Effect of interface bonding process on bending strength in CFRP/metal hybrid composites

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Abstract. Recently, vehicle parts such as center pillars and impact beams used in automobiles have been requiring materials that satisfy both high strength and impact absorption. Therefore, in this study, the applicability of the forming process of CR340 (cold rolled steel sheet)/CFRP Hybrid Composites which are a bonded material of cold rolled steel sheet having excellent formability and carbon fiber prepreg having high strength and high collision absorption in the vehicle parts was investigated. Hybrid composites are fabricated by stacking carbon fiber reinforced plastic (CFRP) prepreg on a cold rolled steel sheet (CR340) with Zn coating. Bonding materials were used at the interface between the CFRP prepreg and steel sheet. In addition, in the case of CR340/CFRP Hybrid composites which are made by bonding CFRP prepreg to the surface of press-formed CR340 material, it is impossible to manufacture complicated shapes due to an interfacial bonding separation phenomenon between the reinforcement and steel sheet. An adhesive agent developed by this research team was applied on the cold rolled sheet between CFRP and CR340 materials to enable the blank production of CR340/CFRP Hybrid composites. The heating time and temperature required for bending test were set similar to the curing curve of the CFRP prepreg. The surface roughness of steel materials is important in terms of their tensile strength and bending strength. In this study, the steel sheet used was cold rolled 340 with Zn coating without surface roughness treatment for application to mass production in industry. This study investigates the properties of a CFRP/metal hybrid composite material. The hybrid was fabricated after spreading a developed binder on high-strength steel sheets (CR980) prepared by cold rolling and pressing. During the preparation of the CR980/CFRP hybrid composite, and its mechanical characteristics were investigated through bending, tensile, and lap shear adhesion test experiments.

1. Introduction
There is now a demand for high-fuel-efficiency and lightweight vehicle in the automotive industry. As gas mileage has received increasing attention because of environmental regulations and high oil prices, weight reduction has become a necessity rather than an option for automobile manufacturers [1]. Recently, the weight reduction of automobiles has become a hot topic as environmental regulations and gas mileage regulations have been reinforced. Thus, there are many studies on weight reduction using aluminium alloy, magnesium alloy, titanium alloy, and high strength steel (HSS) in place of steel materials [2]. In addition, advanced high strength steel (AHSS) and composite materials are used to reduce weight. One of these composite materials is carbon fibre reinforced plastic (CFRP), which has a higher strength-to-weight ratio and rigidity than steel materials while being lighter than aluminium. Therefore, CFRP must be studied to reduce the weight of automobiles.

Currently, there are many studies being conducted on fibre reinforced plastic (FRP) [3] and its machining [4]. There are also many ongoing studies on the use of pre-impregnated carbon fibre reinforced plastic (CFRP prepreg) [5]. Prepreg is intermediate material of FRP, wherein resin, which is a matrix, is pre-impregnated into fibres.

Yanagimoto et al. researched formability using a dummy sheet for embossing (shallow drawing), hat bending, and V-bending experiments. In their experiments, unidirectional CFRP prepreg, which is one of the CFRP prepregs, was hardened using various laminating methods. Uriya et al. conducted a V-bending experiment and studied the subsequent elastic recovery [6]. In addition to the above, studies using carbon fibre reinforced thermoplastic (CFRTP) are also in progress. Isogawa et al. used a hemispherical punch in their research [7], while Behrens et al. used deep drawing [8]. CR340LA is a material used in automobile pillars, which play a very important role in the safety and protection of the passengers by absorbing the shock during a car crash. However, CFRP has mechanical properties that vary according to the fibre orientation and forming processes. Because of its low elongation and fracture toughness, there are many limitations to its application in automobile parts. Thus, many studies are being performed to overcome such problems using hybrid CFRP-metal composite materials.

2. Experiment procedure

2.1. Tensile and bending test

2.1.1. Preparation of specimen

Tables 1 and 2[9] show the properties of the carbon fiber composite material and steel sheet(CR340) used in the test.

In this study, the fabric style with epoxy in a liquid state is plain weave-type CFRP prepreg using automobile part fabrication. This weave-type was used as it has higher strength as well as low thickness compared to stain and twill weaves.

**Table 1.** Properties of plain weave carbon fabric prepreg (CF3327EPC, HANKUK CARBON).

| Construction | Carbon fibre weight (gr/m2) | Resin weight (gr/m2) | Resin content (%) | Total weight (gr/m2) | Fabric thickness (mm) |
|--------------|-----------------------------|----------------------|-------------------|----------------------|----------------------|
| Plain        | 205                         | 150                  | 42±2              | 352                  | 0.27±0.050           |

**Table 2.** Properties of carbon fibre composites material (Fiber/Epoxy resin 120°C cure) (HANKUK CARBON Co. Ltd) [9] and steel (CR340).

| Type               | Tensile strength (MPa) | Young modulus (GPa) | Elongation (%) | Density (g/cc) | n  |
|--------------------|------------------------|---------------------|----------------|----------------|----|
| 3K Carbon fibre    | 1500                   | 135                 | 1.05           | 1.6            | -  |
| CR340LA            | 396                    | 496                 | 27             | 7.6            | 0.18 |
A 25-ton material testing system (MTS) device was used in this experiment for the preparation of the specimen. The specimen was prepared by varying the number of CFRP laminations with the compression moulding method and curing for 30 min while maintaining a pressure of 0.5 MPa and temperature of 140°C. There are many methods for producing vehicle parts using CFRP. It is recommended that production methods appropriate for each vehicle part be based on KS M 3713:2012 [10].

In addition, the standard guide for CFRP testing methods is ASTM D4762 [11].

2.1.2. Tensile and bending test of CFRP
ASTM D638 and D3039/D3039M were referred to for the CFRP tensile testing method [12]. A 10-ton MTS device was used for the tensile test, with a displacement rate of 2 mm/min applied in the test. Caution is required when testing a composite material because it is very sensitive to the strain rates [13].

The use of an extensometer is not recommended because the high strength of the composite material compared to its low elongation causes a great impact and can overload the testing equipment. ASTM D790, D7264/D7264M, and KS M ISO 14125:2012 were referred to for the CFRP bending testing method [14, 15, 16].

The 25-ton MTS device was used for the bending test. In the case of the bending test, the span-to-thickness ratio was used for the experiment, with a displacement rate of 1 mm/min. Figure 1 briefly describes the specimen preparation and testing methods for the tensile and bending tests, while figure 2 shows the equipment used.
2.2. Lap shear adhesion test

For bending strength, the CR340LA/CFRP hybrid composite, the interfacial shear strength of the bi-material is also important. CR340LA is one of the materials used for automobile body parts [17]. It is also used for the automobile pillar. Galvanized CR340LA (GI CR340LA) is used as the steel in automobiles to prevent corrosion. It is reported that galvanizing above a certain thickness is considerably effective at preventing corrosion [18]. Preventive effects against the galvanic corrosion that may be present with hybrid composite materials can also be obtained [19]. There are many studies being conducted on the bonding relationship between CFRP and steel [20, 21].

![Figure 3. Schematic diagram of lap shear adhesion test.](image)

Here, a lap shear adhesion test was conducted for the interfacial shear strength, which is briefly described in figure 3. Four sheets of CFRP were laminated to prepare a specimen with the same thickness as the CR340LA. Then, a dummy sheet material was added to the laminated CFRP to prevent the separation of the bi-material and deformation of the carbon fibre during the compression moulding. After it was cut to an appropriate specimen size, aluminium tabs were attached to prevent any moment that could be present in the specimens due to the misalignment of the pulling axis during the lap shear adhesion test. ASTM D5868 and D3168 were referred to for the test method [22, 23].

3. Experiment results and discussion

3.1. Results of tensile and bending test of CFRP

3.1.1. Results tensile and bending test of CFRP

![Figure 4. Tensile strength and displacement of CFRP according to number of CFRP prepreg laminating.](image)

![Figure 5. Ultimate tensile strength and applied force of CFRP according to numbers of CFRP prepreg laminating.](image)
Figure 4 and 5 show the results of the tensile test. As presented, it can be observed that the tensile strength increases as the number of laminations increases. The average tensile strengths were 520.717, 578.511, and 592.317 MPa. For every condition, 10 specimens were prepared, for a total of 30 specimens used in the experiment. However, because of the characteristics of composite materials, many of the tests failed, and such failed tests were excluded from the results. The types of failures in the tensile tests are shown in detail in the previously noted ASTM D3039/D3039M [12].

![Figure 6. Flexural strength and displacement of CFRP according to number of CFRP prepreg laminating.](image)

![Figure 7. Ultimate flexural strength and Applied force of CFRP according to numbers of CFRP prepreg laminating.](image)

The results of the bending test are shown in figure 6 and 7. In contrast to the tensile test results, it can be observed that as the number of laminations increases, the results decrease. In addition, the average flexural strengths were 850.476, 823.432, and 764.780 MPa, according to the number of laminations. In the case of the bending test, 12 specimens were prepared for every condition for a total of 36 specimens used in the experiment. Unlike the tensile test, all the bending tests were successfully conducted without failures.

3.1.2. Results of lap shear adhesion test

![Figure 8. Interfacial shear strength (τ) and load (F_s) of CFRP to CR340LA with or without zinc coating.](image)

![Figure 9. Shear load (F_s) and displacement (δ_s) according to surface conditions of CR340LA with or without zinc coating.](image)
Figure 10. Shear strength ($\tau$) and displacement ($\delta$) according to surface conditions of CR340LA with or without zinc coating.

Figure 8, 9, and 10 show the shear strengths from the lap shear adhesion test of the CR340LA according to the presence or absence of a galvanized coating. When an automobile pillar is produced from the CR340LA/CFRP hybrid composite, the CR340LA corrodes at a faster rate than the galvanized CR340LA because of the galvanic corrosion between the two materials. Therefore, a galvanized material is sometimes used.

4. Conclusion
In this study, Effect of Interface Bonding Process on Bending Strength in CR340LA/CFRP hybrid composite material. Based on the changes in various mechanical properties in relation to the number of laminated layers of CFRP, and the lap shear adhesion test results for CR340LA and CFRP, the following conclusions were reached in this study.

(1) When producing a CFRP part using the compression moulding method, the drawn part possesses different mechanical properties according to the number of laminations. The tensile strength increases with the number of laminations, whereas the bending strength decreases.

(2) Because of the increased outflow of epoxy as the number of laminations increases, the epoxy volume fraction decreases, and the carbon fibre volume fraction increases. The factor that most affects the tensile test is the carbon fibre. The results obtained are the results with an increased carbon fibre volume fraction. In the case of the bending test, the results obtained are the results for the decreased epoxy volume fraction that transfers stresses between the carbon fibres.

(3) The shear strength of the CR340LA and CFRP was 13.73 MPa, and that for the CR340LA with the zinc coating and CFRP was 11.79 MPa. Thus, the shear strength of the CR340LA and CFRP was higher than that of the CR340LA with the zinc coating and CFRP.

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