THE DEVELOPMENT OF NOVEL CARBON-FIBER-REINFORCED STAMPABLE THERMOPLASTIC SHEETS

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Abstract

We have developed a new thermoplastic sheet for press-molding composites with in-plane randomly oriented and dispersed carbon fibers. This press sheet shows superior composite properties because the fiber lengths are easily controlled, and it possesses a specific mechanical characteristics because of its long fiber length. For example, by controlling the interface property between carbon fiber and the matrix, the impact strength improves extremely. Furthermore, this press sheet has a good formability, and complex-shaped components, such as rib structures, are easily manufactured without significant mechanical property reductions.

1.Introduction

Carbon-fiber-reinforced plastics (CFRP) are well known for their excellent mechanical properties and weight reduction potential. They are widely applied in aerospace, sports, and other industrial fields. Aerospace industries in particular are aggressively adopting CFRP because fuel efficiency is critical for both reducing environmental loads and for economic benefits. The body of the newest airplane, the Boeing 787, is composed of about 50wt% CFRP and is expected to reduce engine power requirements by 35%. Automotive industries have also started adopting CFRP in some car parts, but currently this trend is limited to luxury vehicles or high-class sports cars. Adopting CFRP in production vehicles requires high-cycle processes and recycling technology. In recent years, CFRP using thermo-plastics (CFRTP) on become attractive because of their high-cycle molding ability and recyclability.

Injection molding and compression molding are general methods of molding CFRTP. In these methods, discontinuous carbon fiber (CF) composites are frequently used for complex-shaped components having curved surfaces and rib structures. However, discontinuous fiber-reinforced plastic is usually much weaker than continuous fiber-reinforced plastic. Moreover, biased fiber orientation often becomes a quality control problem. To overcome these issues, a high-strength, isotropic CFRTP sheet was developed.

2. Concept

We chose polypropylene as the matrix resin because it is a lightweight and economical resin with outstanding water and oil resistance. The following points were considered important in developing the new CFRTP sheets.

1) Controlling fiber length and orientation.
2) Homogeneous dispersion of carbon fiber.

3) Impregnating CF mat with thermoplastic resin.

Short-fiber CFRP usually exhibits poorer mechanical properties due to matrix breakage or interfacial debonding (Fig. 1). However, short-fiber CFRP enables forming complex-shaped products.

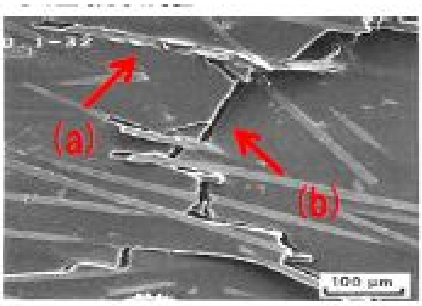

Fig. 1. (a) Interfacial debonding (b) Matrix breakage

Fiber orientation causes anisotropic characteristics and warping of molded products. Homogeneous fiber dispersion is important for achieving the full carbon fiber potential. Well-dispersed fibers may prevent matrix cracks from growing. Additionally, a bundle of fibers could break easier than a single fiber around the end of the fiber. A good fiber dispersion also has better visual appearance.

To develop high-performance materials compatible with good formability, it is important to control CF length, orientation, and dispersion.

Thermoplastic resin has difficulty impregnating the CF mat due to its high melt viscosity. Therefore, stampable CFRTP sheet needs high temperatures and pressures in order to have a good impregnation. An efficient impregnation method will be needed for mass production.

3. Development of new CFRTP stampable sheet

3.1 Material production

The CF mats can be produced from dry-laid (carded) or wet-laid webs. CF strands are dispersed individually in this mat (Fig. 2). Extruded polypropylene resin films and CF mats were laid up and melt-pressed to produce CFRTP stampable sheet (Fig. 3). The specific pressure required for impregnation varies depending on the fiber volume fraction (Vf), material thickness and resin viscosity. One-millimeter-thick polypropylene CFRTP sheet requires less than 3MPa of specific pressure in 200℃ melt-pressing conditions.

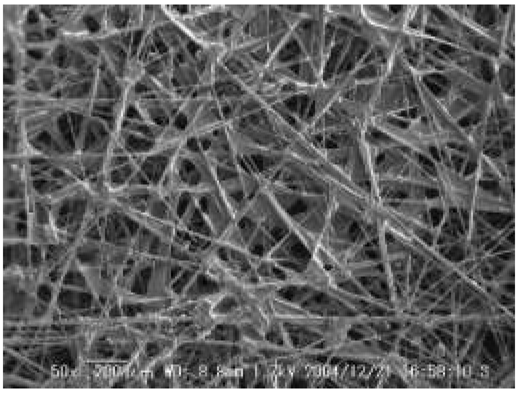

Fig. 2. Carbon-fiber mat

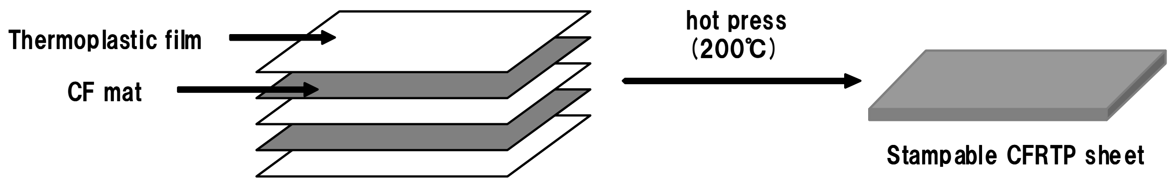

Fig. 3. Preparation of CFRTP stampable sheet (laboratory scale)

Considering continuous productivity, double-belt press lamination is a suitable process for impregnation. A double-belt press is a laminating machine having two flat moving vertical belts. Stacked materials are pressed between these moving belts while heated and a laminated sheet is manufactured continuously (Fig. 4).

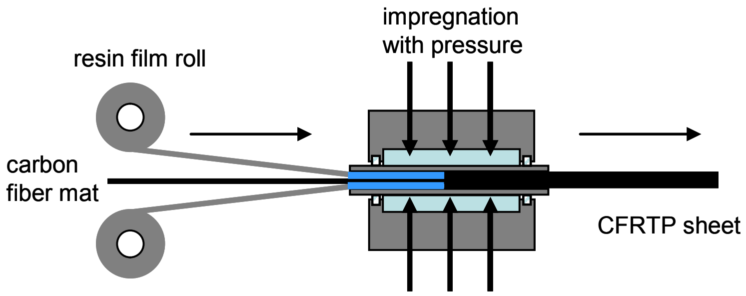

Fig. 4. Preparation of CFRTP stampable sheet (continuous production)

3.2 Fiber length controlling

We estimated the relationship between fiber length and tensile strength by an analytical technique[1]. The analytical results are confirmed by the experimental data shown in Fig. 5.

In the case of polypropylene matrix, longer fiber lengths were required to obtain a similar tensile strength than the thermoset (epoxy) matrix composite[1]. Based on this, we controlled the appropriate fiber length depending on the situation.

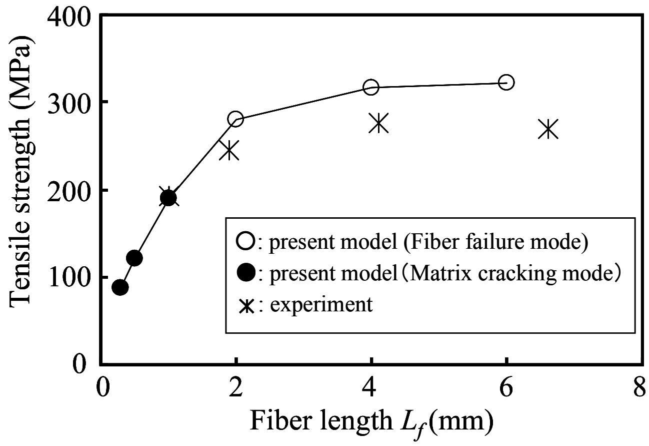

Fig. 5. relationship between fiber length and composite strength (Vf 17%)

3.3 Impact strength improves extremely by interfacial controlling

Adopting acid-modified polypropylene is known to improve interfacial strength[2]. Additionally, we developed a new interfacial layer that works as adhesive agent (Fig. 6), and so we could make the CFRTP flexural strength higher (Fig. 7)[3].

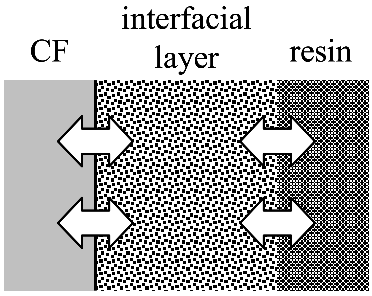

Fig. 6. Image of interfacial layer

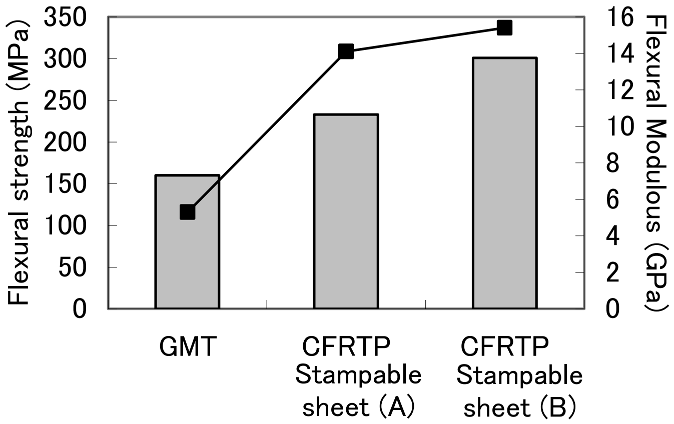

Fig.7. Flexural properties of the stampable sheet (Vf 20%)
(A): controlled for high impact strength
(B): controlled for high flexural strength

Interfacial properties can be controlled by adjusting the surface treatment, interfacial layers and matrix properties. The new CFRTP sheets will be designed with a wide variety of mechanical properties to meet these requirements.

For example, we designed interfacial property for high impact strength, and we obtained the new stampable sheets with high impact strength. (Fig. 8)

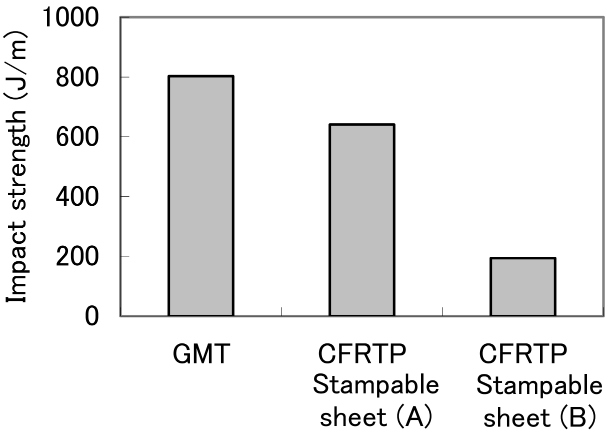

Fig. 8. Impact strength of the stampable sheet (Vf 20%)
(A): controlled for high impact strength
(B): controlled for high flexural strength

4. Formability and mechanical property of a rib structure

4.1 Formation of a rib structure by stamping press

The CFRTP sheets are suitable for stamping presses. The stamping press method forms preheated sheets using a mold that is cooled. It is suitable for car manufacturing because it is possible to achieve low cycle times (about 1min).

A stamping press for this CFRTP sheet was developed using an integrated press system (a 500t press with an automatic transfer line and a preheating system).

We tried to form rib structures shown in Fig. 9, so we could examine the formability and mechanical properties. During the experimental program we assessed the influence of the molding pressure on the formability. Our goal was to obtain a final product, which was filled to the top of the rib with fibers.

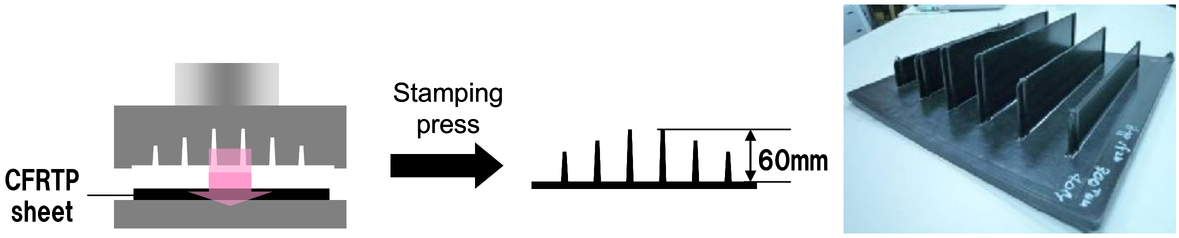

Fig. 9. Formation of the rib structure and molded product

The required molding pressure to achieve good formability depends on the volume fraction of carbon fiber (Vf). In the case of Vf 20%, higher pressure is required to achieve a good quality. Reducing the Vf reduces molding pressures dramatically..

4.2 Vf and flexural property of the rib structure

We evaluated the Vf and flexural properties of the rib structures, the mechanical properties of the rib structures have potential to change by the flowage when they are formed. The specimens are prepared by cutting the rib in axial directions (A.D.) and in transverse directions (T.D.) with the flow direction (Fig. 10).

The results are shown in Fig. 11. Vf was similar to the flat CFRTP sheets, while the flexural properties were maintained at about 90% levels in A.D., and at about 60% levels in T.D..

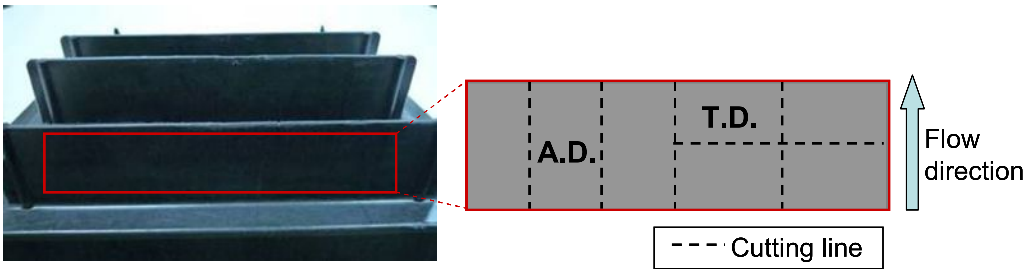

Fig. 10. Preparing the specimens

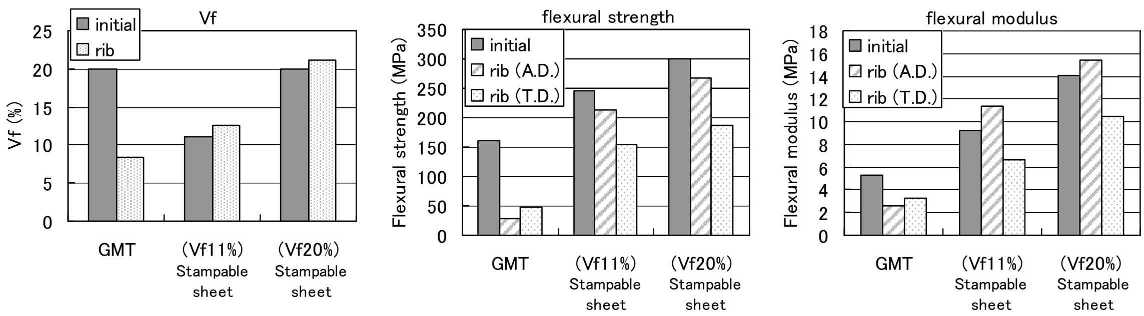

Fig. 11. Vf and flexural properties of the rib structure

5. Conclusion

A new high-performance stampable polypropylene CFRTP sheet has been developed. This sheet was found to be suitable for press molding and effectively reduced the weight of molded products.

6. Acknowledgement

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