Preliminary

Development of Environmentally-Friendly and High-Strength Kraft Pulp Fiber Based Materials*[1]

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Introduction

Kraft pulp (KP) is a raw material used widely for making paper products. Page[1)] *et al.* reported that the tensile strength of KP fiber reaches 1.7 GPa at a density of 1.4 g/cm^3. Considering that the tensile strength of carbon fiber is around 3 GPa at a density of 1.8 g/cm^3, KP fiber can be called as a high-strength fiber as well.

In this study, we attempted to produce high-strength, environmentally-friendly products based on KP fiber. KP was mechanically treated and was reconstituted without using any additives other than starch to ensure the bio-degradability and recyclability of paper.

The results showed that the mechanical properties of KP molded products increased due to mechanical fibrillation. In addition, adding a small amount of starch as a binder was effective not only in improving mechanical property but also in reducing molding pressure.

Materials and Methods

NBKP (White Spruce : 40%, Pine : 50%, Douglas fir : 10%) with a whiteness (ISO) of 89% was used. The KP was treated mechanically using a PFI mill, an ordinary beater or a high-pressure homogenizer that can fibrillate KP fiber into the microfibrill order[2)]. The degree of treatment was controlled by rotation number for the PFI mill and by number of passes for the high-pressure homogenizer.

As microfibrillated plant fiber has extremely high water retention ability due to its huge surface area the treated pulp was subjected to a centrifuge treatment to condense the slurry into a 10% solid content. When using starch, it was added after this process. Then, centrifuge treated KP was put in a stainless die with a porous metal plate (30 to 50 micron diameter pores) at the bottom, and squeezed gradually to 5 MPa at room temperature to make a sample (100 mm×100 mm×4 mm) with a moisture content of around 100%. After that, the mat was dried at 105°C to reduce moisture content 2% and hot-pressed at 150°C and 100 MPa for 30 minutes. On the other hand, the mat with starch was dried until the moisture content was 20% and hot-pressed at 120°C and 20 MPa or 100 MPa for 60 minutes.

Samples with a size of 40 mm×8 mm×1.5 mm were prepared from the hot-pressed mat and were subjected to a three point bending test at a cross-head speed of 5 mm/min and a test span of 30 mm.

To evaluate the degree of fibrillation, the moisture content of fibers from 2% slurry was measured after centrifuge treatment at 1,000 G for 15 min as water retention value (WRV).

Results and Discussion

The effects of mechanical treatment on the modulus of elasticity (MOE) and modulus of rupture (MOR) are shown in Fig. 1. In the case of PFI mill treated fiber, MOE as well as MOR increased with the increase in rotation number. At a rotation number of 80,000, MOR reached 120 MPa, three times higher than untreated KP, and MOE, which is 3 GPa for untreated KP, reached 7 GPa.

The high-pressure homogenizer treatment resulted in a drastic change to the bending properties. MOR reached 180 MPa at two passes, and reached 240 MPa at 18 or 30 passes, which is six times higher than untreated KP. Density, however, reached 1.45 g/cm^3 at two passes and did not increase after that. The density of 1.45 g/cm^3 is almost the same as that of cellulose, which means that most of the cavity in the material was removed. MOE increased by homogenizer treatment as well, and reached

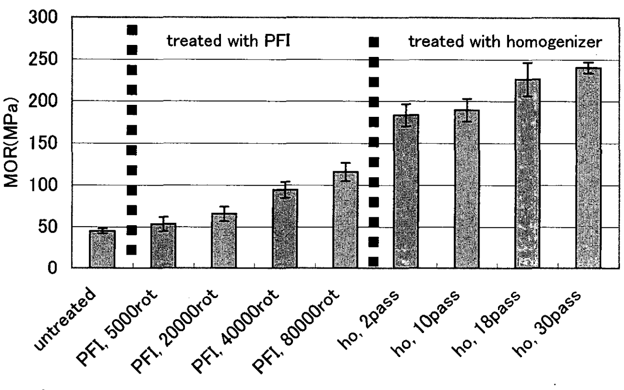

Fig. 1. Effect of the mechanical treatment on MOR. Pressing pressure : 100 MPa, Pressing temperature : 150°C. Pressing time : 30 min, mat moisture content : 2%, bars : standard deviation, PFI : PFI mill, ho : homogenizer.

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16 GPa at 30 passes. All the samples treated with homogenizer were transparent at the thickness of 1.5 mm, and looked like plastics. It is worth noting that extremely high bending strength compared to ordinary wood based materials was obtained without using any binders.

Table 1. Effect of mechanical treatment on water retention value (WRV) of kraft pulp.

Mechanical treatment	WRV (%)
untreated	116
PFI, 5000 rot	133
PFI, 20000 rot	162
PFI, 40000 rot	194
PFI, 80000 rot	218
ho, 2 pass	389
ho, 10 pass	430
ho, 18 pass	485
ho, 30 pass	491

PFI: PFI mill, ho: homogenizer.

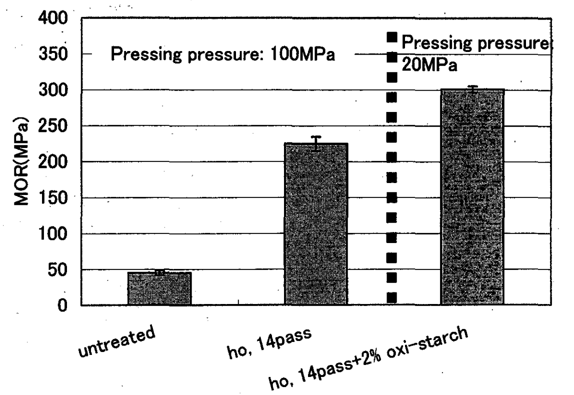

Fig. 2. The effects of adding starch on MOR. ho: homogenizer, oxi-starch: oxidized starch, bars: standard deviation.

Observation using an optical microscope showed that internal and external fibrillation occurred due to these mechanical treatments. To quantitatively evaluate the difference in the degree of fibrillation between the two treatments, WRV was compared. The results are shown in Table 1. The difference in WRV between the two treatments was clear, and a positive correlation was observed between WRV and MOR regardless of the treatment. We found that due to the fibrillation, the contact area between the fibers increased, which resulted in a great increase in the interactive forces between the fibers, without the uses of adhesives.

The effect of adding starch on MOR is shown in Fig. 2. By adding only 2% of oxidized starch, MOR increased by about 70 MPa, and consequently surpassed 300 MPa, although density and MOE did not change. It is worth to noting that a high MOR was obtained despite the reduction of pressing pressure from 100 MPa to 20 MPa. It shows that starch acted not only as a binder but also as a plasticizer to pack the fibers well and thus obtain higher interactive forces.

The MOR of microfibrillated kraft pulp materials is 5 to 10 times higher than that of ordinary wood-based panels, such as MDF and hardboard, and is comparable to that of aluminum alloy and soft steel, although the density is one-half and one-fifth of them, respectively. Because plant is the most abundant biomass on earth and its frame is microfibril, it is clear that microfibrillated kraft pulp based material is a promising material combining strength and low environmental impact.

References

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