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Ultrasonic treatment to improve the quality of recycled pulp fiber

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Abstract The effect of ultrasound on the quality of recycled fibers was investigated. Ultrasound was applied to recycled pulp fiber suspension before ink removal by conventional flotation. The ultrasonic treatment induced an increase in the sedimentation volume of the fiber, which implies that the flexibility and bulkiness of the fiber increase. The water retention value of the ultrasonically treated fiber recovered from the loss caused by the recycling. These facts are due to a beating effect of the treatment. The paper sheets prepared from the ultrasonically treated fiber suspension showed higher sheet density, tensile strength, and brightness than that from an untreated fiber suspension. The process, which consists of ultrasonic treatment for 1 min following flotation deinking, requires about 1.4 times as much energy as the conventional flotation deinking process, but it induced 20% improvement in brightness. The results indicate that the ultrasonic treatment is effective in improving recycled fiber quality.

Key words Ultrasonic frequencies · Deinking · Waste papers · Recycling · Reclaimed fibers

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Introduction

Waste paper is a major fiber raw material source for the pulp and paper industry. In Japan about 55% of waste paper is now utilized as fiber sources for papermaking fibers. It had been hoped that 56% of its consumption would be recovered by the twenty-first century. As the recovery rate increases, the quality of the recycled paper decreases. A novel process for contaminant removal is needed to upgrade the recycled paper to the extent that it can be used for many grades of paper.[1] Numerous researchers have made efforts to remove contaminants such as ink particles,[2–8] stickies,[9] and other chemicals.[10,11]

Removal of ink particles has been chosen as the research topic in many cases as it is directly concerned with the quality of the recycled paper. Nowadays, most newspapers are printed by offset printing, and removal of the offset or lithographic inks from pulp fibers is more difficult than that of other inks (e.g., letterpress inks) because the resins in the former inks tend to polymerize oxidatively as time passes. The use of xerographic or laser-print inks is increasing rapidly, especially in offices. These inks make large, flat particles on printed paper, so they are much more difficult to deink. The use of sound waves for deinking has been studied for the last two decades.[2,3] However, these studies have been limited and did not include study of xerographic or laser-printed office paper. Recently, some studies have dealt with such papers using ultrasound to deink.[5,6] They have reported that the sizes of the laser-printed ink particles were decreased by the ultrasonic treatment, but there are no statements concerning the properties of the treated fibers and of the paper sheet prepared from the fibers. This subject requires further investigation.

In our research ultrasonic treatment has been introduced to recycled fiber suspensions before ink removal by conventional flotation. The suspensions were prepared from offset-printed newspaper and laser-printed office paper. We investigated the effect of ultrasound on fiber properties such as sedimentation volume and water retention. The physical properties of the sheet prepared from the treated fiber were also investigated.

Materials and methods

Materials

Samples were offset-printed newspaper and laser-printed office paper. The former was published a month before experimental use. The latter was made in our laboratory with a Canon laser printer by printing 30% black dots on commercially available acid-free paper for xerography. Additionally, a commercially available softwood bleached kraft pulp (softwood BKP) was used to measure the sedimentation volume and water retention value of fiber.

Methods

Fiber suspensions were prepared from the waste papers according to Japan TAPPI test method no. 39. That is, 70 g of sample on an oven-dried basis was disintegrated in 1.5 l of water at 50°C with NaOH (0.7 g), Na_2SiO_3 (1.4 g), 30% H_2O_2 (0.7 g), and deinking agent (0.07 g). The deinking agent was DI-767, a fatty alcohol kindly supplied by Kao Corporation. Additionally, neutral deinking was carried out under the same conditions except for the absence of NaOH and Na_2SiO_3.

Ultrasonic treatment was performed with an ultrasonic disrupter (UR-200P; Tomy Seiko Co., Japan). The power and the frequency were 200 W and 20 kHz, respectively. The ultrasonic waves were transferred to a 1% fiber suspension by a probe inserted into a 100-ml container of fiber. Before flotation deinking the suspensions were diluted to 0.33% and were kept at 40°C for 1 h. Flotation deinking was carried out at 30°C for 10 min. The flotation cell was a Kyoei Kiko FW-IK with a 3-l vessel. The foaming agent was Kao DI-380, which was kindly supplied from Kao Corporation. After flotation the samples were washed with continuous stirring for 15 min using a classifier equipped with a 100-mesh screen.

Sedimentation measurement was carried out in a fiber concentration range of 0.05%–0.33%. Fiber suspension (14 ml) was pored into a test tube; and the sedimentation volume, which is the volume of the fiber layer, was measured with the corresponding time of sedimentation.[12] The percent sedimentation volume change was described by the sedimentation volume/total volume ratio.

Water retention value (WRV) of fibers was tested under the condition of 3000 g for 15 min.[13] For WRV measurement the fibers were recycled up to 5 times. The recycling procedure consisted of soaking the fiber in tap water for 1 day and then disintegrating, filtering, and drying the fiber for 1 day at 80°C.[14]

Handsheets with a basis weight of about 60 g/m^2 were made according to TAPPI test method T205. The dried handsheets were allowed to stand at 20°C and 55% relative humidity for more than 1 day. The tensile strength of the handsheets was measured according to TAPPI test methods. The brightness of the handsheets was measured with a photovolt-type reflectometer with a blue filter under a condition of 0°–45°. The sheets and fibers were observed with an optical microscope, a scanning electron microscope (SEM: JSM-T330A, JEOL, Japan), and a video-microscope (OVM1000N; Olympus Optical, Japan).

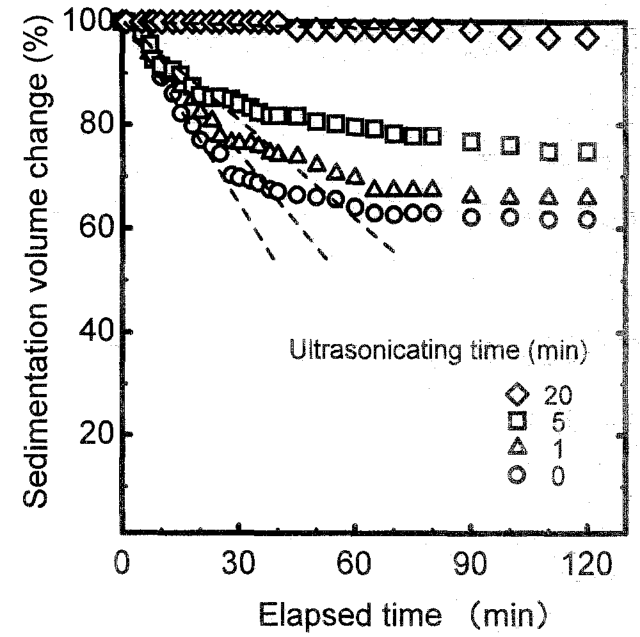

Fig. 1. Sedimentation volume change against elapsed time for 0.33% suspension of fiber from old newspaper at various ultrasonicating times. The slope of each broken line shows the initial sedimentation rate

Results and discussion

Sedimentation volume

Sedimentation volume is an index of dispersion stability. Figure 1 shows the plots of the sedimentation volume change versus the elapsed time for various ultrasonicating times. The sample is a 0.33% suspension prepared from old newspaper. As time passed the sedimentation volume decreased, and finally the fiber column was compressed almost to its equilibrium volume. Each sample reached its equilibrium volume within 1 day. The initial portion of this plot can be approximated by a straight line (shown as broken lines), and the initial sedimentation rate can be estimated as a slope of the straight line. The sedimentation volume change and the initial sedimentation rate decrease as the ultrasonicating time increases. Similar results were obtained for samples with other fiber concentrations. For pulp fiber suspension, the sedimentation rate decreases with decreasing coarseness and with increasing specific surface area of fiber.[12] Therefore, the results imply that the fibers are made flexible and bulky by the ultrasonic treatment.

Figure 2 shows the equilibrium volume normalized by the weight of fiber contained in the suspension plotted versus the fiber concentrations. The values obtained by extrapolating each curve to the zero concentration demonstrate the specific volume of a fiber (milliliters per gram) in the suspension. The specific volume for the untreated fiber was about 280 ml/g, and the volume for the fiber treated for 20 min was almost doubled. Figure 3 shows scanning electron microscopic (SEM) images of the fibers prepared from newspaper, both untreated and treated for 10 min with ultrasound. There are more external fibrils on the ultrasonicated fiber surface than on the untreated fiber surface, which indicates that the increase in the specific volume of the ultrasonicated fiber is caused by external fibrillation due to the ultrasonic treatment. Figure 3 shows that few fines were produced by the ultrasonic treatment, which agrees with an earlier study on ultrasonically beating pulp fiber.[15] For example, the fines contents (200 mesh passed) before and after the ultrasonic treatment were 7.6% and 9.1%, respectively.

The specific area of fibers increases after mechanical beating. Figure 4 shows the equilibrium volumes of ultrasonically treated softwood BKP as well as the lightly [Canadian Standard Freeness (CSF) 530 ml] and heavily (CSF 160 ml) beaten softwood BKP, using a PFI mill. The equilibrium volume of the ultrasonically treated fiber increases almost linearly with increasing ultrasonicating time. On the other hand, there is only a slight increase in the equilibrium volume of the lightly beaten fiber, though the volume of the heavily beaten fiber increases as much as that of the 20-min ultrasonicated fiber. It is known that light

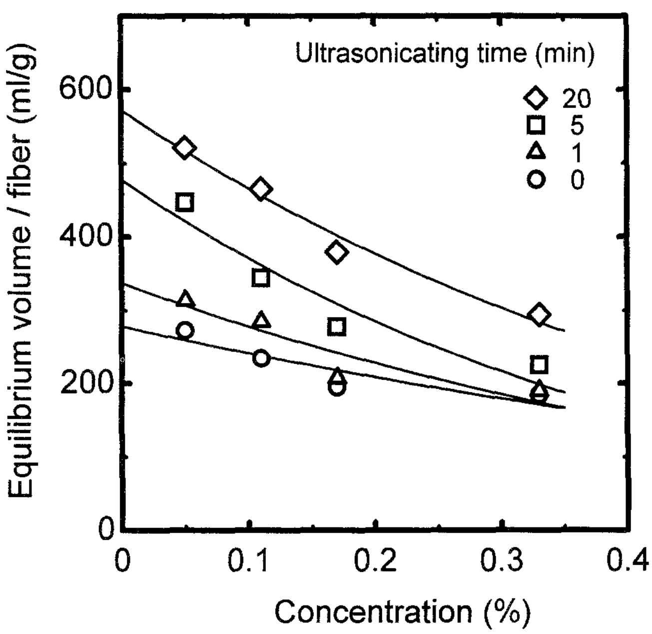

Fig. 2. Normalized equilibrium volume against fiber concentration at various ultrasonicating times

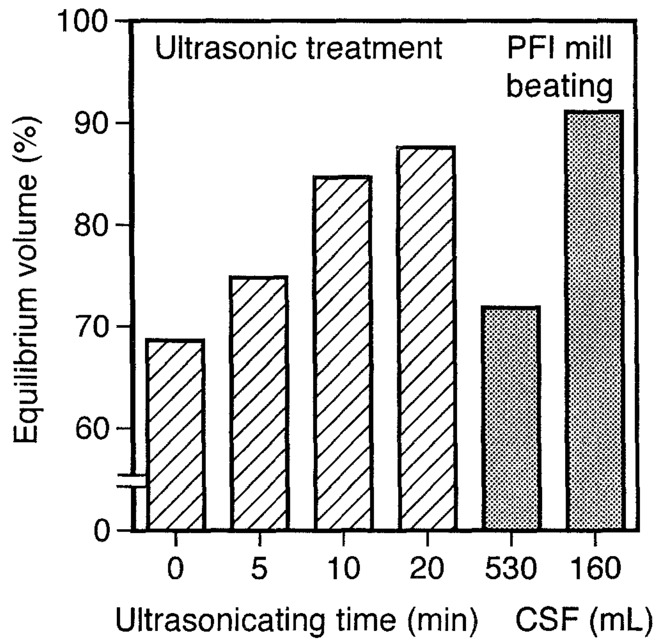

Fig. 4. Equilibrium volume for ultrasonically treated or beaten softwood bleached kraft pulp. *CSF*, Canadian Standard Freeness

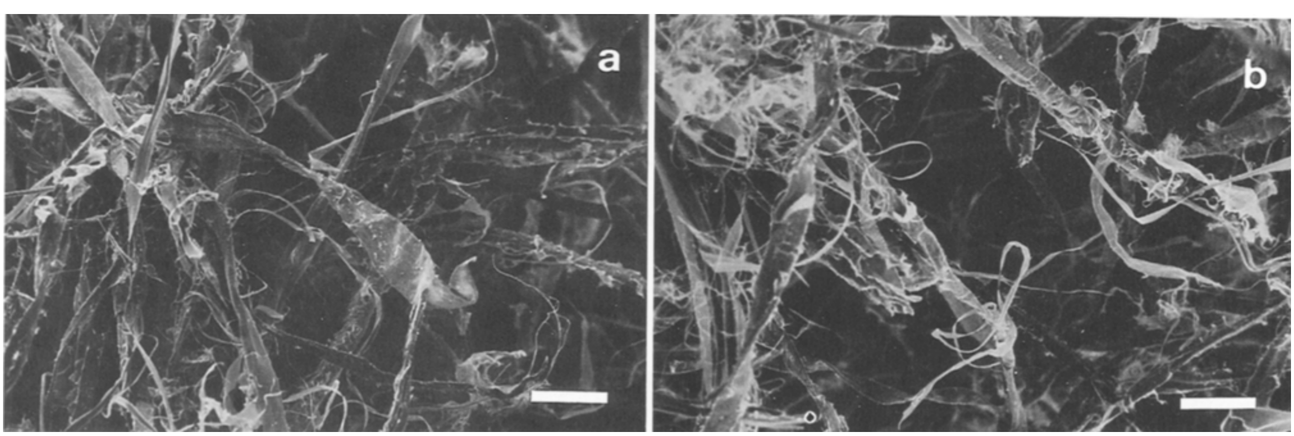

Fig. 3. Scanning electron microscopy (SEM) micrographs of fibers prepared from old newspaper: untreated (**a**) and treated for 10 min (**b**) with ultrasound. Bars 100 μm

beating induces internal fibrillation but not external fibrillation so much, whereas heavily beaten fibers are internally and externally fibrillated.[16] The internal fibrillation should little affect the sedimentation volume. That is, the above results indicate that the increased equilibrium volume of ultrasonicated fiber is mainly induced by external fibrillation due to the beating effect of the ultrasonic treatment.[15,17]

Fiber swelling

The water retention value is used as a measure of pulp fiber swelling. The WRV of pulp fibers decreases with recycling,[18] caused by a loss in the swelling power of the fiber, which has been called hornification; it induces a loss in the plasticity and strength of the fiber.[19] Recovery of the WRV, or swelling power, of recycled pulp fiber is required to improve the quality of recycled paper. Figure 5 illustrates the relation

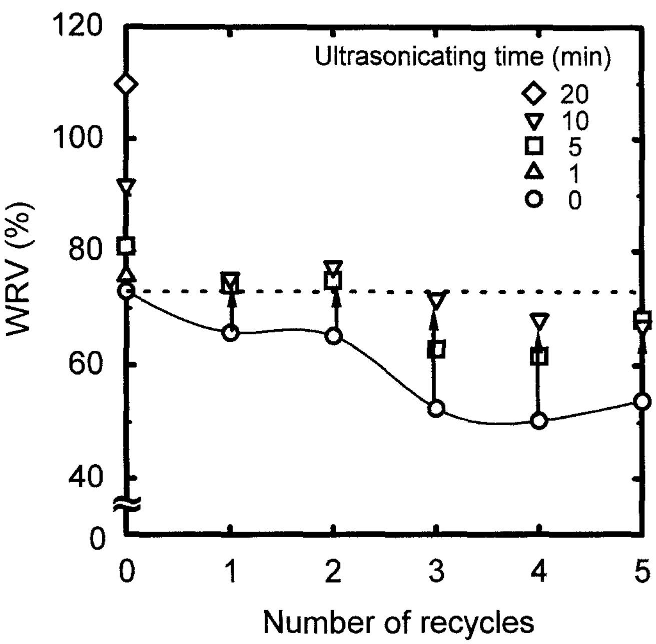

Fig. 5. Water retention value (*WRV*) versus the recycle number. *Arrows* indicate the recovery of WRV by ultrasonic treatment

between the WRV of softwood BKP and the number of times the material is recycled; it shows that the WRV of fibers decreases with increasing recycling times. The ultrasonic treatment made the WRV increase to the original level, as the arrows in Fig. 5 indicate. Although the WRV can also increase after the production of fines, it is not the case in this experiment, as described above. It is thought that recovery of WRV is due to the beating effect of the ultrasonic treatment.

Properties of sheet prepared from ultrasonically treated fiber

Figure 6 shows micrographs of the sheets prepared from the laser-printed office paper: untreated (UT), deinked by a conventional flotation method (FL), and deinked by the ultrasonic treatment and following flotation (UF). The figure indicates that the laser-print ink particles are hardly removed by flotation alone (FL), whereas only a few particles remain on the surface of the sheets treated with ultrasound and flotation (UF).

The properties of these sheets are shown in Table 1. For the sheets derived from both old newspaper and laser-printed office paper, the UF sheets have higher densities and tensile indices than the FL sheets. Hence, the ultrasonic treatment improves the strength of recycled paper, which can be attributed to both ink removal and the beating effect of the ultrasonic treatment.

Regardless of the origin of the fibers, the UF sheets showed higher brightness than the UT and FL sheets. Table 1 also shows the brightness of neutrally deinked paper prepared from old newspaper. Neutral deinking is helpful to keep hemicellulose in fiber, which improves fiber recyclability.[20] Table 1 shows that the ultrasound also has an advantage in deinking paper neutrally.

Figure 7 shows the energy consumption of the treatments. The ultrasonic treatment for 1 min and following flotation (UF) requires 1.4 times as much energy as flotation alone (FL). However, it induced 20% improvement of brightness, indicating that the ultrasonic treatment has an advantage when a little extra energy consumption is added. Furthermore, with the flotation process the froth effluence

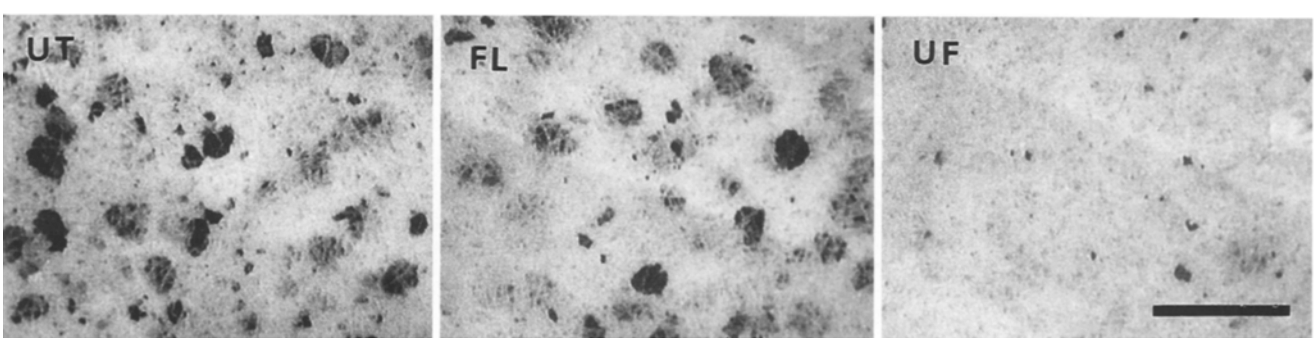

Fig. 6. Surface micrographs of the sheets prepared from laser-printed office paper: untreated (*UT*), deinked by conventional flotation (*FL*), and deinked by ultrasonic treatment and following flotation (*UF*). Bar 1 mm

Table 1. Physical properties of handsheets prepared from deinked fibers

Sample	Sheet density (kg/m^3)	Tensile index (kNm/kg)	Brightness (%)	
			Alkaline deinking	Neutral deinking
Old newspaper				
UT[a]	436	41.5	53.2	34.4
FL[b]	343	26.1	61.6	44.3
UF[c]	373	31.4	66.7	47.4
Laser-printed office paper				
UT[a]	520	34.6	53.0	
FL[b]	481	23.8	53.3	
UF[c]	494	33.8	78.0	

[a] Untreated
[b] Deinked by conventional flotation
[c] Deinked by ultrasonic treatment and following flotation

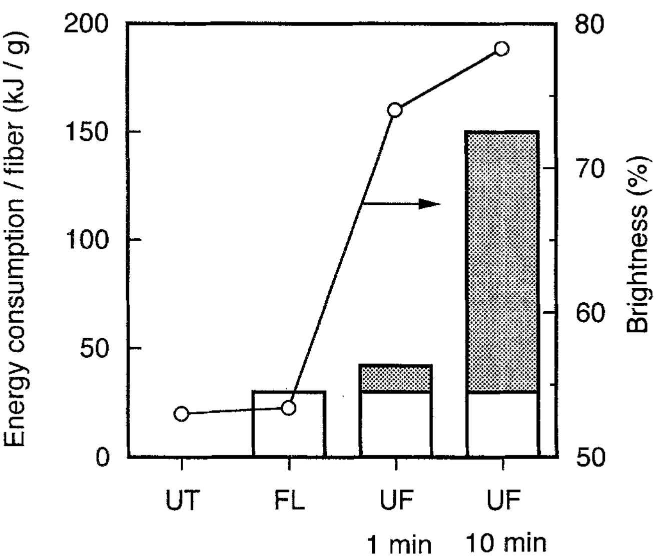

Fig. 7. Relation between energy consumption of ultrasonic treatment and brightness of obtained sheet

of the ultrasonic-treated suspension was about 25% lower than that of the untreated one, implying that the ultrasonic treatment can decrease the water discharge, a concern with fiber loss[21] during the flotation process.

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