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Material Recycling of Waste Plastics for Home Appliances

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The effects of the plastics recycling process consisting of a grinding, mixing, washing and pelletizing on the mechanical properties and the reliability of the recycled plastics were evaluated. The tensile, flexural and Charpy impact properties of the recycled polypropylene obtained from waste refrigerator vegetable case were measured. There were no differences in the static modulus and strength in spite of the recycling processes. On the other hand, the recycled polypropylene subjected to all processes exhibited highest toughness such as ultimate elongation and impact strength. These results showed that the toughness of the recycled polypropylene decreased due to contamination. The recycled polypropylene subjected to all processes has the same the coefficient of variation of the mechanical properties as virgin polypropylene.

Key words: Recycling Process, Polypropylene, Mechanical Property, Coefficient of variation, Toughness

1. INTRODUCTION

In Japan, the 'Law for Recycling of Specified Kinds of Home Appliances ' came into effect in 2001. The manufacturers were responsible for 50～60% weight ratio recycling of each home appliances such as refrigerator, washing machine, air conditioner and television. Furthermore, in anticipation of the 80～90% weight ratio recycling requirement in 2008, development of material recycling technologies for plastics is needed to achieve 80 % weight ratio recycling. Material recycling simultaneously leads to reduce environmental load and cost.

Recently, several basic studies[1) 2) 3) 4) 5)] on the recycling of plastic materials have been reported. For example, the mechanical properties and their coefficients of various waste plastics from the vegetable case of refrigerator and the tub of washing machine were investigated[6)] . However, there are few reports that studied the relationship between mechanical properties of the recycled materials and the recycling process systematically.

The purpose of this study is to clarify the influence of the recycling processes on the mechanical properties of the recycled materials. The recycled materials from each recycling process such as grinding, washing, mixing process were recovered, and their mechanical properties and coefficients of variation of the recycled materials were evaluated.

2. EXPERIMENTAL PROCEDURES

2.1 Materials and Recycling Process

The vegetable case of the waste refrigerator, which was collected in HCS (Hyper Cycle Systems Co., Ltd., Chiba, Japan), was made from the polypropylene (PP), which is factory recycling household appliances. The recycling processes in this study are shown in **Figure1**. The recycling processes were comprised of grinding, washing, mixing and pelletizing process. In the grinding process, the vegetable case was ground into flakes having an average diameter of 15mm. The contamination of the flakes was removed in the washing process. In the mixing process, the quality of the flakes became uniform. The pelletizing process with mesh screening removed the contamination of the flakes using a PCM45-28.5 twin-screw extruder (Ikegai tekkou Corp.). The recycled PP was made into pellets at 200℃ cylinder temperature. Conclusively, six kinds of recycled PP were made from the recycling process, as shown in **Figure1**. The recycled PP was named flake-A, flake-B, pellet-C, pellet-D, pellet-E and pellet-F. The shapes of the recycled PP are shown in **Figure2**. Additionally, for the sake of comparison, the virgin PP used to manufacture the vegetable case was also studied.

2.2 Specimens and Testing Method

The recycled and virgin PP were injection molded into dumbbell shape using an injection-molding machine TH80E-9VE (Nissei Plastic Industrial Co., Ltd.). Schematic illustration of the dumbbell specimen is shown in **Figure3**. The injection molding conditions for all materials are shown in **Table Ⅰ**.

Tensile and Flexural tests were carried out with a universal testing machine AG-500 (Shimadzu Co., Ltd.) in accordance with the ISO 527-1 and ISO 178. Tensile tests were performed at 50mm/min testing speed. The testing speed was 2mm/min for flexural test. The Charpy impact tests were carried out using a digital impact tester DG-U type (Toyo Seiki Seisaku-sho, Ltd.) in accordance with the ISO 179. All tests were performed at room temperature. Each mechanical property value was an average of twenty measurements, and the coefficients of variation (=standard deviation/average×100[%]) of the mechanical properties were calculated to evaluate the reliability of the recycled PP.

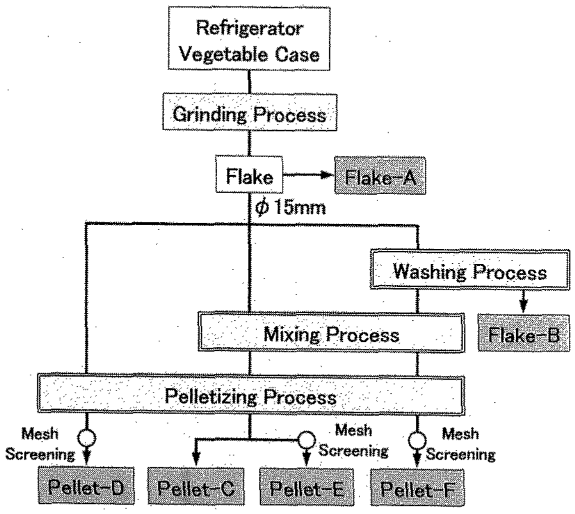

Fig.1 Flow Chart of Recycling process

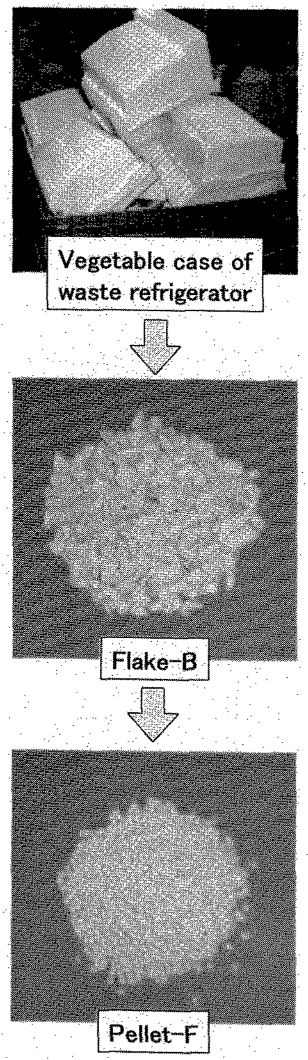

Fig.2 The shapes of recycled PP
−Vegetable case, Flake-B and Pellet-F−

Table I Injection-Molding Conditions

Injection Molding Condition		
Cylinder Temperature (℃)		200
Mold Temperature (℃)		40
Injection Speed (cc/sec)		31
Injection Time (sec)		12
Holding Pressure (MPa)	First step	90
	Second step	40
Cooling Time (sec)		10

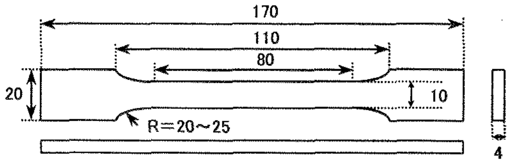

Fig.3 ISO Dumbbell specimen (unit: mm)

2.3 Observations and Analysis of Contamination

The fracture surface of a dumbbell specimen after the tensile testing was observed using a digital microscope VH-700 (KEYENCE Corp.). The contaminations on the fracture surface were analyzed using infrared spectrometer JIR-5500 type (JEOL Ltd.), and the constitution of contamination was identified.

3.RESULTS AND DISCUSSION

3.1 Mechanical properties of the recycled PP

Table II-IV show the tensile, flexural and Charpy impact properties for the six recycled PP types.

It is indicated that the stiffness and strength, such as the tensile strength, flexural modulus and flexural strength of recycled PP was almost the same as the virgin PP. There were no differences in the stiffness and strength in spite of the recycling processes.

Toughness indicators, such as the ultimate elongation and the impact strength of the pellet-F were 1.7 times and 3.2 times higher than that of flake-A. The ultimate elongation and the impact strength of the pellet-F (with washing process) were 1.2 times and 1.4 times higher respectively than that of the pellet-E (without washing process). The ultimate elongation of pellet-F (with pelletizing process) was 1.6 times higher than that of the flake-B (without pelletizing process), and the impact strength of the pellet-F was 2.4 times higher than that of the flake-B. There were no differences between pellet-D (without mixing process) and pellet-E (with mixing process) in the ultimate elongation and impact strength. From these results, it was cleared that mesh screening in the pelletizing process and washing process greatly affect the toughness of the recycled PP.

Figure4 shows a comparison between recycled and virgin PP mechanical properties. The pellet-F exhibited the most superior mechanical properties among the recycled PP. Comparing the pellet-F to virgin PP, the mechanical properties of pellet-F except the impact properties are almost the same as that of virgin PP.

TableⅡ Tensile properties of recycled and virgin PP

Material	Strength (MPa)	Ultimate Elongation (%)
Flake-A	27 (1.8)	10.5 (12.0)
Flake-B	28 (1.4)	10.9 (13.8)
Pellet-C	28 (0.7)	11.0 (17.0)
Pellet-D	28 (1.0)	15.0 (10.9)
Pellet-E	28 (0.7)	13.3 (10.1)
Pellet-F	28 (0.6)	17.4 (13.3)
Virgin	30 (0.3)	23.9 (17.9)

※ ( ) : Coefficient of variation

TableⅢ Flexural properties of recycled and virgin PP

Material	Modulus (MPa)	Strength (MPa)
Flake-A	1750 (3.8)	39 (1.2)
Flake-B	1850 (1.4)	40 (1.5)
Pellet-C	1560 (0.5)	38 (0.5)
Pellet-D	1550 (0.7)	38 (0.9)
Pellet-E	1560 (1.5)	38 (0.5)
Pellet-F	1600 (1.0)	39 (0.4)
Virgin	1810 (1.5)	43 (1.3)

※ ( ) : Coefficient of variation

TableⅣ Charpy impact properties of recycled and virgin PP

Material	Notched (kJ/m^2)	Un-notched (kJ/m^2)
Flake-A	1.6 (22.3)	33 (16.2)
Flake-B	1.6 (19.0)	45 (11.2)
Pellet-C	2.9 (10.4)	60 (25.5)
Pellet-D	2.9 (9.1)	78 (12.0)
Pellet-E	2.8 (11.7)	68 (17.3)
Pellet-F	4.4 (5.3)	107 (19.8)
Virgin	3.0 (6.0)	147 (18.8)

※ ( ) : Coefficient of variation

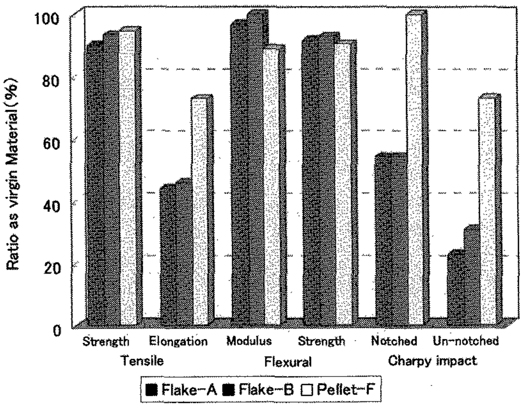

Fig.4 Comparison between the mechanical properties of the recycled and virgin PP

3.2 Reliability of the recycled PP

The results that evaluated the coefficient of variation of the mechanical properties in recycled PP are shown in **TableⅡ-Ⅳ**, compare the recycled PP to the virgin PP. The coefficients of variation of strength in the recycled PP were higher than that in the virgin PP, however the coefficients of variation of the toughness in the recycled PP were less than that of the virgin PP and then the coefficients of variation of the mechanical properties become to small in the ultimate elongation. The initial fracture of the material is generally attributed to the contamination of the recycled PP. Therefore, it might be considered that, the coefficient of variation differences between the recycled and virgin PP were caused by the presence of the contamination.

Since the coefficients of variations of mechanical properties in pellet-F were similar to those of the virgin PP, it was expected that pellet-F had little contamination.

3.3 Observation of the contamination in the recycled PP

Photographs of the tensile fracture surface of each recycled PP are shown in **Figure5**. The results of the observations of the contamination on the fracture surface of the recycled PP are shown in **TableⅤ**. Here, Area ratio is defined as the ratio of the contamination area to the whole section area.

As a result of analyzing the contamination by FT-IR analysis, Polystyrene resin, Polyurethane resin and Polysaccharide accompanying food were detected from flake-A and pellet-C. Polyurethane resin and Polysaccharide were detected from flake-B. On the other hand, Polyurethane resin was detected from pellet-D, pellet-E and pellet-F. Polysaccharide was removed by mesh screening in the pelletizing process. Polystyrene and Polyurethane were removed accordingly in the washing process. Polyurethane resin might have been mixed during the grinding process.

The Area ratio in each recycling process was calculated from the area ratio of each recycled PP. For example, when Area ratio in the washing process was calculated, the difference of flake-A and flake-B was calculated by comparing flake-A and flake-B (flake-A－flake-B＝0.8％). The same thing was said of pellet-E and pellet-F (pellet-E－pellet-F＝0.4％). The above result showed that the value of Area ratio of contamination removal in the washing process was 0.4～0.8％. From the result which averaged the value calculated above, the values of Area ratio of contamination removal in the washing process became 0.6％. The results of Area ratio in each recycling process are shown in **TableⅥ**. Here, Contribution is defined as the degree of contribution ratio of contamination removal. The most effective recycling processes for removing contamination were pelletizing, mesh screening and the washing process.

Figure6 shows the relationship between Charpy impact strength and the ratio of the contamination area to the section area. The result of **Figure6** clearly shows Charpy impact properties of the recycled PP were proportional to Area ratio, in other words the amount of contamination. The same thing might be said of the ultimate elongation. A correlation is shown between removing the contamination and improving mechanical properties limited to the toughness.

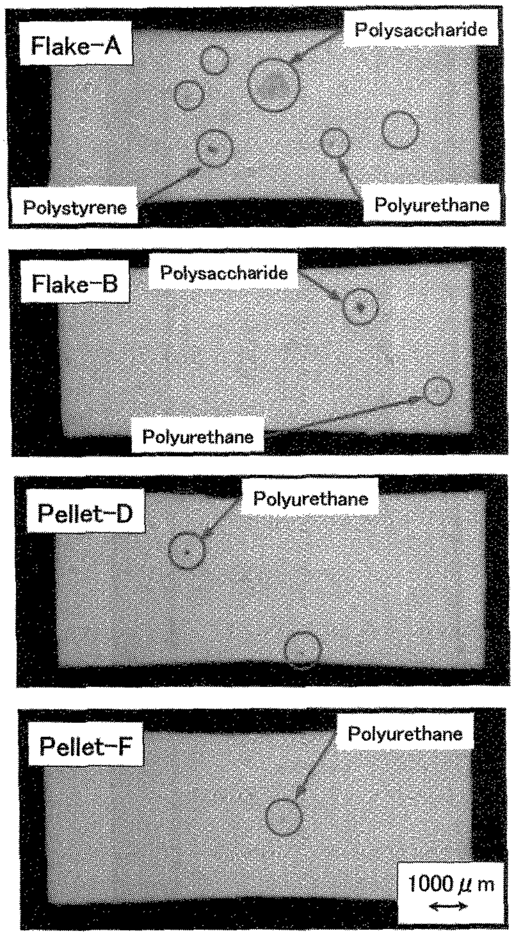

Fig.5 Photographs of the fracture surface of recycled PP —Flake-A, B, Pellet-D and F

Table V Constitution of contamination in the recycled PP

Material	Constitution of contamination	Area ratio (%)
Flake-A	Polysaccharide, Polystyrene Polyurethane	3.3
Flake-B	Polysaccharide, Polyurethane	2.5
Pellet-C	Polysaccharide, Polystyrene Polyurethane	2.2
Pellet-D	Polyurethane	1.4
Pellet-E	Polyurethane	1.3
Pellet-F	Polyurethane	0.9

※Area ratio : ratio of the contamination area to the whole section area

Table VI The removal effect of contamination of Area ratio and contribution in each recycling process

Process	Area ratio (%)	Contribution (%)
Washing	0.6	24
Mesh screening	0.9	36
Pelletizing	1.0	40

※Contribution : the degree of contribution ratio of contamination removal

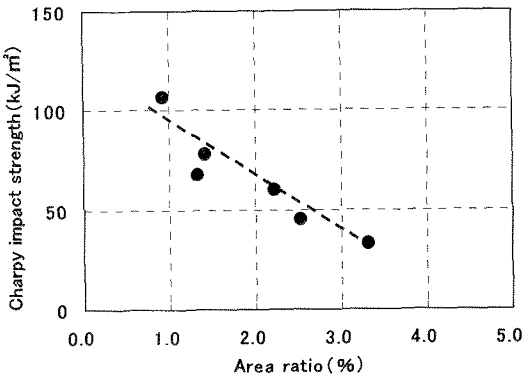

Fig.6 Relation between Charpy impact strength and Area ratio

4.CONCLUSION

We examined the influence of the recycling processes on the mechanical properties of the recycled PP, and compared the mechanical properties and the coefficients of variation of the recycled PP with those of the virgin PP.

Consequently, there were no differences in the stiffness and strength of the recycled PP in spite of the recycling processes. However, the recycled PP subjected to all processes exhibited the highest toughness such as ultimate elongation and impact strength. These results showed that the toughness of the recycled PP decreased due to the contamination. In addition, it was established that mesh screening in the pelletizing process and washing process largely affected the toughness of the recycled PP.

The coefficients of variations of mechanical properties in pellet-F subjected to all processes were similar to those of the virgin PP, it was expected that pellet-F had few contamination.

The result of the observation of the fracture surface of recycled PP showed that the toughness of the recycled PP was proportional to the Area ratio, in other words the amount of contamination.

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