MECHANICAL PROPERTIES OF RECYCLED CFRP BY INJECTION MOLDING METHOD

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Abstract

Energy consumption of the running stage of automobiles can be drastically reduced by lightening their weight by CFRP (carbon fiber reinforced plastics). However, energy consumption of the CFRP manufacturing is so big to cancel the energy saving of the running stage. To reduce energy consumption and cost of CFRP manufacturing, reuse of carbon fiber is the most effective. Then, the objective of this study is to develop CFRTP (carbon fiber reinforced thermoplastics) by using waste CFRP, and the target of the mechanical properties of the recycled CFRP is more than those of secondary structural parts of current automobile.

1 Introduction

For more than a century, population, food production, industrial production, consumption of resources and pollution are all growing. Among them, we have been studying the increase of energy consumption by car-orientated society [1-4]. Figure 1 shows sectional energy consumption in the world. Comparing sectional energy consumption, that of transport sector has too much depended on oil for a long time, and been increasing firmly. Considering the motorization of non-OECD countries, in especially BRICs, it is easy to predict that energy consumption of transport sector will more and more grow from now on. For example, as shown in figure 2, energy consumption in transport sector of China will become equal level to the current world energy consumption in transport sector in the future without any drastic measurement [3, 4]. So, we need to develop effective measurements as soon as possible. Although fuel cell technology is now under development, it takes much time to be practical application.

From such a background, we have focused on lightening the weight of automobile by using CFRP (carbon fiber reinforced plastics). CFRP is used for the aircraft or space field since their high specific strength, specific rigidity and lightweight. However current CFRP is not suitable to mass production because of its high cost and recyclability [5]. In this paper we investigated recyclability of CFRP for mass production.

2 Recycle Method in This Study

As a method of CFRP recycling, heat recovery and material recycling have been investigated, and material recycling is better from a viewpoint of LCA (life cycle assessment) since carbon fiber should be reused as not just carbon but carbon fiber. Figure 3 shows the energy intensity of parts manufacturing by using steel, CFRTS (carbon fiber reinforced thermosetting resin) and CFRTP (carbon fiber reinforced thermoplastics) [6, 7]. As a result, recycling of CFRP contributes to reduce not only waste but life cycle energy consumption as shown in figure 4. Furthermore, considering that the cost of recycled CFRP must be very cheap as shown in figure 3, establishment of the recycling technology of CFRP will drastically contribute to lower-pricing of CFRP products. Hence, the recycling technology of CFRP is indispensable in the mass-production application, in especially passenger automobile, to contribute global energy saving.

As a method of taking out carbon fiber from waste CFRP, evaporation [8] and a chemical depolymerization of thermosetting resin [9] are reported as shown in figure 5. According to these methods, there is a possibility that a high performance recycled material can be molded with a press molding because long carbon fiber is taken out. However, the process becomes complex in these methods so that it may become a problem in the usage as automotive parts since the manufacturing time is too long. Then, in this paper, the injection molding method by crushed CFRP (PAN based carbon fiber with epoxy resin) with thermoplastics is investigated to obtain the recycled material at lower cost and higher speed. As the thermoplastics ABS (acrylonitrile-butadiene-styren) and PP (polypropylene) are used in this study.

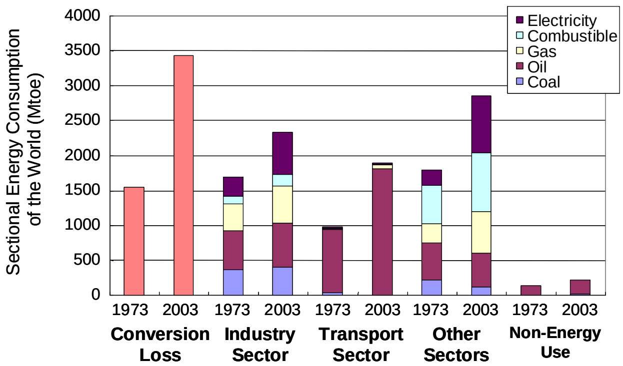


Fig. 1. Sectional energy consumption of the world.

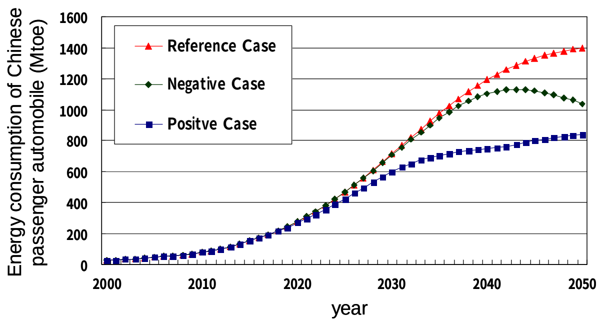


Fig. 2. Energy consumption by Chinese automobile.

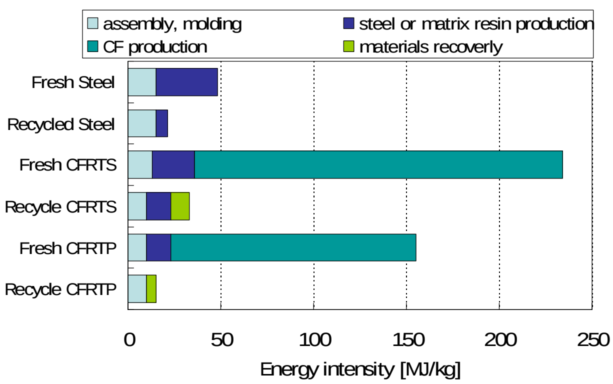


Fig. 3. Energy intensity of parts manufacturing.

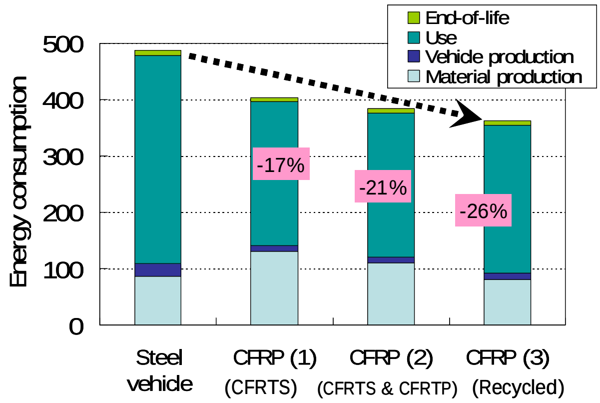


Fig. 4. Effect of CFRP recycling on the energy saving of passenger automobile from a viewpoint of LCA.

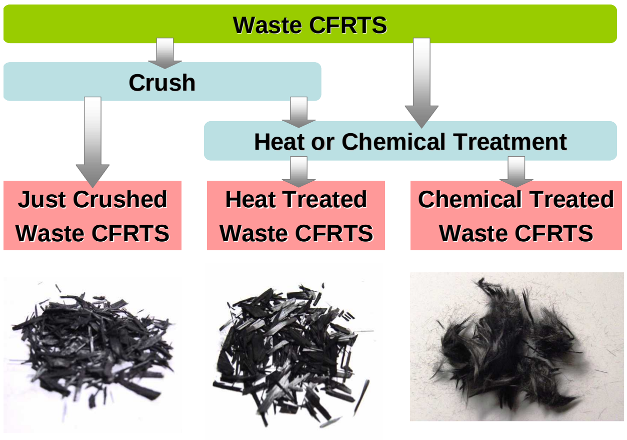


Fig. 5. Pretreatment of CFRP recycling; crush, heat treatment and chemical treatment.

3 Recycled CFRTP Specimens Made by Injection Molding

CFRP was crushed into square of about 1 cm as shown in figure 5, and thermoplastics were dried for 8 hours at a temperature of 80 degree Centigrade. Then, CFRTP pellets were made with the crushed CFRP and the thermoplastics by using a two axis palletizing machine (HK25D (41D), PAEKER, inc.). Fiber volume fractions of the pellets are 7, 15, 24 and 30 %. Then bending, tensile, impact specimens and panels were made by an injection molding machine (CLOCKNER F40) by using respective pellets of volume fractions.

JIS standard mechanical tests were performed first, and the results are summarized in figures 6. And we also investigated a directional difference in mechanical properties by using the injection molded plates to understand an actual performance of injection molded automotive parts. The injection gate of the metal mold of the panel is designed as one place so that anisotropy similar to actual injection molded parts might appear to the molded panels. Then, in order to examine the directional properties, flexural test specimens are cut out from these panels in both the direction of injection and the vertical direction.

4 Experimental Results of Panel Specimens

The size of the flexural test specimens were length 80 mm * width 15 mm * thickness 3 mm, and three points bending test and Izot impact energy absorption test were performed. Five times tests were performed for every condition; thermoplastics without CF, longitudinal and transversal specimens of CFRTP with Vf = 30 % of fresh CF, longitudinal and transversal specimens of CFRTP with Vf = 7, 15, 24 and 30 % of recycled CF.

The result of these tests is summarized in figures 7 and 8, where “F” means the specimen made by fresh CF, “L” means longitudinal specimen and “T” means transversal specimen, and the number means volume fraction of recycled CF respectively. Brittle fracture occurred in compressive side in every specimen.

In the same manner, we investigated the influence of the repetition of recycling. Recycled CF/PP specimens whose fiber volume fraction is 15 % were crushed and remolded by injection molding method to obtain the second, third and fourth recycled specimens. The results are summarized in figures 9.

5 Discussions

5.1 JIS Standard Specimens

In case of the flexural test shown in figure 6, there is little difference in mechanical properties between Fresh 30 and Recycle 30, hence the degradation may be quite little in recycling process. In terms of the flexural strength, the specimens with the fiber volume fraction of 24 % show higher strength than those with the fiber volume fraction of 30 %. It may be caused by the poor impregnation of thermoplastics into recycled CF in the cases that the fiber volume fraction is larger than 24 %. Then, the appropriate volume fraction at this recycle method may be around 24 % or less.

In case of the tensile test, fresh material had highest mechanical property. Difference from the flexural test was that the fracture occurred at the weakest point of the specimen in tensile test. And the weak point may caused by the poor impregnation of thermoplastics into recycled CF.

In case of the Izot impact energy absorption test, even in the CFRTP made by fresh CF, energy absorption ability fell down drastically due to the mixture of CF in thermoplastics.

5.2 Specimens Cut Out From The Injection Molded Panel

As shown in figures 7 (a) and 8 (a), a big difference between longitudinal and transversal direction was shown especially in flexural modulus. The flexural modulus of longitudinal direction became large almost in proportion to the fiber volume fraction like JIS standard specimen, however those of transversal direction showed low and almost constant regardless of fiber volume fraction. Consequently, when the fiber volume fraction became larger, anisotropy became stronger. Furthermore, although the influence of fiber volume fraction on the flexural modulus of longitudinal direction showed almost the same tendency as JIS standard specimens, the values were about 70 % of JIS standard specimens. This is because the anisotropy of JIS standard specimen was much stronger.

Although the failure strain of transversal direction was larger than that of longitudinal direction, there was not so much difference which was shown in flexural modulus. When the fiber volume fraction becomes smaller, failure strain of both transversal and longitudinal direction becomes larger, which is the same tendency of JIS standard specimens. However, it should be noted that even the failure strain of the longitudinal direction is more than twice of the JIS standard specimens.

As a result, like JIS standard specimens, recommended fiber volume fraction is about 24 % since a peak value of the strength was shown around 24 %. However, since almost the same strength holds to the fiber volume fraction of 15 %, recycled CFRTP with fiber volume fraction of about 15 % is also recommended for a purpose of larger failure strain if the rigidity is not so serious requirement.

By the way, the strength of longitudinal direction shows approximately 20 % smaller than that of JIS standard specimens. To a contrary, injection molded CF/PP parts whose fiber volume fraction is between 15 to 24 % are expected the

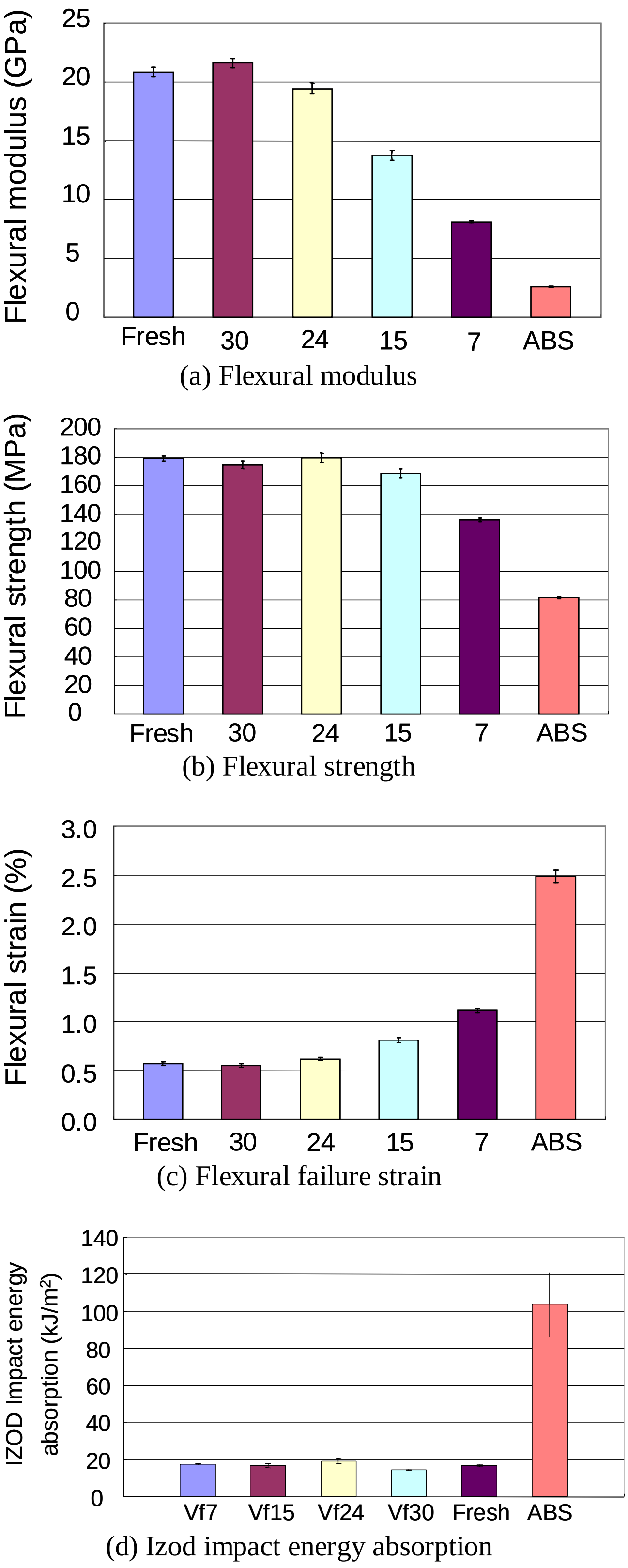


Fig. 6. Flexural properties of the recycled CF/ABS JIS standard specimens.

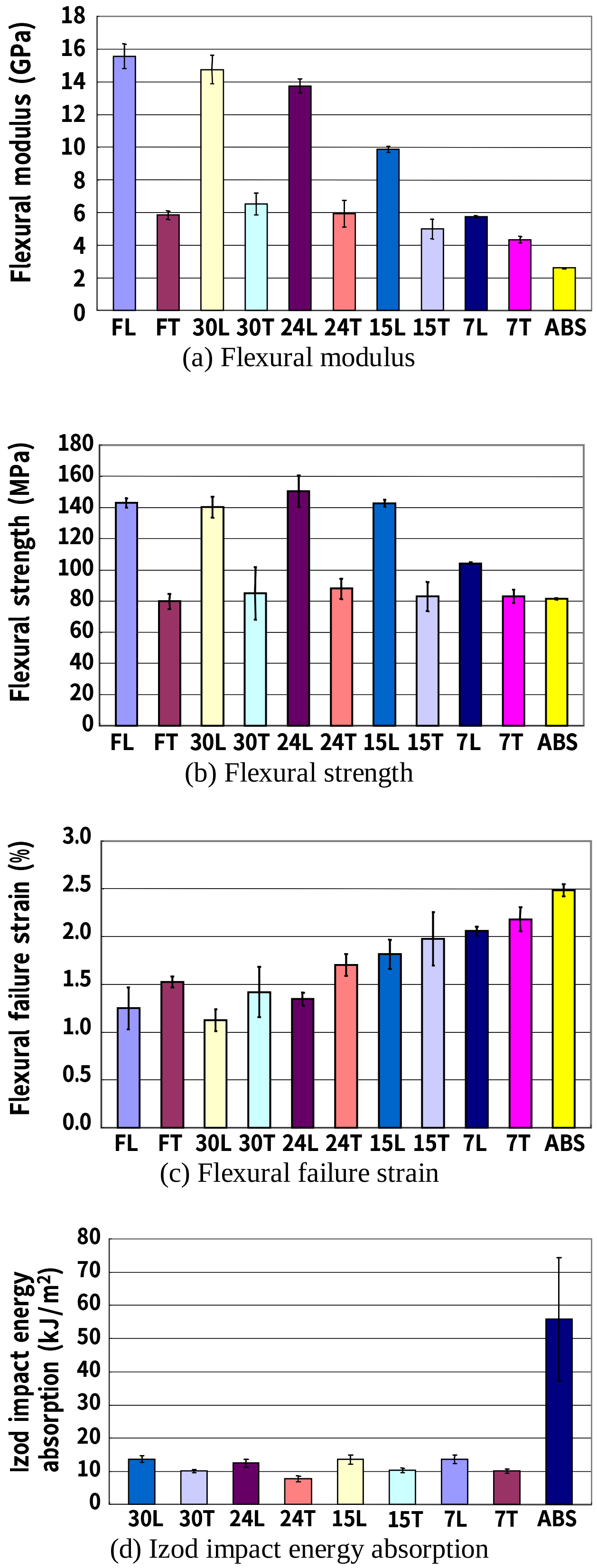
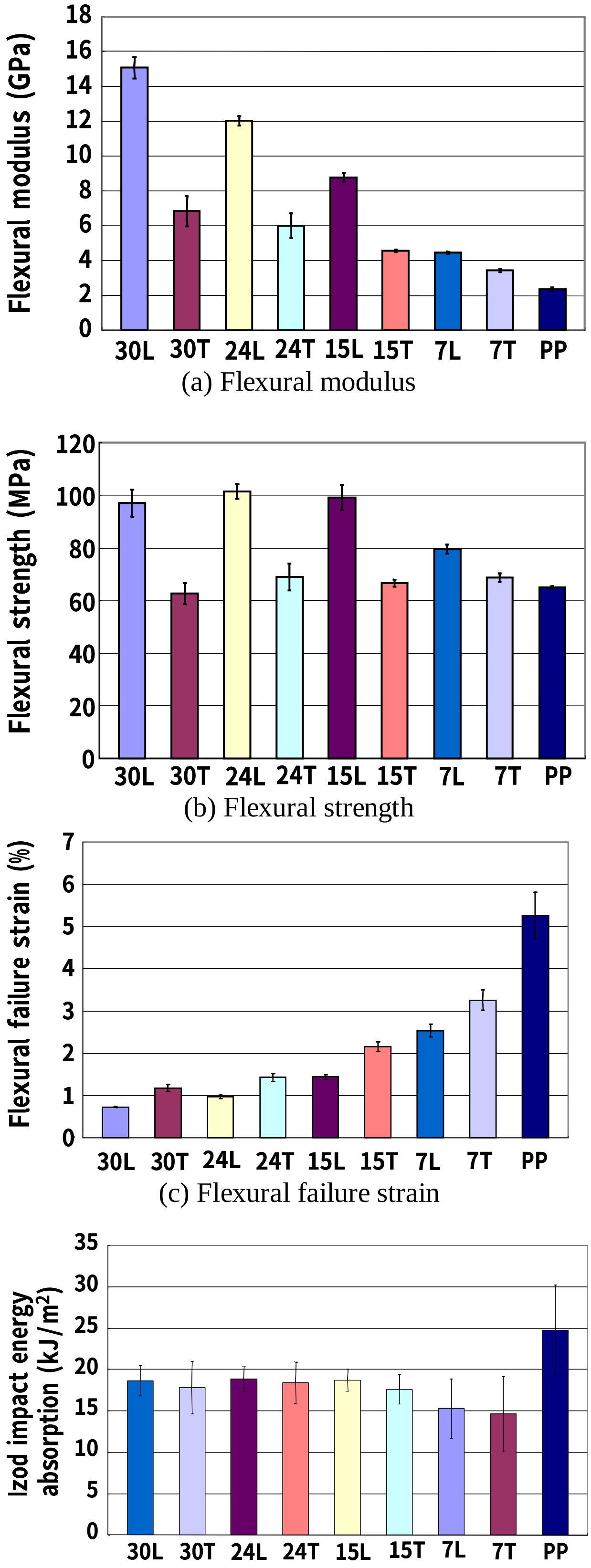


Fig. 7. Flexural properties of the recycled CF/ABS specimens cut out from the injection molded plate.



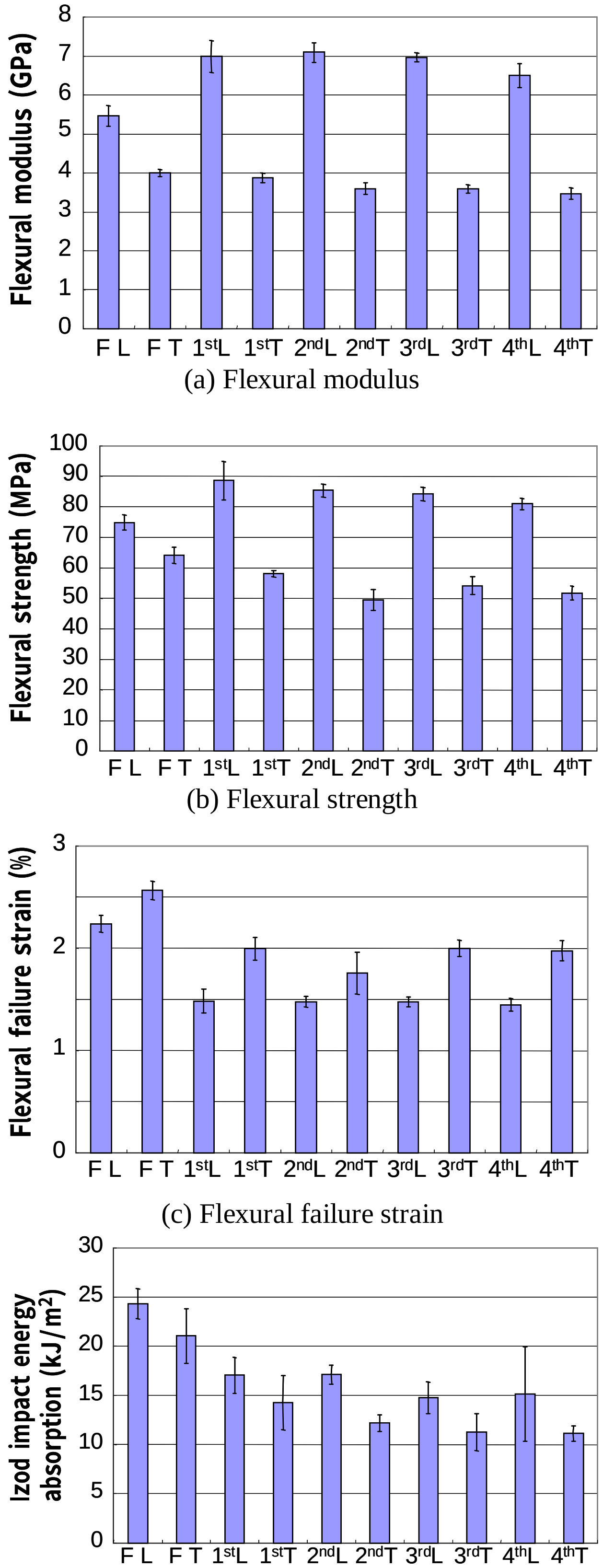
(a) Flexural modulus

(b) Flexural strength

(c) Flexural failure strain

(d) Izod impact energy absorption

Fig. 8. Flexural properties of the recycled CF/PP specimens cut out from the injection molded plate.



(a) Flexural modulus

(b) Flexural strength

(c) Flexural failure strain

(d) Izod impact energy absorption

Fig. 9. Influence of the repetition of recycling on the flexural properties of the CF/PP.

flexural strength of 120 MPa and flexural modulus of 12 to 17 GPa from a viewpoint of JIS standard test. These mechanical properties are almost the same or more than those of current GFRTP automotive secondary parts.

Finally, figure 9 shows that mechanical properties change very little during the repetition of injection molding. Increase of the flexural modulus and strength of recycled CF/PP from fresh CF/PP may caused by the existence of un-extracted CF/EP bundle. And the small decrease of impact energy absorption may due to the shortness of CF during the repetition of injection molding.

6 Conclusions

Obtained results are summarized as follows.

(1) Though strength and modulus in the direction of injection are about twice of those in the vertical direction, failure strain is larger in the vertical direction.

(2) Even if the crushed CFRP is not processed by the heat or chemical treatment, mechanical properties of recycled CFRP, i.e. CFRTP made by crushed CFRP and thermoplastics, are almost the same as those of CFRTP made by fresh CF and thermoplastics. Furthermore, these properties are not changed during the four times repetition of injection molding.

(3) Molding becomes unstable when fiber volume fraction becomes 24 % or more, and the improvement of mechanical properties reaches the ceiling, too. It may be caused by the poor impregnation of thermoplastics into recycled CF.

(4) Failure strain improves when fiber volume fraction becomes 24 % or less though strength and modulus decrease.

(5) Comparing the recycled CF/ABS and CF/PP, the mechanical properties of CF/ABS is higher, but CF/PP is superior in the chemical resistance. Hence, selection of the thermoplastic resin which is suited for purpose is necessary.

Consequentially, it can be concluded that CFRP is able to be recycled at high-speed and low cost by injection molding method, and the mechanical properties of recycled CFRP can be controlled by selecting fiber volume fraction according to the purpose. And the recycled CFRP can be used as secondary automotive parts, although it is necessary to note that there is a big anisotropy in the injection molded parts even if a filler and resin are mixed well.

Acknowledgment

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