Effect of pulp consistency during refining on physical and mechanical characteristics of handsheets

A V Ushakov, Y D Alashkevich, VA Kozhukhov and R A Marchenko
Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Ave., Krasnoyarsk, 660037, Russian Federation

E-mail: al.ushakov2194@mail.ru

Abstract. At the moment, the pulp and paper industry produces a wide variety of types of paper and board, which can serve as an alternative to plastic packaging products. The main requirement for paper packaging is high strength properties, which include: breaking length, resistance to breaking, bursting and tearing. The required strength properties can be ensured at the stage of refining the semi-finished product from which the paper product will be made by changing the consistency of the pulp. Since the influence of the consistency of the pulp during refining on the strength characteristics of the finished product has not been fully studied, it was of interest to find out how the strength properties of castings change when refining the pulp with a change in concentration.

1. Introduction

The global demand for paper packaging (container and boxboards) is currently quite large. It accounts for about 50% of the consumption of pulp and paper products in the world and about 70% - in the Russian Federation [1]. Paper packaging must have a sufficiently high mechanical strength under high dynamic loads. One of the main ways to increase the mechanical strength of packaging products is to create proper refining conditions for the original semi-finished product [1, 2, 3].

Evaluating the technological factors that determine the process of refining fibrous semi-finished products, an important factor is the consistency of the fibrous mass. Analysis of literature sources [4, 5] shows that in the process of refining various semi-finished products react differently to changes in concentration, therefore, the indicators of physical and mechanical characteristics of paper castings also have different values. In general, considering the refining of the pulp at high concentration, the researchers come to the conclusion that this method of grinding makes it possible to increase the strength of the finished product, especially in the production of packaging paper and cardboard, for which the indicators of physical and mechanical characteristics are of the greatest importance [4, 5, 6]. In addition to the growth of strength characteristics, researchers note a number of undoubted advantages, which include the following:

1. Maintaining the original fibre length. This is because, at a high consistency in the refining process, not individual fibres, but a bundle of fibres is refined in the knife gap, respectively, when the knives strike, the internal fibres in the bundle are destroyed along weak bonds along the fibres, and the process of fibrillation of the fibres appears. While maintaining the original fibre length and increasing fibrillation, the physical and mechanical properties of the paper sheet increase. The use of refining at a
high consistency is especially advisable when refining cellulose from hardwood and annual plants containing a large number of short fibres [5];

2. Increased productivity of refining equipment. With an increase in the consistency of the pulp in the refining zone, the proportion of the hydraulic component in the fibre suspension decreases, due to the increase in the mass of the percentage of air-dry fibre;

3. Decrease in specific energy consumption. With an increase in productivity, the specific energy consumption will decrease. It is worth noting that the specific energy consumption is reduced not only due to an increase in productivity, but also due to a decrease in the percentage of the amount of water, the energy loss during idling will be less.

Along with the advantages, refining a mass of high consistency has a number of disadvantages, which include:

1. Refining at a high consistency leads to additional costs compared to refining at a low concentration, since it causes additional costs for the purchase of equipment for thickening, dosing and transporting the mass to the refining bodies. The feeding of the pulp into the refining zone must be uniform, and the conveying device must have a performance adjustment;

2. High friction between fibres. An increase in the circumferential speed of refining bodies in some cases entails excessive friction between the fibres and, as a consequence, an increase in the temperature of the mass in the refining zone, as a result of which the phenomenon of flocculation of fibres occurs, thereby reducing the strength characteristics of the paper product. Therefore, it is necessary to avoid excessive overheating of the mass and maintain the peripheral speed of the working bodies of the refining installation within optimal limits;

3. Plugging of pulp between refining bodies. The centrifugal force of the refining bodies is the driving force of the fibrous mass aimed at overcoming the resistance forces of the fibrous material passing through the refining zone. In cases where centrifugal force prevails over resistance forces, refining takes place under normal conditions. Therefore, for the smooth operation of the refining equipment, it is necessary to provide such a supply of fibrous material to the refining zone, which would correspond to the productivity of this equipment [4].

To study the issues related to the influence of the consistency of the pulp during the refining process on the physical and mechanical characteristics of paper castings, a refining installation in the form of a disk mill has been designed and developed (figure 1). The disc mill consists of the following elements: refining zone 1, consisting of two discs, one of which is movable rotor 2, the second stationary stator 3. Additive device 4, which provides adjustment of the gap between the rotor and stator knives. Screw feeder 5, which ensures the movement of the mass into the refining zone. The rotation of the rotor disk is carried out from the electric motor 6. The mass is moved to the refining zone by a screw feeder, which is driven by an electric motor 7 through a worm gear 8. This disc mill has the ability to adjust the main technological factors of the refining process, including: the consistency of the pulp, the gap between the rotor disc and the stator, the circumferential speed of the rotor, as well as the speed of feeding the pulp into the refining zone. Table 1 shows the technical characteristics of the disc mill.

Figure 1. Scheme of a disk mill (1 - refining zone; 2 - stator; 3 - rotor; 4 - filler; 5 - screw feeder; 6 - rotor motor; 7 - screw feeder drive motor; 8 - worm gear reducer of the screw feeder drive, 9 - container for pulp).
Table 1. Specifications of the disc mill.

| Specifications                        | Value       |
|---------------------------------------|-------------|
| Disc diameter, mm                     | 200         |
| The gap between the refining surfaces of the discs, mm | 0.1 – 2.5   |
| Power of the electric motor of rotation of the rotor, kW, | 4           |
| The number of revolutions of the rotor disk, rpm, | 500 - 2500  |
| Electric motor power of the screw feeder drive, kW, | 0.55        |
| Gear ratio of worm gear                | 1:30        |
| The number of revolutions of the screw feeder shaft, rpm | 45 - 92     |
| Refining mass concentration, %        | 1-20        |

2. Technique of the experiment

The research was carried out in the laboratory “Machines and devices of industrial technologies” of the Siberian State University of Science and Technology named after academician M.F. Reshetnev.

Sulphate bleached cellulose from hardwood with an initial refining degree of 16ShR semi-finished product of JSC "Ilim Group" branch of the city of Bratsk was subjected to refining. Before the experiment, the fibrous semi-finished product was subjected to dissolution in a disintegrator. The experiment was carried out at a pulp consistency of 10%, 15%, 20%, a rotor speed of 2000 rpm. The gap between the stator and the rotor was 1.5 mm, the pulp was fed to the refining zone by a screw feeder at a screw speed of 90 rpm. The technical characteristics of a set with a curved shape of knives used in the experiment are presented in table 2.

Table 2. Technical characteristics of the steel.

| Steel diameter, mm | Second cutting length, m / s | Width, mm | Knife height h, mm | Ratio, b / h |
|--------------------|------------------------------|-----------|-------------------|--------------|
| 200                | 33177                        | 6         | 7                 | 7            |
|                    |                              |           |                   | 0.85         |

The basis for assessing the effect of the consistency of the pulp in the refining process on the strength characteristics of the finished product were the indicators of the physical and mechanical characteristics of castings made on a sheet-molding machine. Comparison of the properties of indicators of physical and mechanical characteristics of castings was carried out at several degrees of refining mass 15, 30, 45, 60 ° ShR.

3. Results and discussion

The pulp consistency during refining has a significant effect on the strength properties of paper castings. Figure 2 shows graphs of the dependence of the breaking length on the degree of freeness at various concentrations of the pulp, all other things being equal. All graphs are characterized by an increase in breaking length with an increase in the degree of refining up to 60 ° ShR. However, with an increase in the consistency of pulp from 10% to 20% at equal degrees of refining (60 ° ShR), a decrease in this indicator is observed. For a mass milled at a consistency of 10%, this indicator is within 7000 m, which is 30% higher than for a mass milled at a consistency of 20%.
The graphs of the dependence of the punching shear resistance on the degree of refining are presented in figure 3, as can be seen from the graphs, there is an increase in this indicator with an increase in the degree of refining to 60 ° ShR. As in the case of the breaking length, the best result of the bursting resistance indicator was obtained at a consistency of 10%, a further increase in consistency leads to a decrease in this indicator. Analysing the indicators of resistance to fracture and tearing (figure 4, 5), there is a tendency for these indicators to decrease with an increase in the consistency of pulp. Moreover, for the analysis of resistance to fracture at a consistency of 10%, this indicator is 90% higher at equal degrees of refining (60 ° ShR).
4. Conclusions

Refining of high-consistency pulp on a set with a curved shape of knives at a consistency of 10% revealed the best result of physical and mechanical characteristics than at a consistency of 15% and 20%, which contradicts the results of studies carried out earlier [4, 5, 7], which show an increase in physical mechanical characteristics of paper castings with an increase in the consistency of pulp in the refining process. For a more detailed study and understanding of the nature of the decrease in the strength properties of paper castings with an increase in the consistency of pulp in the refining process, it is necessary to understand how the structure of the paper-forming properties of the pulp affects the structure of the disc sets of the refining equipment, which has a significant effect on both the properties of the fibre during the refining process, therefore, on the strength of castings, which is especially important in the production of packaging products.

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