Preparation and Mechanical Properties of Recycled Thermoplastic Composites with Rice Hull Particles

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In order to extend the utilization of rice hull (RH) and the recycled plastic resins made from fishing nets, which have been drifted ashore on the coats, mechanical behavior for the composites of the resin and RH was analyzed. Fourier transformed infrared spectrometry (FTIR) and differential scanning calorimetry (DSC) measurements revealed that the fishing nets used in this study were composed of polypropylene (PP) and polyethylene (PE) materials. Results of the tensile and bending tests means that the composites of the recycled resin became more brittle by adding the RH. The tensile and bending elastic modulus of the composites increased with RH content, while the breaking stress and the degree of elongation in both tests decreased. It was found that decreasing rate of the breaking stress was reduced by the RH with the size less than 177 μm.

Key words: fishing nets, polymer recycling, composite, rice hull, mechanical behavior

1. INTRODUCTION
Investigations of technical potentiality for using rice hull (RH) particles as high-performance materials have been received much attention from the view points of utilization of agricultural wastes. The amount of it is estimated to be 2.6 million tons per year in Japan[1]. The rice hull contains about 20wt% of inorganic compound and 80% of organic compound[2]. One of the utilization of RH is for sliding materials such as linear motion bearing by carbonizing the RH at 1173K in a nitrogen gas atmosphere[3-4]. Another attempt is introducing the RH as filler into the polymers. The RH fillers/polymer composites are expected to be high tensile and compression elastic modulus, undeformable, and heat resistant due to characters of RH components[5]. On the other hand, large amount of waste plastics product, i.e., fishing nets, ropes, bottles, container, and so on, which have been drifted ashore on the coats of Yamagata Prefecture in Japan, have been recognized as recent environmental problems. Among of the wastes, the fishing nets and ropes are too hard to ignore. The authors have analyzed the waste nets and ropes and revealed that these are composed of thermoplastic synthetic polymers. Thermoplastic resins can be recycled by melting and processing at high temperature under high pressure. If the composites of RH and the resins obtained from fishing nets and ropes would be high-performance materials, they might contribute solving the environmental problem. The basic characterizations of the composites are usually mechanical properties. The main objective of this study is to investigate the breaking stress, degree of elongation and elastic modulus, in tensile and bending mode, for the RH/thermoplastic resin recycled from fishing nets. In addition, comparison of such mechanical behavior by differing RH, i.e., particle size and carbonized and non-carbonized RH, were also conducted.

2. EXPERIMENTAL PROCEDURE
2.1 Materials
The RH was dried for 8 hours at 120°C, and reduced to particles by using the ball mill and then sieved. Figure 1 shows aspects of the RH obtained by milling and sieving. Two types of particle sizes were used, i.e., 710～350 μm (RH1) and less than 177 μm (RH2).

![Fig. 1](image-url) Outer shape of various particle sizes of RH after sieving. (a): more than 710 μm, (b): RH1, 710～350 μm, (c): RH2, less than 177 μm.
For comparison another type of RH (RH3) was also used, which was carbonized at 1173K under the nitrogen atmosphere and reduced to particles. The median diameter size of the RH3 was 42.2 μm. The recycled resin used was made from waste fishing nets, which have been drifted ashore on the coats and have been collected by authors. They were cut into pieces by the shear and then extruded at 180°C using extrusion machine (Imoto Seisakusho PPKR IMC-1895). Figure 2 shows the outer shape of fishing nets after cutting.

**Fig. 2** Pieces obtained from fishing nets after cutting.

Analysis of fourier transformed infrared spectrometry (FTIR) and differential scanning calorimetry (DSC) were conducted in order to obtain information about chemical structure and thermal properties of the fishing nets, respectively. Spectra of the FTIR were obtained between from 4000 to 750 cm$^{-1}$ of wave numbers with a resolution of 4 cm$^{-1}$ using attenuated total reflection method. DSC thermograms were obtained from 100 to 200°C at a heating rate of 10°C/min under the nitrogen atmosphere.

**2.2 Processing**

The RH particles were mixed with the recycled resin at 180°C using the extrusion machine. The composites extruded was cut to columnar shape as shown in Figure 3. The mixed samples were prepared into test specimens by using the molding machine. Moldings were conducted using pressure of 10 MPa at the temperature from 175 to 180°C for 10 min. The dimension of the test specimens was 80(w) x 5(d) x 0.5(t) mm for tensile and 40(w) x 10(d) x 1(t) mm for bending tests, respectively.

**2.3 Mechanical tests**

The tensile and bending tests were based on the Japanese Industrial Standards of JIS-K7162 and 7171. These tests were conducted by using Shimadzu EZ Test (type EZ-S) with 100 N maximum load. The crosshead speed was 1 mm/min for tensile and 10 mm/min for bending modes, respectively. Hardness on surface of the composites was measured by using the durometer (type A).

**3. RESULTS AND DISCUSSION**

Figure 4 shows the typical infrared spectroscopic data for the fishing nets. The absorption bands at 2900, 1450-1550 cm$^{-1}$ correspond to vibration of chemical bond between carbon and hydrogen atoms. The band at 1370 implies existence of methyl group (CH$_3$), which is the part of structure of polypropylene (PP).

**Fig. 4** FTIR spectrum for fishing nets.

Figure 5 shows the DSC curve for the fishing nets. The endothermic peaks were observed at about 138 and 170°C, which correspond to melting of the polyethylene (PE) and PP, respectively. From the results of FTIR and DSC, it was found out that the fishing nets used in this study was composed of PP and PE materials.

**Fig. 5** DSC thermogram for the fishing nets.
Figure 6 shows the typical plots of stress-strain curves by the tensile mode using the testing machine for the composites with the RH2 of 50 phr content (phr: parts per hundred parts of resin). The tests were conducted using at least 5 pieces of the samples. It can be seen that stress increased markedly as the strain increases. As the values of stress passed through the maximum point on the curves, the specimen was broken and the stress suddenly decreased.

![Stress vs. strain curves for the composites with the RH1 of 50 phr content.](image)

Fig. 6 Stress vs. strain curves for the composites with the RH1 of 50 phr content.

Figure 7 (a) and (b) show relation between the breaking stress on the curves and RH content under the tensile and bending mode, respectively. Both of tensile and bending strength gradually decreased with RH content. This figure shows that the decline of the expansion and bending strength was more gradual for the composite containing RH1 (710 ~ 350 μm) than RH2 (less than 177 μm). Figure 8 shows the degree of elongation under tensile and bending modes for the composites against RH content. The degree of elongation suddenly decreased as the RH content increases, although there is little difference in the degree of elongation between RH1 and RH2 at high RH content. Apparent difference in the degree of elongation between RH1 and RH2 at low RH content was observed. The reason why the composite became brittle by adding the RH is due to weak interface interaction between the filler and resin, which leads to lower efficiency of mechanical energy transfer from resin to the filler through the interface.

![Relation between breaking stress and RH content under tensile (a) and bending (b) modes, respectively.](image)

Fig. 7 Relation between breaking stress and RH content under tensile (a) and bending (b) modes, respectively.

![Relation between elongation at maximum point and RH content under tensile (a) and bending (b) modes, respectively.](image)

Fig. 8 Relation between elongation at maximum point and RH content under tensile (a) and bending (b) modes, respectively.
and tensile and bending elastic modulus depend on RH size as well as RH content. In general, as particle size of the filler become smaller, the tensile strength and modulus of the composites increases[7]. This may be due to the homogeneity on mixture of resin with the fine RH particles in composites. As well, the surface area between the resin and the RH2 particles is considerably more larger than that of RH1. Large surface area between the resin and RH causes the energy transfer more dispersive.

Figure 10 shows the hardness at surface of the composites containing RH1, RH2 and RH3. As shown in the figure, the hardness of three composites with RH was superior than that of the resin without RH, rubbery materials and cork. By adding the RH, the composites became harder. The hardness of the composites was approximately comparable with that of plywood. There is little difference on hardness among the composites with various particle size. Thus, it is suggested that the hardness is not depend on the particle size contained in resin. The reason of the particle size dependence of hardness is under consideration.

4. SUMMARY

The composite of resin made from fishing net and RH has been fabricated and the mechanical behavior has been measured. FTIR and DSC measurements revealed that the fishing nets used in this study was composed of PP and PE materials. Results of the tensile and bending test means that the composite of the recycled resin became more brittle by adding the RH. The breaking stress and elastic modulus of the composites in tensile and bending modes increased with RH content, while the degree of elongation decreased. Particle size of RH also affects those mechanical properties. The tensile and bending breaking stress and the degree of elongation for the composites containing fine particles such as RH2 was superior than RH1. By adding the RH, the composites became harder. The hardness is not depend on the particle size contained in resin.

REFERENCES


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