INFLUENCE OF THE PRETREATMENT ON THE MECHANICAL PROPERTIES OF THE RECYCLED CFRP

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ABSTRACT

In this paper, an influence of the pretreatment method of crushed CFRP, which is the raw material of recycled CFRP, on the mechanical properties of recycled CFRP is investigated. We evaluated various pretreatment methods to fibers by using PP-CFRTP. CFRP is first crushed into a flake of 5 to 10 mm, and treated by heat or chemically before being remolded with thermoplastics. Then, except for impact energy absorption property, mechanical properties of recycled CFRP using untreated crushed CFRP are better than those using heat and/or chemical treated crushed CFRP. By SEM observation, epoxy resin in heat and/or chemical treated crushed CFRP are almost removed but residual epoxy resin in just crushed CFRP is shown to contribute the straight alignment of carbon fibers in the recycled CFRP which may cause the higher rigidity. On the other hand, there are some residual flakes of CFRP in the recycled CFRP with untreated crushed CFRP, which may cause the lower impact energy absorption.

KEY WORDS: Crushed CFRP, Recycle, CFRTP

1. INTRODUCTION

The world energy consumption continues to increase yearly. When you see it by classified section, you will find rapidly growth in the transport and residential sector. Especially, expecting development of developing countries representing China, vehicle energy consumption which occupies most of the part of the transport sector can be expected to increase larger, and urgent measure is expected. For the measure, research of ultra lightweight vehicle is started using CFRP (carbon fiber reinforced plastics). CFRP is used for the aircraft or space field since their high specific strength, specific rigidity and lightness [1]. However, one of the problems of applying and spreading CFRP to the future broad range of area is recycle efficiency [2].

Today, there are some recycle methods of carbon fiber reinforced thermosetting resin (CFRTS), i.e. mixing with thermoplastic resin after crushed and dividing carbon fiber from composites by chemical treatment, etc. But each recycling system is under developing and not established yet. On the other hand, there is closed- recycling system using CFRTP that is superior to CFRTS in recyclability but it is inferior to CFRTS in rigidity and strength. In this research, we focused on establishment of recycling with crushed CFRTP, because it is proper to mass production, cheap and easy to be recycled. The problem in recycle with crushed...
CFRP is the declining of mechanical properties due to fibers getting short. We evaluate influence of pretreatment methods before molding of crushed CFRP to mechanical properties of recycled CFRP.

2. PRETREATMENT METHOD OF CRUSHED CFRP

2.1 Materials

In this research, T700S produced by TORAY Co. LTD., Japan, was used for carbon fiber. Matrix of crushed CFRP was epoxy resin and Vf was 60% (figure 1). As main material for molding, polypropylene (PP, J3000GP produced by CALP Co. LTD., Japan) was used.

2.2 Pretreatment

Crushed CFRP (figure 2) was chemically [3] and thermally treated [4] [5] before molding. Among chemical treatments or heat treatments, there are some different conditions of remove rate of epoxy resin [6]. As evaluation of treatment is supposed for use in recycle, we also molded CF/PP (fresh materials) and compared. That is, in this research, we compared 7 kinds of conditions as shown in Table 1.

Table 1 Prepared materials for molding with PP.

<table>
<thead>
<tr>
<th>notation</th>
<th>preparing condition</th>
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<tbody>
<tr>
<td>Fresh</td>
<td>chopped fresh CF (6 mm length, see figure 1)</td>
</tr>
<tr>
<td>Crushed</td>
<td>just crushed CF/EP (5 to 10 mm length, see figure 2)</td>
</tr>
<tr>
<td>Chemical A</td>
<td>crushed and chemically treated (5 minutes)</td>
</tr>
<tr>
<td>Chemical B</td>
<td>crushed and chemically treated (180 minutes)</td>
</tr>
<tr>
<td>Heat a</td>
<td>crushed and heat treated (nitrogen, 700C, 2hours)</td>
</tr>
<tr>
<td>Heat b</td>
<td>crushed and heat treated (oxygen, 500C, 2hours)</td>
</tr>
<tr>
<td>Heat c</td>
<td>crushed and heat treated (nitrogen, 700C, 2hours + oxygen, 500C, 2hours)</td>
</tr>
</tbody>
</table>

2.3 Molding

After each treatment, CFRPs were kneaded with PP by two-axis mixing machine, and
molded into plate by hot press machine. Besides, for improvement of adhesivility, maleic acid was added at the mixing process. Finally, the molded plates were cut out for test piece, and three points bending test and Izod impact test were performed.

3. EXPERIMENTAL RESULTS

3.1 Three Points Bending Test

From the result of three points bending test, flexural modulus, flexural strength, and failure strain were calculated as shown figures 3 and 4 according to ASTM D790-03 (2002).

![Fig.3 Flexural modulus and strength of recycled CFRP (crushed CFRP/PP)](image1)

![Fig.4 Flexural failure strain of recycled CFRP (crushed CFRP/PP)](image2)
3.2 Izod Impact Energy Absorption Test

From the result of Izod impact test, Izod impact energy absorption [7] were calculated as shown in figure 5. Figure 6 shows SEM pictures of fracture surface of Crush and Heat a specimens after the impact test.

![Fig.5 Izod impact energy absorption of recycled CFRP (crushed CFRP/PP)](image)

![Fig.6 SEM photographs (left: Crush ×150, right: Heat a ×2000)](image)
4. DISCUSSION

4.1 Discussions of Experimental Results

From figure 3, Crush, Chemical A, and Heat a show high values of flexural modulus. This is supposed that they are reinforced by remaining CF bundled by epoxy resin, whose characteristics of unidirectional material in high Vf value partly came out. On the other hand, the values of flexural modulus of Chemical B, Heat b and Heat c are relatively low, which epoxy resin are perfectly eliminated. This is because fibers were taken apart in the treatment process, and random orientation characteristic was strengthened. Strength of each treated materials were about 75% compared to which of Fresh. This is because in Crush, Chemical A, Heat a, concentration of stress occurred where mass of remaining epoxy resin exists, and fracture proceeded.

Figure 4 shows that flexure failure strain of Heat b was high and its dispersion was large. This is because the influence of test pieces, which were curved little during molding. Dispersion of failure strain of Crush is also large owing to a position of crushed pieces. Dispersion of failure strain tends to get low as epoxy resin eliminated.

From figure 5, it is shown that as epoxy resin eliminated more, impact-absorbing ability gets higher. Value of absorbed impact energy is sum of energy occurs when fibers came out of resins or cut off when test pieces broke. So, absorbed impact energy of Crush and Heat a are low, because remaining epoxy resin came out at once when they got impact.

Comparing chemical treatment and heat treatment, from result of three points bending test and impact test, if rate of epoxy resin elimination is same, either treatment shows same mechanical properties. But chemical treatment can take out fibers without damage, so chemical treatment is superior to heat treatment in fiber length, strength and balance.

4.2 Observation of Fracture Surface

We observed fracture surface of impact test piece using SEM. Figure 6 shows the part of it, showing holes epoxy resin came out in the Crush’s fracture surface. Sticking of epoxy resin to fiber surface of Heat a was observed. Fracture surface of Heat b has nothing to stick to it, although fiber of Heat c had some PP. This is because adhesion of fibers and PP in Heat c is stronger than that of Heat b.

5. CONCLUSIONS

In this research, we evaluated the influence of pretreatment condition on mechanical properties of recycled CFRP made by crushed CFRP and PP. Comparing a pretreatment condition of crushed CFRP before molding, i.e. just crushed, chemically treated and heat treated, following results are obtained.
1. Mechanical properties of recycled CFRP are influenced by elimination rate of epoxy resin.
2. The remaining CF/epoxy bundle improves the stiffness of recycled CFRP.
3. On the contrary, the remaining CF/epoxy bundle lessens impact energy absorption ability of recycled CFRP.
4. The remaining epoxy on the surface of CF may induce stronger adhesiveness with PP than clean CF surface.
5. In the chemical treatment, fibers were collected without damage and in a short time.
6. Even just crushed CFRP, mechanical properties of recycled CFRP are almost the same to
other pretreated CFRPs. It is desirable to recycle only with just crushed CFRP in the respect of recycle speed and cost.

The future direction of this study will be a design of the properties of recycled CFRP aiming toward practical applications. In this research, we evaluated the specimens with fiber volume fraction of 15% and molded by hot press machine. This is because smaller fiber volume fraction and hot press machine are both suitable for parametric study though mechanical properties are usually not enough from a viewpoint of practical application. It is assumed that the specimens with higher fiber volume fraction and/or made by injection molding, higher and uniform mechanical properties are expected.

And at the time to put it to practical use, the most suitable treatment and the most suitable condition are necessary to be investigated, judging from demanded properties, mass of production, treatment speed, and cost. For example, if rigidity and productivity is demanded for use, the best method will be the use of just crushed CFRP. And also, if toughness to impact and stable properties are demanded, it is desirable to collect fibers with chemical pretreatment. In this way, it is needed to achieve CFRP recycle that every pretreatment method is decided on a case-by-case basis.

REFERENCES