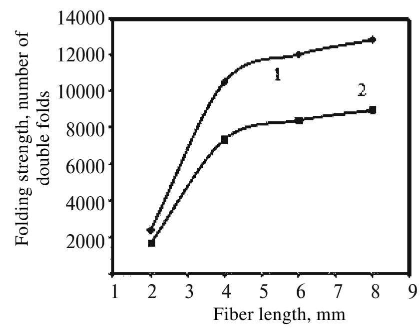

Fig. 5. Folding strength (the number of double folds) of the paper as a function of fiber cutting length of CBM (*1*) and Arselon fibers (*2*).

100-110 kgf/cm^2. In the process of hot pressing, the number of contacts of the swollen fibers increases, the swelling agent is removed and the fibers are firmly bonded at the points of contact. After pressing, paper is washed in water to remove salts that crystallize on the surface of the paper during hot pressing.

Since fiber cutting length affects the strength properties of paper, studies were conducted to determine the dependence of changes in the properties of paper based on heat-resistant and fire-resistant polymer fibers on their cutting length. The main characteristics affected by the fiber cutting length are tearing resistance, bursting strength, and folding endurance. Paper with a surface density of 65 g/m^2 was the subject of the study.

Fig. 3 shows the dependence of tear resistance of the paper on fiber cutting length. As can be seen, increasing the fiber cutting length in the range from 2 to 4 mm leads to an increase in the tensile strength of the paper. However, with a further increase in fiber cutting length, tensile strength begins to decrease. In general, for paper based on CBM and Arselon fibers, an increase in the fiber cutting length to 4 mm increases the tear resistance. Tear resistance of CBM fiber-based paper is higher compared to Arselon fiber-based paper.

Bursting strength can hardly be considered one of the main properties of paper. When considering current standards, it is provided for a very limited number of types of paper. This indicator is of fundamental importance for wrapping paper. However, its practical significance cannot be ignored due to the fact that this characteristic is also a qualitative indicator of the strength of the paper structure. Bursting strength is associated with indicators of the breaking load of paper and its elongation at break. Fig. 4 shows the dependence of the bursting strength on the fiber cutting length. Based on the obtained dependence, it can be concluded that the optimal fiber cutting length lies in the range of 4-5 mm. With a fiber length of more than 5 mm, bursting strength is reduced. The bursting strength of Arselon fiber-based paper is lower than that of CBM fiber-based paper.

One of the essential indicators of mechanical strength of paper is folding endurance. This indicator depends not only on the length of the fibers from which the paper is formed, but also on their strength, flexibility and the strength of the bond between them. Given this, it can be assumed that paper made from long and strong fibers will have the highest folding endurance. Fig. 5 shows the dependence of the folding endurance of paper made from Arselon and CBM fibers on the fiber cutting length. With increasing fiber cutting length, folding endurance increases. For both types of paper, the nature of the curve indicates a sharp increase in folding endurance with an increase in fiber cutting length from 2 to 4 mm.

The number of double folds that a test piece of paper made from CBM fiber can withstand increases from 2400 to 10500. After that, the number gradually increases. The maximum number of double folds that a sheet of paper can withstand is 12800 with a fiber length of 8 mm. However, with increasing fiber length, paper uniformity decreases, which adversely affects its other properties.

A similar pattern is observed for Arselon fiber-based paper. The number of double folds that the test sheet can withstand increases from 1680 to 7350. The maximum number of double folds of a sheet of paper is 8960 with a fiber length of 8 mm. But with an increase in the fiber cutting length, as in the case of CBM fiber-based paper, the uniformity of the paper decreases, adversely affecting its other properties.

REFERENCES

1. S. V. Burinsky, I. O. Tsybuk, and E. A. Antonova, *Vestnik SPGUTD, Ser. 1, Estestvennye i Tehnicheskie Nauki* [*Bulletin of St. Petersburg State University of Technology and Design. 1. A Series of Natural and Technical Sciences*], No. 3 , 39-43 (2016).
2. I. O. Tsybuk, S. V. Burinsky, and A. A. Lysenko, *Khim. Volokna*, No. 3, 72-74 (2016).
3. S. V. Burinsky, V. A. Lysenko, and P. Yu. Salnikova, *Dizain. Materialy. Tekhnologiya*, No. 5, 26-29 (2013).
4. B. B. Gutman, L. N. Yanchenko, and L. I. Gurevich, *Synthetic Fiber Paper* [in Russian], Lesnaya Promyshlennost', Leningrad (1971). 184 p.
5. K. E. Perepelkin, *Rossijskij Khimicheskij Zhurnal*, 46, No. 1, 31-48 (2002).
6. L. V. Avrorova, A. V. Volokhina, et al., *Khim. Volokna*, No. 4, 21-26 (1989).
7. G. I. Kudryavtsev, A. V. Tokarev, et al., *Khim. Volokna*, No. 6, 70-71 (1974).
8. E. S. Zelensky, et al., *Rossijskij Khimicheskij Zhurnal*, 45, No. 2, 56-74 (2001).
9. K. E. Perepelkin, S. A. Baranova, and E. Yu. Gurova, *Khim. Volokna*, No. 1, 34-38 (1995).
10. E. M. Egorova, A. A. Revina, et al., *Vestnik Moskovskogo Universiteta*, No. 5, p. 56-57 (2001).
11. G. A. Budnitsky, G. I. Kudryavtsev, and G. G. Frenkel, *Innovations in the field of heat-resistant polymers and fibers. A Review* [in Russian], Series: Chemical Fiber Industry, NIITEKhim, Moscow (1978) 88 p.
12. L. B. Sokolov, V. D. Gerasimov, et al., *Heat-Resistant Aromatic Polyamides* [in Russian], Khimiya, Moscow (1975) 256 p.
13. S. V. Burinsky, T. V. Zosina, and L. A. Wolf, "Auto-adhesion-related materials made of heat-resistant fibers," In: *High-Strength Reinforced Polymer Materials for Structural Purposes* [in Russian], LDNTP, Leningrad (1978) p. 48-50.
14. S. V. Burinsky, G. M. Mubarakshin, et al., Author's Cert. 606909 USSR, MKI^3 D 04 H 1/50. No. 2432056. Decl. 01/20/76. Publ. 05/15/78. Bull. 18.
15. E. Kalinovsky and T. V. Urbanchik, *Chemical Fibers* [in Russian], Legkaya Industriya, Moscow (1966) 320 p.
16. D. M. Flyate, *Paper Technology* [in Russian], univ. textbook, Lesnaya Promyshlennost', Moscow (1988) 440 p.
17. J. Clark, *Cellulose Technology (the Science of Pulp and Paper, Pulp Preparation, Its Processing for Paper, Test Methods)* [transl. from English to Russian by A. V. Obolenskaya], Ed. G. A. Pazukhina, Lesnaya Promyshlennost', Moscow (1983) 456 p.