# NOVEL CARBON-FIBER-REINFORCED STAMPABLE THERMOPLASTIC SHEET WITH HIGH STRENGTH

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## 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 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%. Reducing weight has been also an important mission for automotive industries. Resin or FRP parts have been developed, but CFRP application is limited to luxury vehicles or high-class sports cars.

Adopting CFRP in automotive industries requires high-cycle process and recycling technology. In recent years, CFRP using thermo-plastic matrices (CFRTP) has become attractive because of its 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 surface 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

The following points were considered important in the developing the new CFRTP sheet.

1) Controlling fiber length and orientation.
2) 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. Fiber orientation causes anisotropic characteristics and warping of molded products.

Homogeneous fiber dispersion is important for achieving carbon fiber potential. Well-dispersed fiber may prevent matrix cracks from growing. Additionally, a bundle of fiber could break easier than a single fiber around the end of the fiber. Good fiber dispersion also has better appearance.

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

Thermoplastic resin has difficulty penetrating the CF mat due to its high melt viscosity. Stampable CFRTP sheet needs high temperature and pressure for impregnation. An efficient impregnation method will be needed for mass production.

## 3. Production of new CFRTP stampable sheet

CF mat can be produced from drylaid (carded) or wetlaid webs. Fiber length in the web is 6 to 10mm. CF strands are dispersed individually in this mat (Fig. 2). Extruded thermoplastic resin films and CF mat were laid up and melt-pressed to produce CFRTP stampable sheet (Fig. 3). The specific pressure required for impregnation varies depending on the material thickness and resin viscosity. One-millimeter-thick polypropylene CFRTP sheet requires less than 3MPa of specific pressure in 200□ melt-pressing conditions.

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 with heating, and laminated sheet is manufactured continuously (Fig. 4). An isobaric double-belt press is suitable for this process. When a fixed-roller double-belt press was used, the CF mat swelled in melted resin, resulting in a wrinkled product.

Thickness can range from 0.2 to 3mm, and CFRTP stampable sheet is supplied as a roll or sheet (Fig. 5). Various resins are available including polypropylene (PP) and 6-nylon (NY). The standard volume fraction of carbon fiber (Vf) is 20%, but it can be varied from 10 to 30%.

## 4. Features

Figure 5 presents the properties of stampable CFRTP sheet (polypropylene or 6-nylon). CFRP (prepreg) indicates continuous fiber CFRP using thermoset (epoxy) resin with isotropic lamination. CFRP stampable sheet exhibits higher bending strength and lower density than other FRP sheet (SMC, GMT). This means CFRP stampable sheet has benefits of high specific strength (in bending mode) and superior weight reduction.

Injection-molded CFRP (average fiber length less than 0.2mm) has lower bending strength and modulus. These results suggest that our concept (controlled fiber length and dispersion) works effectively.

Steel exhibits high strength and modulus, but its density is seven times that of CFRTP.

It is also worth noting that stampable CFRTP sheet has high specific strength and modulus that exceed 80% that of continuous carbon fiber CFRP (prepreg). This indicates the effective contribution of carbon fiber to composite strength.

Figure 7 plots a map of specific strength and modulus. The upper right portion of the map indicates higher weight reduction. The new CFRTP stampable sheet exhibits three times the specific rigidity and six times the specific strength of steel.

## 5. Press moldings

Stampable CFRTP sheet is suitable for stamping presses. The stamping press method forms preheated sheet using a mold with cooling. It is suitable for car manufacturing because it facilitates 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).

The molded product is depicted in Fig 8. Ribs, deep drawings, and curved surfaces can be formed successfully. Molding time (less than 2 minutes) is very advantageous compared to the thermosetting resin materials (usually more than 10 minutes).

This sheet becomes flowable during press molding at high temperature or pressure. However, it is not suitable for high-flow molding because uniform quality could be sacrificed.

## 3. Conclusion

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

## 4. Acknowledgments

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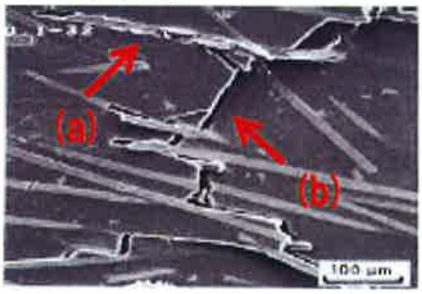


Fig. 1 (a) Interfacial debonding. (b) Matrix breakage.

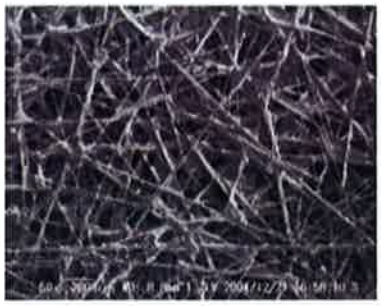

Fig. 2 Carbon-fiber mat

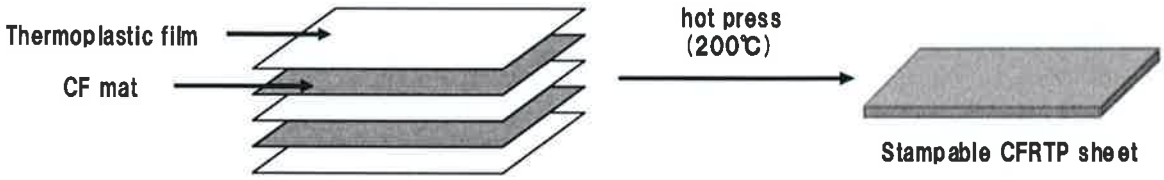


Fig. 3 Preparation of CFRTP stampable sheet (laboratory scale).

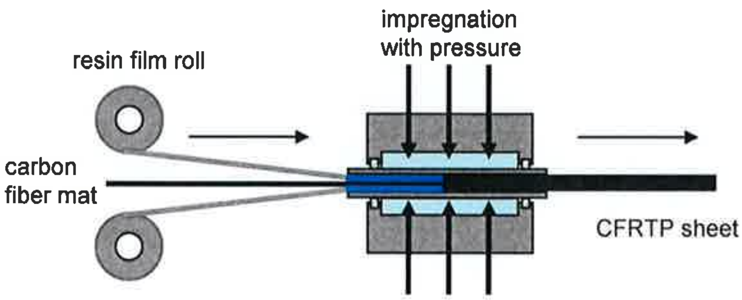


Fig. 4 Preparation of CFRTP stampable sheet (continuous production).

Fig. 5 Stampable CFRTP sheet.

| | | CFRTP stampable sheet | | CFRP (prepreg) | CFRP (injection) | CF-SMC | GMT | Steel | Aluminum |
|---|---|---|---|---|---|---|---|---|---|
| Matrix resin | | PP | Ny6 | epoxy | PP | VEs | PP | - | - |
| Vf | [%] | 20 | 20 | 57 | 20 | 50 | 25 | - | - |
| Density ( ρ ) | | 1.08 | 1.26 | 1.56 | 1.08 | 1.45 | 1.24 | 7.8 | 2.7 |
| Flexural strength ( σ ) | [MPa] | 300 | 450 | 950 | 154 | 340 | 145 | 420 | 160 |
| Flexural modulus (E) | [GPa] | 14 | 16 | 46 | 11 | 29 | 7 | 200 | 71 |
| **Specific strength ($\sqrt{\sigma}/\rho$)*** | | **16.0** | **16.8** | **19.8** | **11.5** | **12.7** | **9.7** | **2.6** | **4.7** |
| **Specific rigidity ($\sqrt[3]{E}/\rho$)*** | | **2.2** | **2.0** | **2.3** | **2.1** | **2.1** | **1.5** | **0.7** | **1.5** |
| Isotropic properties | | ○ | ○ | ○ | × | △ | △ | ○ | ○ |

* bending mode

Fig. 6 Properties of stampable CFRTP sheet and other materials.

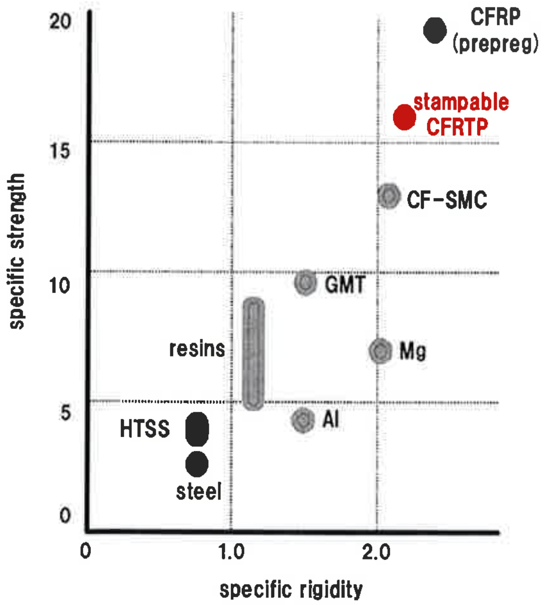


Fig. 7 Specific strength and modulus map (bending mode)

Fig. 8 Molded product (500×300mm).