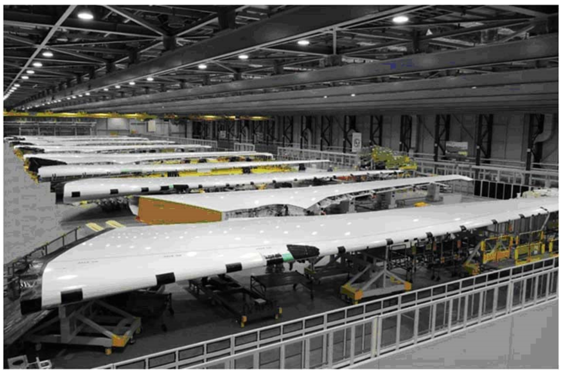
Reduction of Environmental Impact by Recycling Waste Composite Material for Aircraft



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As the utilization of composite materials using lightweight and high-strength carbon fiber has been increasing mainly for aircraft parts, nearly 1,000 tons of waste composite materials are produced annually and are disposed of as industrial waste in our company. The production of carbon fiber includes a large energy load and generates more than twice the amount of CO_2 in comparison with the production of aluminum. In addition, disposing of composite materials as industrial waste also has an impact on the environment. In order to solve this problem, we focused on composite material recycling technology and evaluated the performance of recycled carbon fiber and studied its strength characteristics. This paper describes our efforts to build a new value chain that extracts recycled carbon fiber from waste composite material aiming at the reduction of environmental impact.

1. Introduction

Lightweight and high-strength carbon fiber reinforced plastics (CFRP) has been increasingly used mainly for aircraft parts and automobile parts. Carbon fiber is difficult to burn, light, scatters easily and is conductive, so there are many problems in its disposal. For example, in the case of thermal recycling accompanied by combustion, the scattering of unburned fibers can cause electrical short circuits. For this reason, currently many waste composite materials are disposed of in landfills[1]. In addition, carbon fiber is expensive, and its production includes a large energy load generating more than twice the amount of CO_2 in comparison with the production of aluminum, so there is a great need to use carbon fiber for material recycling in terms of its overall life cycle. However, since recycled carbon fiber is considered to have lower physical properties than virgin carbon fiber, full-scale material recycling has not progressed.[1]

Mitsubishi Heavy Industries, Ltd. (MHI) undertakes orders for the manufacture of composite wings for the Boeing 787 and produces large quantities of composite parts for more than 140 aircraft per year. Through this undertaking, approximately 1,000 tons of waste composite material (**Figure 1**) is generated each year depending on the yield of the prepreg used for the manufacture of the composite material and the waste from the trim process, etc. This results in a large environmental burden and great expense for disposal as industrial waste. In order to solve this problem, we focused on composite material recycling technology (pyrolysis method, solvolysis method, etc.) and evaluated the performance and strength characteristics of recycled carbon fiber. This paper presents the establishment of this new value chain that extracts recycled carbon fiber from waste composite material.

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Figure 1 Waste composite material generated at our company

2. Performance evaluation of recycled carbon fiber

In recent years, the development of composite material recycling technology has been actively carried out in Japan and overseas. In Japan, there is the pyrolysis method, solvolysis method, fluid method, electrolysis method, catalytic decomposition method, etc.[1], as shown in **Table 1**. Considering practical application, the pyrolysis method[2] and the solvolysis method[3] are considered promising at the present stage. Therefore, we extracted recycled carbon fiber from our waste composite material by using the recycling technology of the pyrolysis method and the solvolysis method and evaluated the performance of the recycled carbon fiber.

Table 1 Carbon fiber recycling technology in Japan

Technical classification	Pyrolysis method	Ordinary pressure solvolysis method	Supercritical fluid method	Subcritical fluid method	Electrolysis method	Thermal activation of oxide semiconductor method
Type of resin	All resins	Ester type	Ester type	Ester type	All resins	All resins
Collected matter	CF gas	CF Resin decomposition product	CF Thermosetting resin before curing	CF Resin decomposition product	CF	CF
Temperature	500°C	100 to 200°C	250 to 300°C	300 to 400°C	Acid and alkali electrolysis temperature	400 to 450°C
Pressure	Normal pressure	Normal pressure	5 to 10 MPa	1 to 4 MPa	Normal pressure	Normal pressure
Preparation	None	None	Grinding	None	Chip grinding	None
Scale	2000 tons/year	12 tons/year	Laboratory scale	Laboratory scale	Laboratory scale	Laboratory scale

2.1 Surface observation by SEM (Scanning Electron Microscope)

Figure 2 presents the SEM observation results of the surface of recycled carbon fiber extracted by the pyrolysis method and the solvolysis method. The observation results indicate that residues of resin, contaminants, defects of carbon fibers, etc., were not found in the extract of both methods. The surface of the recycled carbon fiber is considered to be in good condition.

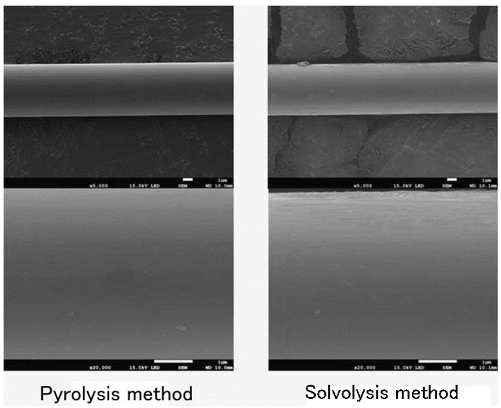

Figure 2 SEM observation results of recycled carbon fiber

2.2 Surface elemental analysis by XPS (X-ray photoelectron spectroscopy)

XPS analysis of the surface of recycled carbon fiber was carried out to calculate the amount of oxygen atoms present on the surfaces of recycled carbon fiber and virgin carbon fiber (**Figure 3**). The surface oxygen atomic weight of recycled carbon fiber was lower than that of virgin carbon fiber. This is considered to be because not only was matrix resin removed during the recycling process, so were functional groups on the surface of the carbon fiber. However, since remaining functional groups containing oxygen atoms were also observed on the recycled carbon fiber surface, adhesion and wettability with matrix resin can be expected.

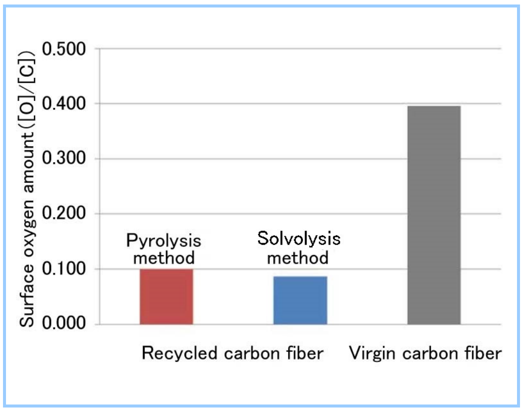

Figure 3 Surface oxygen atomic weight of recycled carbon fiber

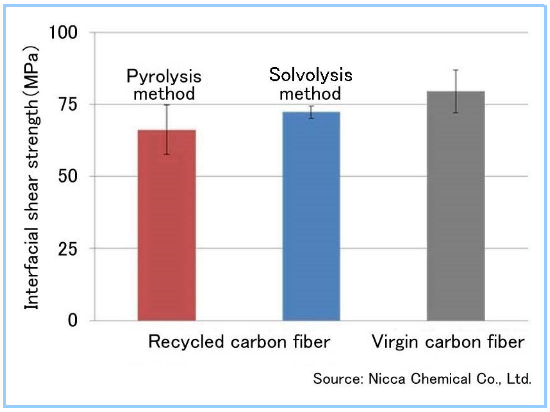

Figure 4 Results of micro droplet test

2.3 Micro droplet test

Next, in order to evaluate the adhesion of the surface of recycled carbon fiber, a micro droplet test was carried out. A monofilament was removed from a recycled carbon fiber bundle, and a micro droplet was formed by attaching epoxy resin to it. Then the interfacial shear strength was calculated from the drawing load obtained by a drawing test (**Figure 4**). Despite the slightly lower value in comparison with virgin carbon fiber, it can be considered that there is sufficient adhesion on the surface of the recycled carbon fiber extracted by the two methods due to the residual effect of the functional group containing oxygen atoms shown in 2.2.

3. Efforts to reduce environmental impact through the effective use of recycled carbon fiber

Since the waste composite material is cut to a predetermined size during the recycling process, it is difficult to extract the recycled carbon fiber as a continuous fiber. The form of recycled carbon fiber includes milled fiber of 1 mm or less, short fiber of 10 mm or less, and long fiber of 10 mm or more. It is desirable to use the fiber forms for highly-value-added methods such as pelletizing and nonwoven fabric manufacturing accordingly.

Figure 5 gives the usage examples. As a versatile and effective utilization method of recycled carbon fiber, the use of short fiber for a composite material with thermoplastic resin is considered in this paper. In addition, we will describe the construction of a value chain incorporating recycling partners as an initiative to reduce environmental impact. In addition, our efforts to reduce environmental impact through the establishment of a value chain incorporating recycling partners are presented.

3.1 Effective utilization of recycled short carbon fiber

Pelletizing recycled carbon fiber and thermoplastic resin was studied. The selected thermoplastic resin was polyamide 12 (PA12) in consideration of its adhesion to carbon fiber. As can be seen in **Figure 6**, raw pellets and recycled carbon fibers were fed into a twin-screw kneading extruder and pelletized. Strength evaluation test pieces were prepared by injection molding the obtained pellets (CF content 20 wt%) for evaluation and comparison with commercially available short fiber pellets (PA12+CF20wt%). The commercially available carbon fiber used was the high-strength type T700 manufactured by Toray Industries, Inc. **Figure 7** provides the results of tensile strength and bending strength tests. The test pieces using recycled carbon fiber showed comparable results to the commercially available product and the effectiveness of recycled carbon fiber was verified.

Figure 5　Form of recycled carbon fiber

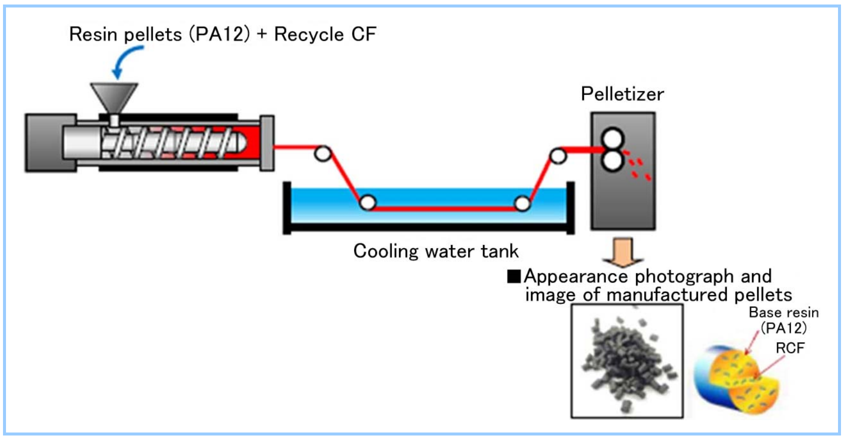

Figure 6　Pelletizing process

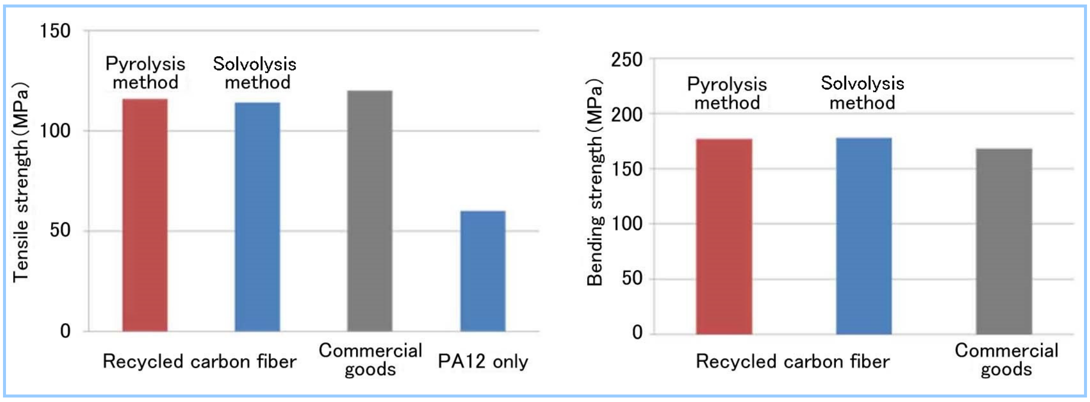

Figure 7　Strength characteristics of composite material of recycled carbon fiber and thermoplastic resin

3.2　Establishment of value chain incorporating recycling partners

Our waste material is appreciated by recycling partners because it consists of a single material without foreign substances and is reliable. In order to supply waste material stably, we are promoting awareness reforms to understand waste materials as "resources," not "garbage," through efforts such as posting posters (**Figure 8**) to prevent materials other than CFRP from being mixed in. We have also established a new value chain covering the areas ranging from the manufacturing to recycling of composite materials ahead of our competitors through cooperation with our customers and recycling partners through efforts such as supplying waste materials in a form that facilitates the recycling process.

It is generally reported that amount of energy required for the production of virgin carbon fiber is 286 MJ/kg and the CO_2 emissions are 22.4 kg-CO_2/kg[4]. However, as a result of this effort, the energy consumption for the production of carbon fiber has been reduced to about 1/6, and the CO_2 emissions have been reduced by nearly 10,000 tons annually by reusing our waste composite material (**Figure 9**).

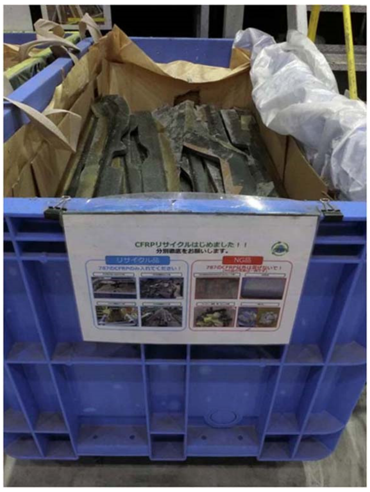

Figure 8 Poster promoting separation of waste materials

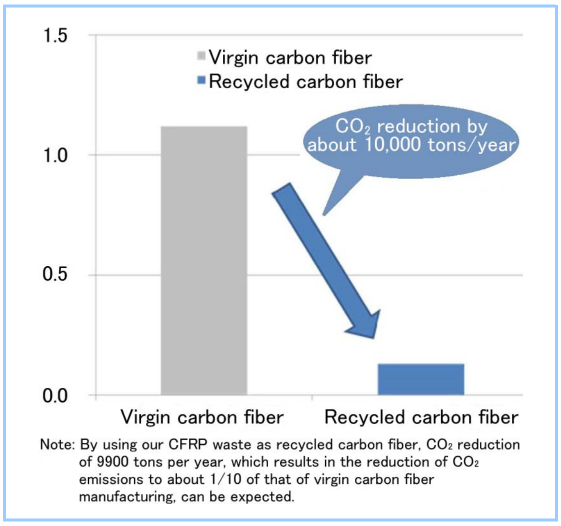

Figure 9 CO_2 emissions reduction effect of recycling our CFRP waste materials

4. Conclusion

This paper assessed recycling methods and evaluated the performance of recycled carbon fiber and verified its effectiveness, and presented our efforts to establish a new value chain that extracts highly-recyclable carbon fiber from waste composite material generated at our company ahead of our competitors by taking advantage of our capability to stably supply waste composite material. We have already established a system to constantly supply waste materials to multiple recycling partners and have started working on the reduction of environmental impact. In addition, the cost of industrial waste disposal became unnecessary, which has resulted in cost reduction.

We are targeting the commercialization of the recycled carbon fiber product in the future as an effort to expand the established value chain in order to reduce environmental impact.

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