# COMPRESSION AFTER IMPACT PROPERTIES OF HYBRID COMPOSITE MATERIALS

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## *Abstract*

*The advanced composite materials, such as graphite fiber reinforced plastics, had lower density, higher strength, higher stiffness, less maintenance than the conventional aluminum alloys. However, the residual compressive strength of graphite fiber reinforced plastics, after out-of-plane low-velocity impact damage was lower than expected due to the interlaminar delamination and so on. In order to go across over the disadvantages of composite materials, a hybrid composite material, with titanium alloy foil and graphite fiber reinforced plastics, was proposed and evaluated the mechanical properties in this paper. The strength of the hybrid composite was slightly higher than that of the pure graphite composites, but the strength-to-weight-ratio was not larger than that of the pure composites. The bonding between titanium foil and the graphite composite seemed to be enough, but further investigation will be needed.*


## 1 Introduction

For developing the commercial transports with the advanced composites materials, it is required to develop and apply high performance polymeric composite materials which will be durable for long term severe environments and more tolerable against impact damages. The advanced composite materials, such as graphite fiber reinforced plastics, had lower density, higher strength, higher stiffness, less maintenance than the conventional aluminum alloys. However, the residual compressive strength of graphite fiber reinforced plastics, after out-of-plane low-velocity impact damage was lower than expected due to the interlaminar delamination and so on. The other weak point was the long term durability under high temperature environment. The aircraft-grade epoxy resin system was oxidized under high temperature environment, and it decreased the weight due to the volatilization of low-molecular-weight oxidation product.

In 1990's, the Boeing and other companies with several universities in the U.S.A. tried to use the hybrid composites, "Ti/Gr" in the supersonic transport project [1]. That hybrid composite materials were almost same portion of the composite materials and the titanium foils [2], so it was quite heavier than the composite materials. The Airbus was applied the GLARE, which is consist from aluminum alloy foils and glass fiber reinforced plastics, to their new aircraft, A380 [3]. The glass fiber reinforced plastics had a higher failure strain, but lower stiffness than the graphite reinforced plastics. It seemed that the advantages of the advanced composite materials were not applied in both cases.

In order to go across over the disadvantages of composite materials, a hybrid composite material, with titanium alloy foil and graphite fiber reinforced plastics, was proposed and evaluated the compression after impact properties in this paper.

## 2 Hybrid Composite Materials

### 2.1 Description of Hybrid Composite Materials

The hybrid composite material in this paper was consisted of titanium alloy foils and graphite fiber reinforced plastics. The graphite fiber reinforced plastics were light weight and had high strength. The titanium foils were almost triple heavier, but had high stiffness and good heat resistance.

In order to reduce the total weight of hybrid material, the usage of titanium alloy foil was wanted to be minimized. The hybrid composite materials in this paper had only two titanium alloy layers, which was located in most outer surface. The titanium alloy foil isolated the graphite fiber reinforced plastics from the external oxygen, as like as a coating, so the graphite fiber reinforced plastics were expected to be less oxidized.

### 2.2 Sample Preparation

The middle modulus graphite fiber, IM600 and the thermoplastic polyimide resin system, PIXA-M, by Mitsui Chemicals, Inc. was selected in this study for heat resistant composite materials. The titanium alloy foil was Ti-15V-3Cr-3Sn-3Al and a nominal thickness of foil was 0.13 mm.

First of all, the surfaces of titanium alloy foils were chemically treated for the good bonding. The titanium alloy foils and the thermoplastic sheets were laminated together one by one, and they were heated and pressurized into the hybrid composite material. The additional bonding film did not used in this study. The stacking sequence of the graphite fiber reinforced plastics was quasi-isotropic, $[45/0/-45/90]_{4S}$. The volume fraction of graphite fiber was between 45% and 55%. Table 1 shows the stacking sequences and the specific gravity (density) of the test specimens, which included the reference specimens with 0 and 3 titanium alloy foils.

The test specimens were cut from the plates and all edges were trimmed and polished to give straight lines with right angles and smooth surfaces. The dimensions of the test specimen were shown in Fig. 1.

Table 1. The stacking sequences and the specific gravity of the test specimens.

| name | Stacking Sequence | Thickness (mm) | Specific Gravity |
|---|---|---|---|
| 0Ti-32C-P | $[45/0/-45/90]_{4S}$ | 4.66 | 1.57 |
| 2Ti-32C-P | $Ti/[45/0/-45/90]_{4S}/Ti$ | 4.74 | 1.75 |
| 3Ti-32C-P | $Ti/[45/0/-45/90]_4/Ti/[90/-45/0/45]_4/Ti$ | 5.00 | 1.80 |

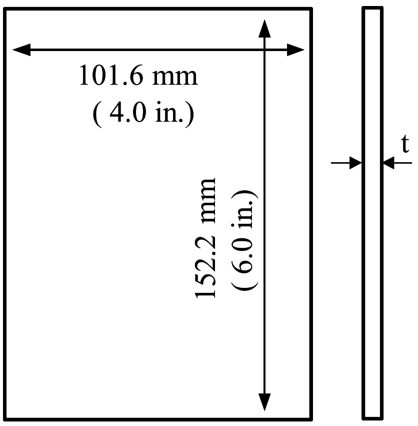


Fig. 1 Dimensions of the test specimens.

## 3 Compression After Impact Properties

### 3.1 Impact Properties

The specimens were impacted at room temperature by means of the impactor with a 15.9 mm (5/8 in.) dia. hemispherical tup at 2.22, 4.44 and 6.67 J/mm (1500in.-lb./in.). The out-of-plane impact damages were investigated by ultrasonic imaging system prior to compressive tests. The damage area was measured and examined by the ultrasonic C-scanning method with 15 MHz probe. Figure 2 shows the ultrasonic image of the impact damage. The results showed that the specimens had a circular projected damaged area in total. The back face of the specimens was observed with the optical camera as shown in Fig. 3. The titanium foil was expanded convexly and some cracks were observed. The front faces of the specimens were measured by the displacement sensor. Figure 4 shows the cross section of the front surface on the impact damges. The depth of the dent were measured. As the impact energy increased, the depth of the dent became deeper in general. However, it was difficult to determine the relationships between the depth of the dent and impact energies.

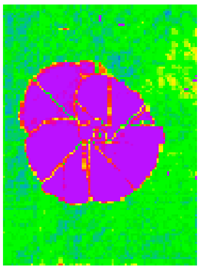

Fig. 2 Ultrasonic image of the impact damage (2Ti-32C-P, 6.67 J/mm).

Fig. 3 Back face of the specimens.

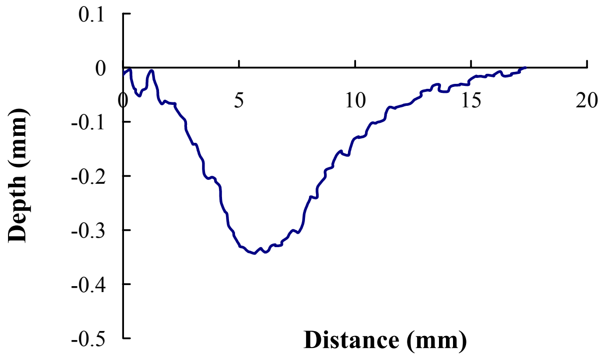

Fig. 4 Cross section result of the front surface on the impact damges.

## 3.2 Compressive Properties

The compressive tests were conducted on the INSTRON-type machine under displacement-controlled mode at the crosshead speed of 1.0 mm/min. at room temperature. A strain gauge was bonded on 25.4 mm (1 inch) far from the two edges of the specimens, according to the test method of SACMA SRM 2R-94. Figure 5 shows the test specimen with the fixture on the test frame.

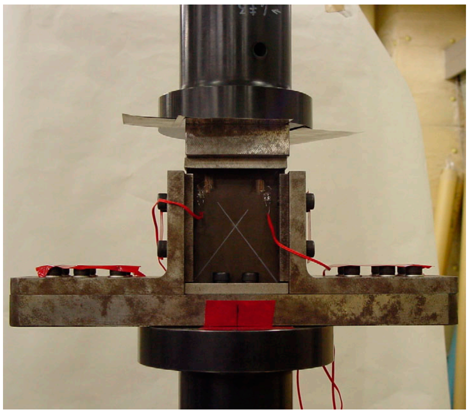
Fig. 5 Test specimen with the fixture set in the test frame.

As the displacement increased, the load increased linearly until the final fracture as shown in Fig. 6. The test specimens were fractured on the impact damage section. The delamination between the titanium alloy foils and the graphite composites were observed around the fracture area as shown in Fig. 7.

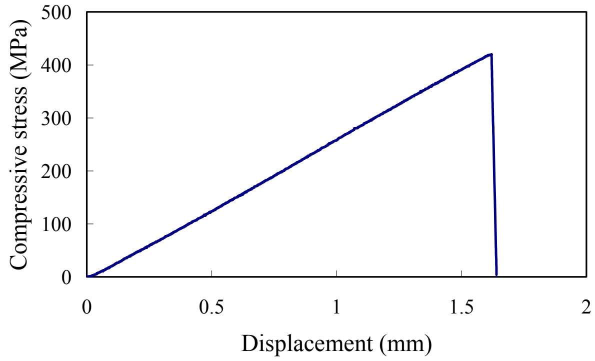

Fig. 6 Relationships between load and displacement (0Ti-32C-P, 6.67 J/mm).

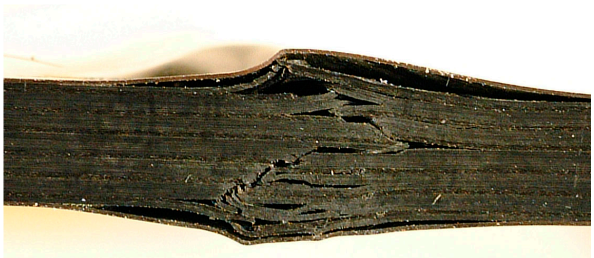
Fig. 7 Cross section view around the fracture (2Ti-32C-P).

The experimental results showed that the compressive strength of hybrid composites after impact damage with 6.67 J/mm was 317 MPa. This strength was slightly higher than that of the pure graphite composites, which was 308 MPa. Figure 8 showed that the relationships between compressive strength after imapct damage and the impact levels. In the small impact level, 2.2 J/mm, the compressive strength of the hybrid composites and the pure graphite composites showed the large differences. It seemed that the impact energy was consumed to the plastic deformation of the titanium alloy foil, and not transferred to the inner graphite composites.

Figure 9 showed that the relationships between compressive strength-to-weight ratio and the impact levels. The specific gravity of the hybrid composites was 10% larger than that of the pure graphite composites, so the compressive strength-to-weight-ratio of the hybrid composites was not larger than that of the pure graphite composites.

Figure 10 shows that the relationships between the compressive strength after imapact, 6.67 J/mm and the specific gravitiy. Also, the relationship between the compressive strength-to-weight-ratio and the specific gravity were shown in Fig. 11. As the specific gravity increased, the strength was slightly increased. The reason was that the strength of the titanium alloy is higher than that of the graphite composites. However, because the titanium alloy foils were almost triple heavier than the graphite composies, the strength-to-weight ratio was decreased.

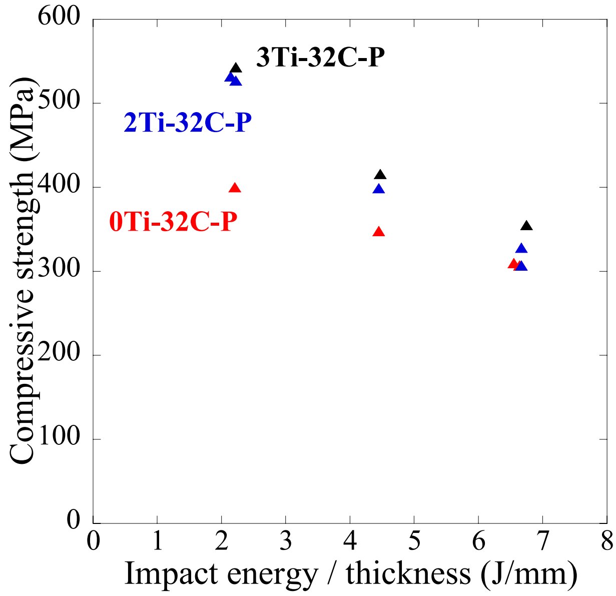


Fig. 8 Relationships between compressive strength after imapct damage and the impact levels.

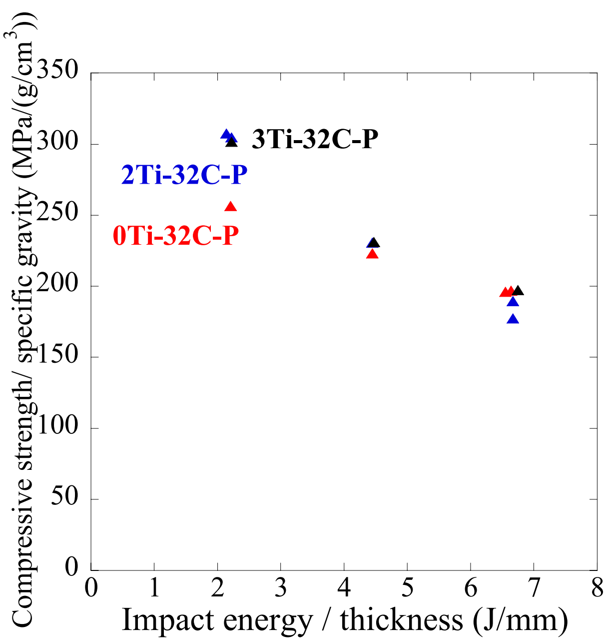


Fig. 9 Relationships between compressive strength-to-weight ratio and the impact levels.

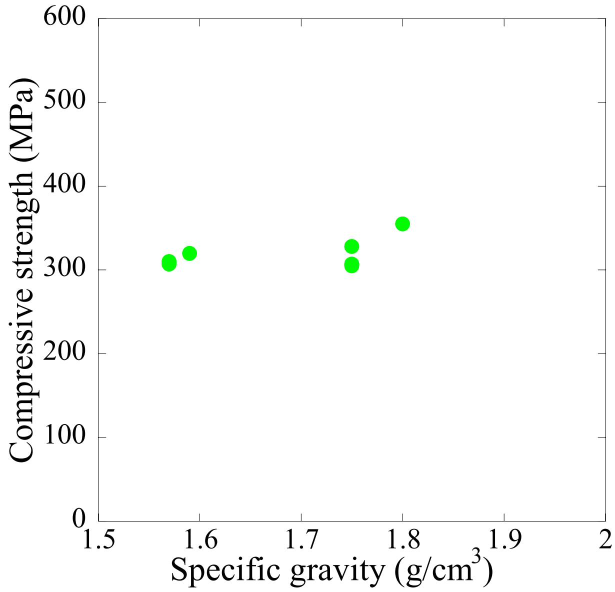


Fig. 10 Relationships between the compressive strength after imapact and the specific gravitiy (6.67 J/mm).

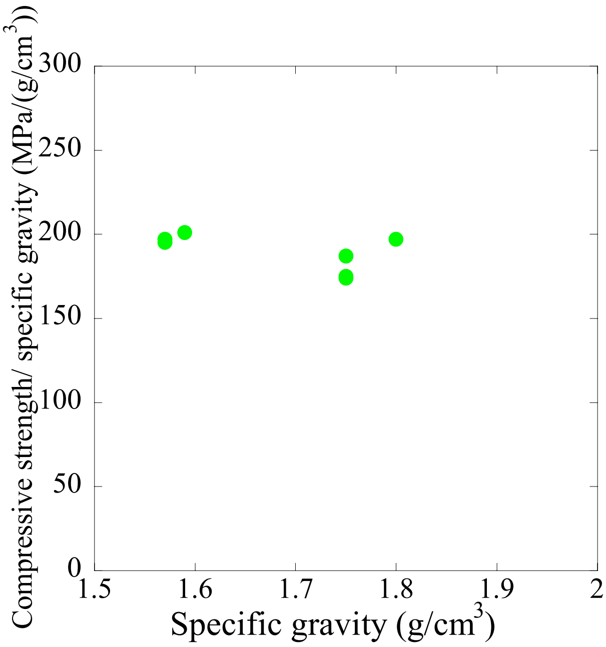


Fig. 11 Relationships between the compressive strength-to-weight-ratio and the specific gravitiy (6.67 J/mm).

## 4 Evaluation of Bonding

One of the keys of the hybrid composite materials was the boding between the titanium alloy foil and the graphite fiber reinforced plastics. The hybrid composite in this study did not use an additional bonding film. After peeling the titanium alloy foil from the base graphite composites, the bonding surface of the titanium alloy foil was observed by the scanning electrical microscope as shown in Fig. 12. Because some resin system were remaining on the surface of the titanium alloy foil, the interface bonding strength showed almost same strength of the resin system itself, but further investigation will be need.

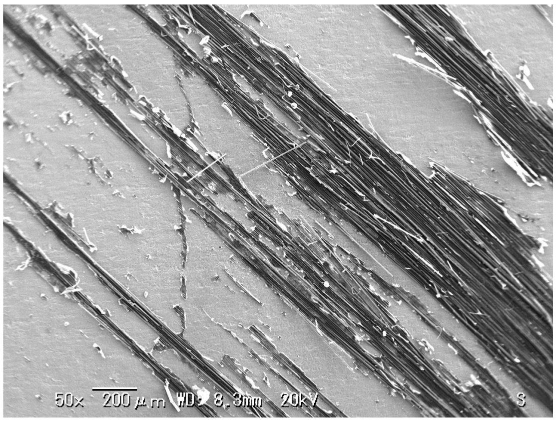

Fig. 12 The bonding surface of the titanium alloy foils.

## 5 Conclusions

The hybrid composite material, with titanium alloy foils and graphite fiber reinforced plastics, was proposed and evaluated the compressive strength after impact damages. The strength of the hybrid composite was slightly higher than that of the pure graphite composites, but the strength-to-weight-ratio was not larger than that of the pure composites. The bonding between the titanium foil and the graphite composite seemed to be enough, but further investigation will be needed.

## References

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