FUNDAMENTAL RESEARCH ON RECYCLING OF CARBON FIBER REINFORCED THERMOPLASTICS

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1 Introduction

In these days, environmental issues resulting from global warming become more and more serious. As a result, reducing CO_2 emission is considered to be very important nowadays. One solution for this problem is replacing steel with carbon fiber reinforced plastics (CFRP) for automobile materials. Because CFRP has higher specific strength than steel, the application of CFRP on automobiles can reduce CO_2 emission observably. So, it is estimated that the demand for CFRP will increase in the next some decades. The increasing use generates an increasing amount of CFRP wastes. But, the recycling system of CFRP is not yet established. To fulfill this large demand in the future, recycling of CFRP is significant. Though CFRP applied at present are mostly carbon fiber reinforced thermosetting plastics (CFRTS), they have difficulties in recycling. They also generate a large amount of wastes of CFRP including out-of-date pre-pregs, manufacturing cut-offs, testing materials, production tools and end-of-life components in producing [1]. We consequently pay attention to carbon fiber reinforced thermoplastics (CFRTP), and test several ways of recycling which can be applied in factories. Mechanical properties of recycled CFRTP (r-CFRTP) and recycling methods are discussed in this paper.

2 Research purpose

CFRTP is fit for recycling because it can be molded again and again by heating. When producing CFRP in factories, many snippets are produced. It is the best usage of them that they are gathered, arranged and formed by hot press since higher mechanical properties can be expected. On the other hand, if it is necessary to form them into more complicate shapes than plates, injection molding should be used. The shear stress by screws in injection molding affects fiber length of CF. It is one of the most important factors for mechanical properties of recycled CFRP [2, 3]. In this paper, these two methods, press molding and injection molding, are investigated as shown in Fig.1.

3 Experiments

3.1 Materials for recycling

Mechanical properties of CFRP depend on fiber volume fraction (V_f). CFRP with higher V_f has higher modulus and strength. But, CFRP with higher V_f is difficult to mold, in especially by injection molding. In this paper, CF/PP with 20% of V_f is molded because in general, the range of V_f in injection molding is 10~20% [4].

Materials for recycling are CF/PP (V_f = 20% or 40%), 6mm length chopped carbon fiber and modified polypropylene with better interfacial adhesion property. Polypropylene is low price, so it is fit for mass production. The carbon fiber is aircraft-grade. These materials are provided by Toray, Toyobo and Mitsubishi Rayon.

3.2 Recycling methods

Three recycling methods are adopted. They are plates recycling, mixed and press molding recycling and mixed and injection molding recycling. For comparison, fresh CF/PP (V_f = 20%) is also molded. Comparing to composite formed by press molding, those by injection molding has anisotropy [5]. In press recycling, two types of screws are used, high shear stress one and low shear stress one, for changing mixing condition.

3.3 Recycling processes

We make 6 types of specimens from CFRTP (V_f = 20%) to compare the differences on mechanical properties among these recycling methods. The 6 types of specimens are Fresh CF/PP (A), Plates recycled CF/PP (B), Plates recycled CF/PP of which outermost layer is covered by one sheet (C), Press molding recycled CF/PP mixed by low and high shear stress screw (D, E), Mixed and injection molding recycled CF/PP (F).

We also make other 4 types of specimens from CFRTP (V_f = 40%), carbon fiber and modified polypropylene by press molding recycling to compare the differences on mechanical properties among different mixing condition and materials. They are mixed in low and high shear stress screw and made from CF/PP (V_f = 40%) and modified polypropylene (G, H), and carbon fiber and modified polypropylene (I, J). Therefore there are 10 types of specimens in this study.

3.4 Mechanical tests

The flexural strength and flexural elastic modulus of these specimens are measured by three-point bending test. The energy absorption value of these specimens is measured by izod impact test.

4 Results and discussions

4.1 Consideration of recycling methods

Figs. 2 and 3 are results from three-point bending tests. The specimens of "C" have the highest flexural strength among recycled CF/PP. This is about 80% of the strength of fresh CF/PP. The strength of the specimens of "B" is not so high, because the boundary of their plates is weaker than other parts. Actually the broken point shifts from the loaded point as you can see in Fig.4. As the mixing shear stress become strong, recycled specimens become weak. It is because that the carbon fibers are shortened by shear stress of screws.

The specimens of "F" have higher flexural elastic modulus than that of "E" though they have similar flexural strength. This means that short fiber length causes low flexural elastic modulus although particular direction of fiber in injection molded CF/PP makes elastic modulus a little bit higher.

Fig.5 is the result of izod impact test. As the fiber length becomes shorter, the energy absorption value decreases. The specimens of "B" have the highest energy absorption value because the crack needs to break through several layers before flexural failure happens.

4.2 Consideration of mixing condition

Figs. 6 and 7 show the results of three-point bending tests of pressed CF/PP. In all materials, specimens mixed by low shear stress screw have higher flexural strength and flexural elastic modulus than those of specimens mixed by high shear stress screw. It is because that high shear stress screw can both shorten carbon fibers and degrade PP.

The specimens of "G" and "I" have similarly high flexural strength. It shows that CF/PP recycled from composite with high V_f has almost the same grade of strength as fresh CF/PP.

Fig.8 is the result of izod impact test. The energy absorption value of CF/PP with high shear stress screw is also lower than that of CF/PP with low shear stress one. The energy absorption of CF/PP made from fresh PP is higher than that of recycled CF/PP. The reason of this is deterioration of the resin caused by multiple heat cycle during recycling.

4.3 Fiber length observation

The length of carbon fiber is an important factor for mechanical properties. PP is burned off from specimens to observe the residual length of carbon fiber as shown in Fig.9. The fibers of "A", "B" and "C" are very long. But fibers of "D" looks very short, and those of "E" and "F" are powdery. These results show that the length of fibers depends on the recycling method. This should have correlation with mechanical properties.

5 Conclusions

In this paper, mechanical properties by each recycling method are compared. The results show that improved plates recycling with sheet covering of the outermost layer is the best recycling method in view of mechanical properties. The recycled CF/PP made from CF/PP with high V_f and PP has fine mechanical properties, which suggests that thermal degradation of PP during recycling process affects mechanical properties of recycled CF/PP. The length of fibers is very important in mixing recycling for gaining high performance recycled CF/PP.

Plates recycling is the best method of recycling in view of mechanical properties, but all CF/PP are not able to be recycled by plates recycling. Other CF/PP should be recycled with long fiber length. In spite of the inevitable deterioration of recycled CF/PP, it can still be applied to low grade parts of automobile.

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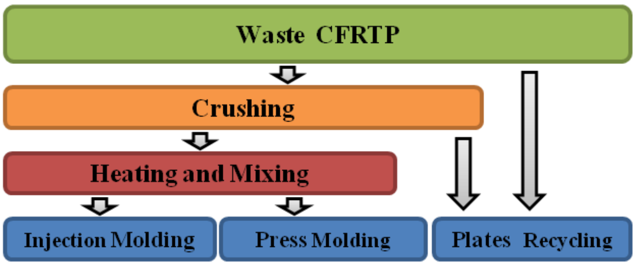

Fig.1 Recycling methods for CFRTP.

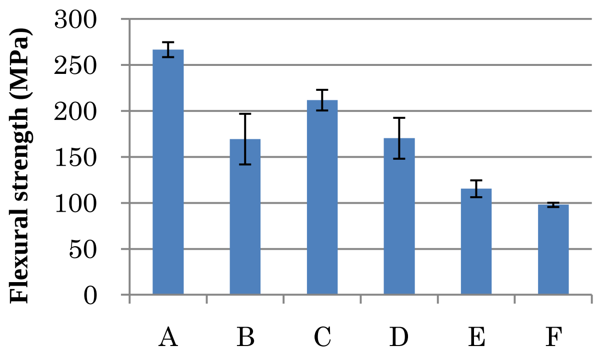

Fig.2 Flexural strength of recycled CF/PP made from V_f 20% materials.

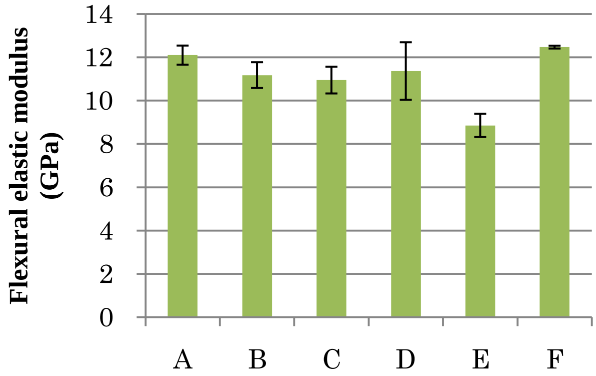

Fig.3 Flexural elastic modulus of recycled CF/PP made from V_f 20% materials.

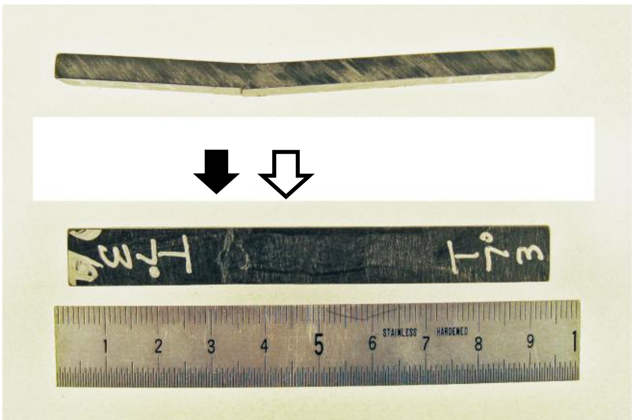

Fig.4 Flexural failure of the specimens of "B".
(Black arrow : failure point
White arrow : load point)

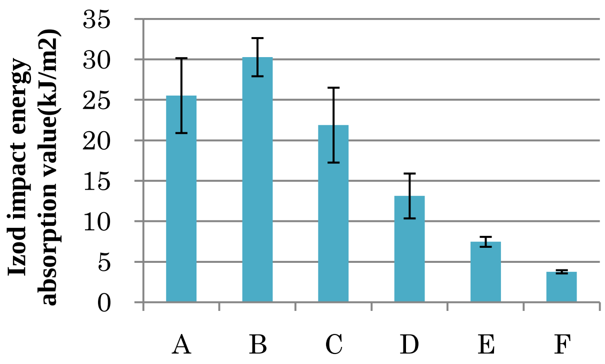

Fig.5 Izod impact value of recycled CF/PP made from V_f 20% materials.

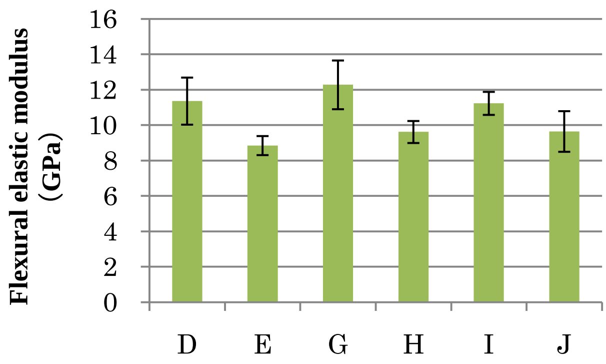

Fig.7 Flexural elastic modulus of recycled CF/PP made by press molding.

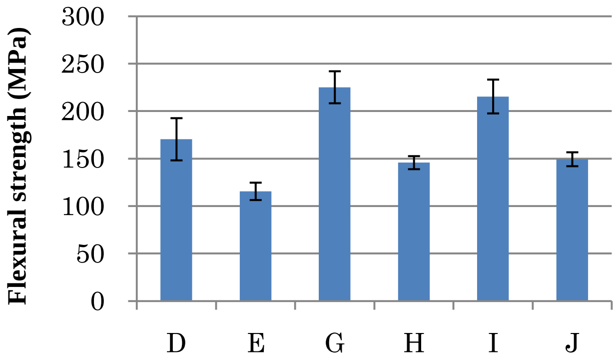

Fig.6 Flexural strength of recycled CF/PP made by press molding.

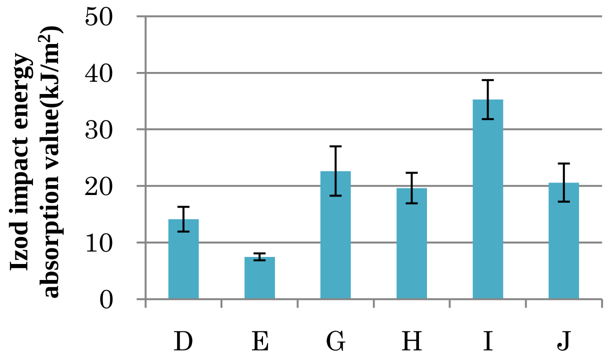

Fig.8 Izod impact value of recycled CF/PP made by press molding.

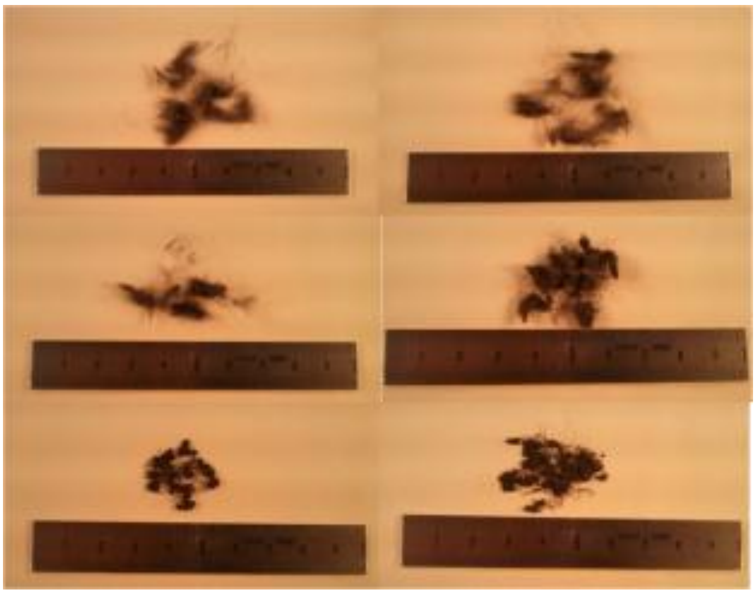

Fig.9 Fiber length of different recycling methods.
(upper left: A; upper right: B; middle left: C; middle right: D; lower right: E; lower right: F)