Recycling and Utilizing Waste Composite Material for Aircraft

MASAYUKI KANEMASU[*1] TAKU YAMAMORI[*2]
WATARU NISHIMURA[*3] KENGO UCHIYAMA[*4]

Carbon fiber composite materials are increasingly being applied to aircraft wings and other parts due to their lightweight and high-strength properties. However, there are significant issues of large energy consumption during carbon fiber production and environmental impact during disposal. Mitsubishi Heavy Industries, Ltd. has been working on the recycling of carbon fiber composite materials. This report outlines an initiative aimed at establishing a supply chain capable of providing stable recycled materials and overcoming technological issues specific to the recycled materials.

1. Introduction

Carbon fiber composites, which are lightweight and high-strength, have been increasingly used, primarily in aircraft components. Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) has also received orders for the manufacture of composite wings for the Boeing 787 and is manufacturing large quantities of composite parts. However, this manufacturing process also generates waste composite materials, such as prepreg (uncured material) generated during composite material production and offcut scraps removed from cured parts. **Figure 1** shows examples of waste composite materials generated from operations at MHI. In addition, carbon fiber production generally has a high energy load and emits more CO_2 than aluminum. Therefore, the disposal of waste composite materials also incurs environmental impact and disposal costs.

MHI has declared its goal of achieving carbon neutrality by 2040 (MISSION NET ZERO), aiming to reduce environmental impact and protect the global environment through efficient resource utilization. This report focuses on composite material recycling technology and introduces MHI's initiative toward establishing a supply chain capable of providing stable recycled materials and overcoming technological issues specific to the recycled materials to achieve the above goal.

*1 Research Manager, Special Purpose Systems Research Department, Research & Innovation Center
*2 Manager, 787 Wing Production Department, Commercial Aviation Systems
*3 Factory Innovation Center, Research & Innovation Center
*4 787 Wing Production Department, Commercial Aviation Systems

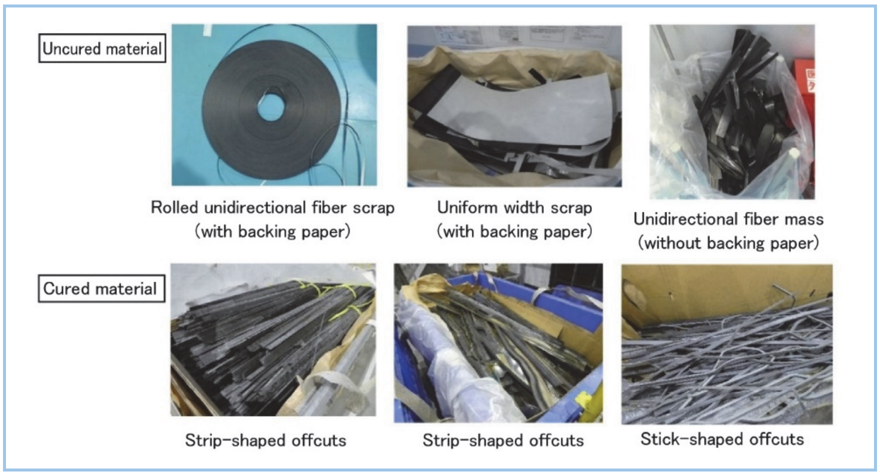

Figure 1 Examples of waste composite materials generated from MHI operations

2. Issues in commercialization of recycled carbon fiber products

In recent years, the development of composite material recycling technologies has been actively pursued both domestically and internationally. MHI has also been advancing the performance evaluation of recycled carbon fibers and demonstrating their effectiveness utilizing recycling technologies [1]. On the other hand, commercialization of recycled carbon fiber products involves the following three issues, in addition to collaboration with various suppliers including recyclers.

(1) Availability of waste materials

Recycled carbon fibers are not well-suited for mass-produced items like automotive parts, as concerns exist regarding insufficient waste material supply depending on part weight and vehicle model. Therefore, their use should be limited to medium- and low-volume production items and requires a stable waste material supply needs to be secured.

(2) Reliability and quality stability of waste material

Prevention of impurity contamination, waste material traceability systems, and useful recycled carbon fiber material standards have not been established, raising concerns about the reliability and quality stability.

(3) Pricing

Recycled carbon fibers are generally less expensive than virgin carbon fibers, but they are more expensive than glass fibers. Therefore, when recycled carbon fibers are used to replace parts made with glass fibers, not only added value such as weight reduction but also a lower price is needed.

Commercialization of recycled carbon fiber products requires solving at least the three issues mentioned above. However, MHI can guarantee a certain level of waste material supply volume and quality by utilizing its strengths, being capable of supplying waste composite materials stably and possessing the traceability system required for aircraft manufacturing, and also reducing sorting costs through waste material separation. The next chapter presents MHI's initiatives.

3. Management of waste composite materials

Waste composite materials from MHI operations are composed of a single material and do not contain foreign objects due to the high-quality processes required in aircraft manufacturing, and are thus evaluated by recycling partners as highly reliable. Furthermore, to prevent contamination with materials other than CFRP, efforts are underway to foster a mindset shift where waste materials are viewed not as "refuse" but as "resources," such as displaying posters like the one shown in **Figure 2** (left). In addition, by implementing personnel training and process change management utilizing the traceability system required in aircraft manufacturing, a scheme was established that not only ensures a stable supply of waste materials but also enables tracking when changes occur, thereby guaranteeing a certain level of waste material form, shape, and quality.

Furthermore, from the perspective of overall supply chain optimization, along with customers and recycling partners, MHI has worked to create a supply chain that produces higher-value recycled carbon fiber. Its initiatives include collecting and supplying waste materials in shapes that facilitate downstream recycling processes, as shown in Figure 2 (right). A system to regularly supply waste materials to multiple recycling partners has already been established, and initiatives to reduce environmental impact and waste disposal costs are in place.

Figure 2 Management of waste composite materials

4. Efforts for commercialization of recycled carbon fiber products

Next, as part of expanding the supply chain for recycled carbon fibers, initiatives began to explore applications for commercialization of recycled carbon fiber products. With the cooperation of the Chubu Bureau of Economy, Trade and Industry, which promotes the circular economy, a stick-type vacuum cleaner (**Figure 3**) manufactured by Mitsubishi Electric Corporation (hereinafter referred to as MELCO) was selected as a candidate. In collaboration with MELCO, studies on applying recycled carbon fibers began in 2020 [(2)]. Aiming to reduce environmental impact and lower costs, initiatives were made to replace the handle and pipe of this stick-type vacuum cleaner, which uses some injection-molded parts made from polypropylene blended with virgin carbon fiber, with recycled carbon fibers.

Figure 3 Mitsubishi Electric Corporation cordless vacuum cleaner "iNSTICK ZUBAQ"

As a recycler extracting recycled carbon fibers from waste composite materials, a cooperative framework with Carbon Fiber Recycle Industry Co., Ltd., located in Gifu Prefecture, was established in consideration of the development status of mass-production systems as well as the reduction of environmental impact and costs associated with the transportation from the Nagoya region where the waste materials are generated. As a resin manufacturer producing pellets blended with recycled carbon fibers, preparations have progressed for mass production with the cooperation of Daicel Miraizu Ltd. (current Novacel Co., Ltd.). **Figure 4** shows the supply chain for this initiative. In particular, the fact that stakeholders shared the required specifications and cost targets from the early stages of development and worked to solve issues from the perspective of overall supply chain optimization is considered a major factor that led to the commercialization.

Next, evaluations for replacing virgin carbon fibers with recycled carbon fibers were conducted in the sequence of a pellet manufacturing test, coupon evaluation, actual molding test, and actual destruction test. The following sections describe the technological issues encountered during the evaluations and their solutions.

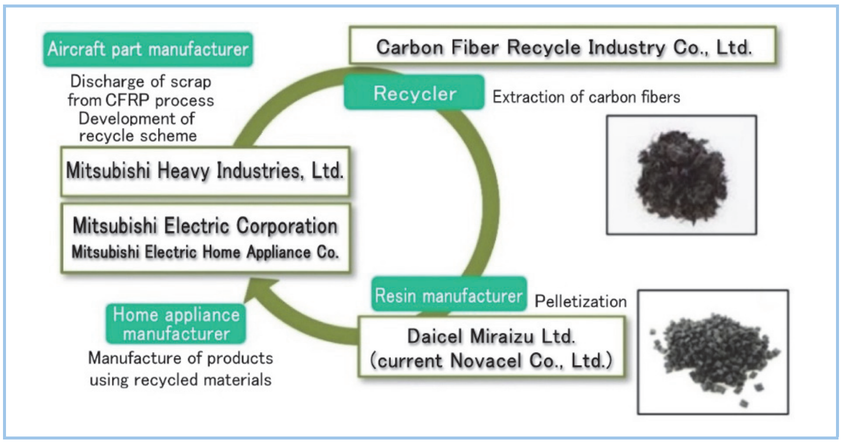

Figure 4　Establishment of supply chain [3]

4.1　Mass production of pellet manufacturing process

The ability to mass produce pellets at a high enough level is necessary for their commercialization. On the other hand, there are two mass production degrading factors, namely, (1) dust generation and (2) the presence of long fibers causing feeder jams (**Figure 5**), which are issues unique to recycled carbon fibers.

The primary causes of (1) dust generation are considered to be finely cut fibers produced when cutting recycled carbon fibers to a fixed length, and the release of soot remaining on the fiber surface due to pyrolysis. Dust generation was able to be suppressed by spraying a sizing agent with good adhesion to polypropylene onto the fiber surface to perform coating, thereby improving the handling properties. On the other hand, regarding (2) the presence of long fibers, since long fibers pass through the wire mesh with a certain probability during the classification process after fixed-length cutting, the number of classifications was increased to suppress this. However, increasing the number of classifications also increases dust generation due to surface abrasion, so the number of classifications was optimized to achieve a balance between the two.

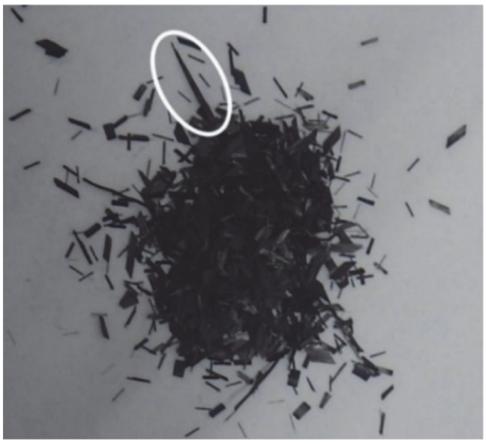

Figure 5　Presence of long fibers

4.2　Strength property

Commercially available pellets used in current parts maintain a certain residual fiber length by impregnating resin into carbon fiber roving cut to a specified length. On the other hand, recycled carbon fibers have shorter residual fiber lengths due to waste composite materials being composed of various layup angles and the impact of fiber cutting during the pelletizing process. Therefore, when the fiber content rate is the same, recycled carbon fiber pellets tend to have equivalent or reduced strength properties compared to commercially available pellets made from virgin carbon fibers. Countermeasures to maintain the strength property include increasing the fiber content of recycled carbon fibers, but this simultaneously increases material costs. Furthermore, considering the fact that the current product involves an additional process of blending resin pellets alone prior to injection molding to dilute the specified fiber content, the fiber content rate was set to 15% to achieve the strength property equivalent to the current product while eliminating the dilution process. Tensile testing conducted in temperature environments from room temperature to one higher than the operating temperature condition revealed that no significant change occurred, and that the target level, equivalent to the current material, was maintained, even considering variations in material properties (**Figure 6**). Furthermore, not only the elimination of processes but also the reduction in total part forming costs through centralized material management was achieved.

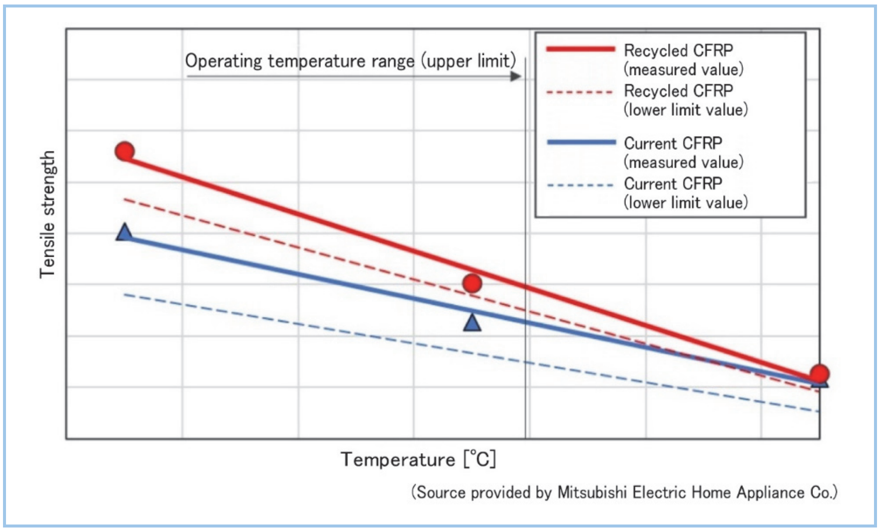

Figure 6　Tensile test results

4.3　Appearance quality

After resolving issues with the level of pellet mass production and reduction in strength, an actual part molding test was conducted. However, during this test phase, whitening and color unevenness caused by the whitening occurred on the surface of the molded part compared to the appearance quality of the current part (**Figure 7**). As a result of an investigation, it was determined that differences in flow characteristics between the selected base resin, which was polypropylene, and the additives caused this phenomenon. As such, by adding carbon black, changing to a resin grade with higher flowability, adding an additive to suppress resin slip on the surface, and optimizing molding conditions to enhance flowability, the appearance quality was improved. In addition, since minor changes in cross-sectional shape occurred due to differences in heat shrinkage rates associated with the base resin change, countermeasures such as revising the design specifications were implemented. When applying recycled carbon fibers, it is necessary to consider not only the effects of the recycled carbon fibers themselves but also other factors such as the characteristics of the base resin and molding conditions.

Figure 7　Appearance quality of injection-molded part using recycled carbon fibers

4.4 Review

The above descriptions reported on the technological issues encountered when applying recycled carbon fibers and their solutions. For some products, virgin carbon fibers can be simply replaced with recycled carbon fibers, but for others, as mentioned in this report, various adjustments may be necessary. However, reduction in strength can be compensated for by increasing the fiber content rate, and the appearance quality can be improved by optimizing the resin and molding conditions. Furthermore, even after implementing these measures, it was confirmed that an apparent price advantage over virgin carbon fibers can be maintained. While momentum for sustainability-conscious manufacturing grows annually, many cases in which higher costs cannot be tolerated also exist. The authors hope that the case study described in this report, which required approximately two and a half years of verification from start to market introduction, will serve as a reference example of the achievement of both sustainability and economic viability.

5. Conclusion

Looking back on this initiative, it can be considered the success factor that, with the cooperation of the Chubu Bureau of Economy, Trade and Industry, all stakeholders, including the waste material generator, recycling partner, resin manufacturer, and end user, shared the required specifications and cost targets from the early development stages and collaborated toward the targets from the perspective of overall supply chain optimization. In particular, for reliability and quality stability, which are issues with recycled carbon fibers, a certain level of waste material quality could be guaranteed based on MHI's expertise cultivated in the aerospace field, and for the quality and cost targets of recycled carbon fibers, consistent quality and low prices could be provided by setting unique quality control requirements utilizing insights gained from consumer products. This can be regarded as a good example of achieving a successful role assignment within the supply chain that leveraged the characteristics of each stakeholder.

This initiative was also highly valued by Boeing, one of MHI's customers, and was exhibited at the Sustainability Forum 2022 (**Figure 8**). Furthermore, MELCO is expanding its application, and has successfully applied recycled carbon fibers to the lower case of canister-type vacuum cleaners (**Figure 9**) by utilizing existing molding dies without additional initial investment. However, the amount of recycled carbon fibers used for product commercialization is small compared to the volume of waste materials generated during aircraft manufacturing. Furthermore, the issue of not reaching the batch quantities required by resin manufacturers is still in place. Taking this achievement of product commercialization as an opportunity, MHI will continue to aim for the expansion of the recycled carbon fiber market and strive to contribute to a sustainable society.

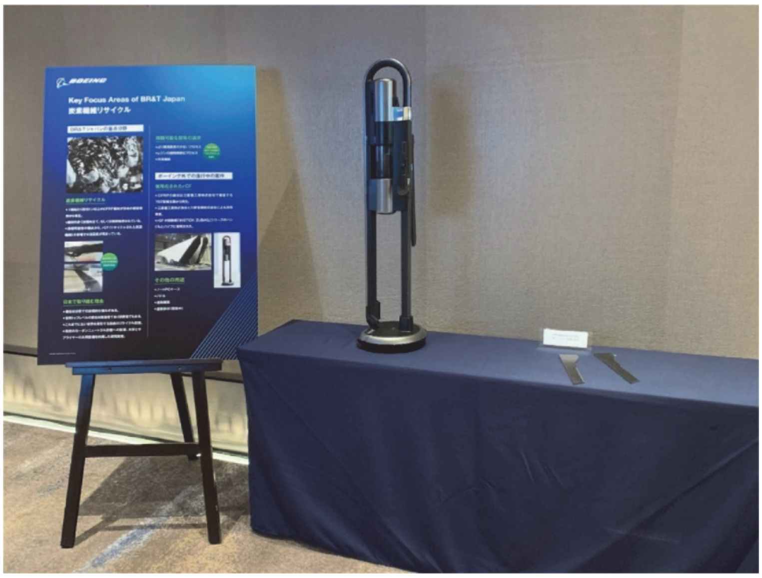

Figure 8 Exhibition at Sustainability Forum 2022

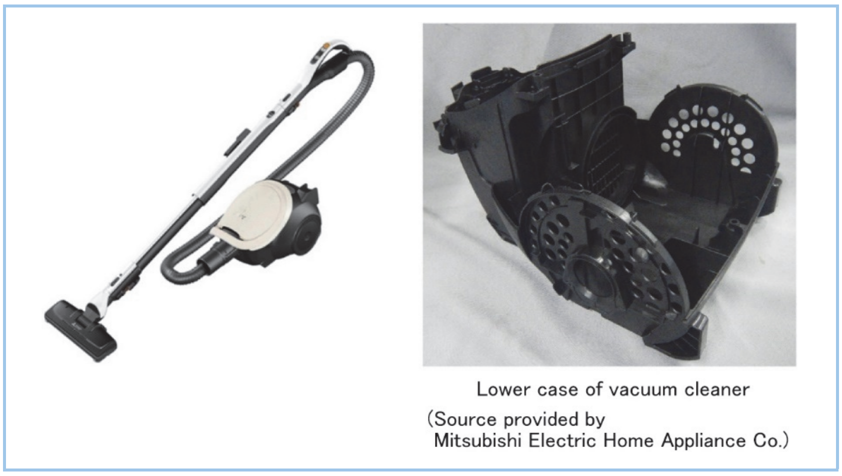

Figure 9 Mitsubishi Electric Corporation home vacuum cleaner TC-GS2E5

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