NEW DESIGN APPROACH FOR HIGH STIFFNESS AND HIGH IMPACT-ABSORBING STRUCTURE BY CARBON FIBER REINFORCED THERMOPLASTIC COMPOSITES

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Abstract

In the process of developing carbon fiber reinforced polypropylene (CF/PP), it was getting clear that the developed material has some important mechanical properties different from carbon fiber reinforced thermosetting composites (CFRTS). We investigated the mechanical behavior by static and dynamic flexural tests. In particular, observation by using a high-speed camera clarified a mechanism of its ductile feature. Those effective properties make it possible to construct a design concept of high stiffness and high energy-absorbing material which has hybrid structure composed of high stiffness part and high toughness part. It leads to a prospective design approach for vehicle structural frame members of the developed CF/PP.

1 Introduction

With the development of advanced material technologies for carbon fiber reinforced thermoplastic composites (CFRTP), which have improved the mechanical properties such as strength, stiffness and impact resistance, it has been expected to achieve significant light-weight body for mass production automobile by replacing the traditional metal body structure with the developing CFRTP body structure.

Complying with this trend, Japanese METI-NEDO project has developed a new type of advanced CFRTP, CF/PP, which is composed of surface-treated carbon fiber by Mitsubishi Rayon and modified polypropylene by TOYOBO, aiming to apply to the automobile main structural members for the purpose of significant reduction of vehicle weight [1][2]. The technological developments for the CF/PP itself and its molding process have potential to achieve high-productivity, low-cost and high-recyclability.

The main frame structural members of automobiles are required high energy absorption for collision safety and high stiffness for vehicle maneuverability. With increasing expectation of wide applications for the developed CF/PP, it is getting more and more important to guide a design method which balances high stiffness and high impact-absorbing.

In this study, focusing on the mechanical behavior of the developed CF/PP examined by static and dynamic flexural tests, we introduce a new design approach of hybrid structural composite material which satisfies both of high stiffness and high impact-absorbing, and discuss an effect about applying the designed material to structural frame members of automotive body structure.

2 Mechanical flexural behavior

2.1 Specimens and static 3-point bending test

At first in this study, the strain-stress relationship of CF/PP was examined by static 3-point bending test using universal testing machine (AUTOGRAPH by SHIMADZU) which can record the load-deflection curve. The schematic and picture of CF/PP specimen and bending test are shown in Fig.1. The specimen is cut from a laminate, in which a lot of chopped CF/PP tapes impregnated with polypropylene are randomly oriented in-plane. And, test result is shown in Fig.2. Here, for comparison, the graph also plots a strain-stress curve of CFRTS, sheet molding compound (CF-SMC) provided by Mitsubishi Rayon, composed of carbon fiber and vinylester resin. Both of chopped tape CF/PP and CF-SMC have the similar fiber reinforcement morphology which include equivalent volume fraction of the same type of carbon fibers (TR50S).

From test results, it was found that the flexural fracture behavior of chopped tape CF/PP is clearly different from that of CF-SMC. In the case of CF-SMC, as illustrated in Fig.2, the stress falls down immediately after reaching the maximum of the stress because of rapidly decrease of the flexural stiffness. On the other hand, the chopped tape CF/PP indicates relatively gradual decline after the maximum stress as shown in Fig.2. In other words, the developed CF/PP has its potential to have higher impact-absorbing than CF-SMC.

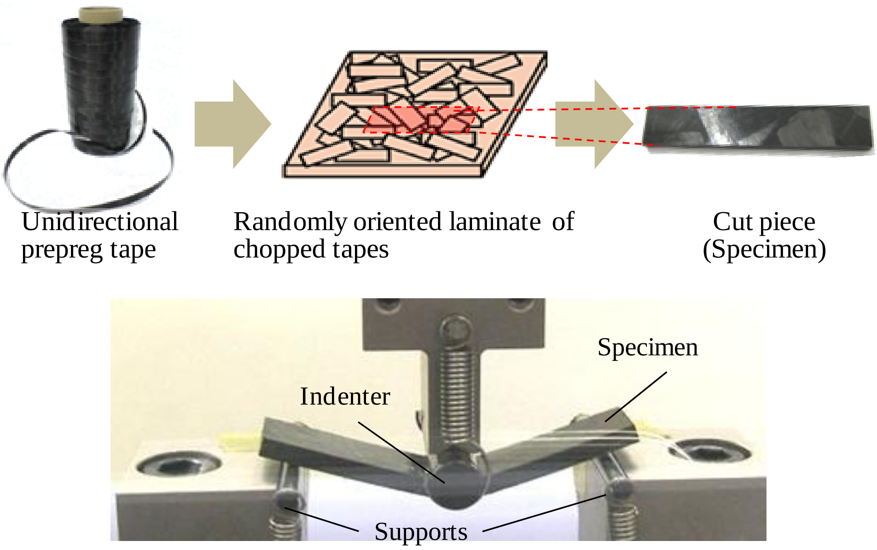

Figure 1. Chopped tapes specimen (upper) and 3-point bending test (lower).

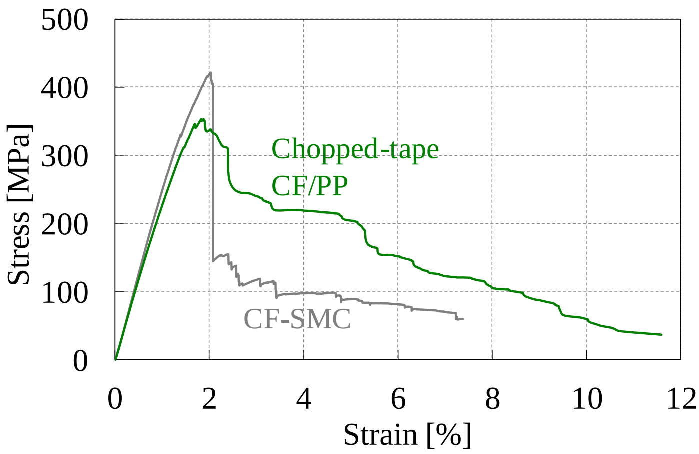

Figure 2. Strain-stress curves.

2.2 Dynamic 3-point bending behavior

2.2.1 Experimental method

In tensile test for carbon fiber reinforced plastics (CFRP), a high-speed photography has great effect in explanation of the fracture behavior of high-strength CFRP [3]. Here in this study, a high-speed camera (Hyper Vision HPV-1 by SHIMADZU) observed the dynamic flexural behavior of the composite materials in high velocity three point bending test by using the impact tower (Dynatup by Instron), which has a recording system of load and deflection. A specimen with rectangular cross section rests on two supports and is impacted by means of dropping a crosshead with a loading nose right above the center of the specimen as shown in Fig.3. Some frames at the instant that the specimen is fractured by the impact load are took by the high-speed camera. The experiments are conducted and compared for both of the developed chopped tape CF/PP and the conventional CF-SMC similar to the specimens mentioned above.

2.2.2 Fracture behavior

From test results, in the case of CF-SMC, as illustrated in Fig.4, at just a 64 micro second intervals of the impact instant, a large range of delamination occurs on the other side of the impacted surface, tensile side in flexural mode. So after the first failure, the flexural stiffness of the specimen decreases rapidly and the load measured by the load cell attached to the loading nose falls down close to zero immediately following the maximum in the load-deflection curve. On the other hand, Fig.5 shows that the chopped tape CF/PP specimen causes a compression failure of only a few surface layers at the beginning of the fracture during the same intervals instead of a large delamination.

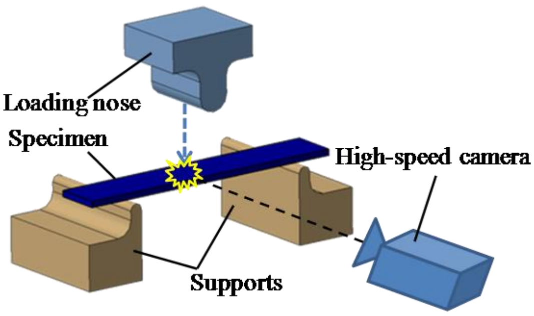

Figure 3. Observation of impact flexural behavior.

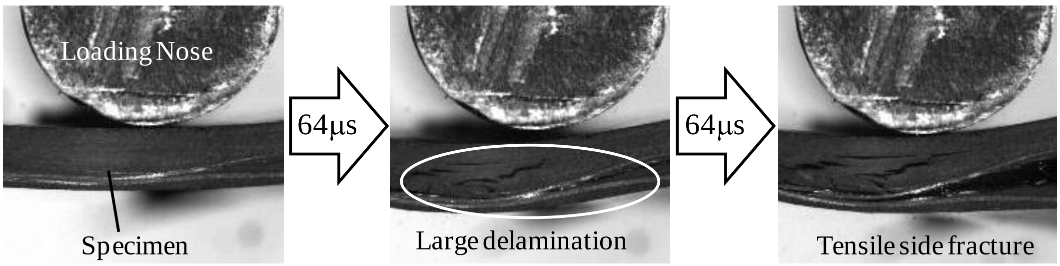

Figure 4. Instant images of flexural fracture of CF-SMC.

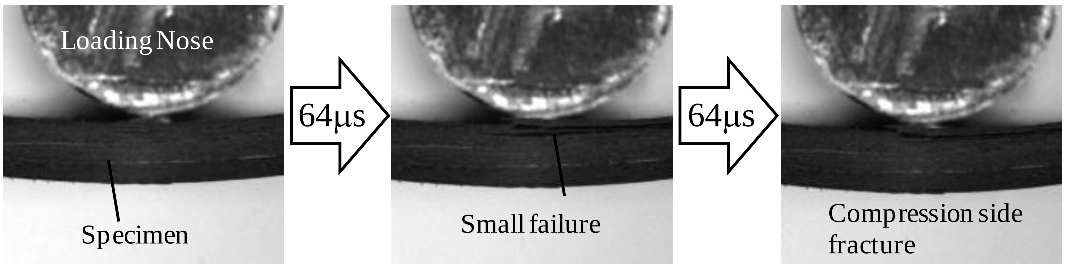

Figure 5. Instant images of flexural fracture of chopped tape CF/PP.

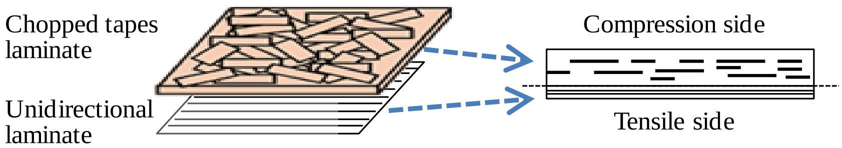

Figure 6. Hybrid structural laminate.

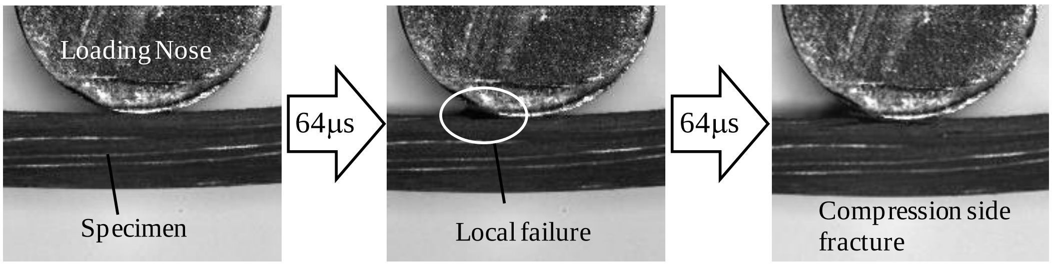

Figure 7. Instant images of flexural fracture of hybrid laminate.

3 Design method for high stiffness and high impact-absorbing

From the above examinations, it can reach at the proposal that the tensile side of the part needs to be adequately stronger than its compression side not to generate delamination in bending fracture process, taking advantage of the developed chopped tape CF/PP that starts to break from the compression side by impact. So, we introduced a hybrid composite structural material whose tensile side is composed of unidirectional laminate and whose compression side is composed of chopped tapes laminate as illustrated in Fig.6. And, the fracture behavior is shown in the instant images shot by high-speed camera in Fig.7. While the tensile-side unidirectional laminate keeps high stiffness of the hybrid material during a damage progression, the compression-side failure remains as small and local as is expected. That mechanism achieves higher impact-absorbing as well as higher stiffness.

4 Conclusion

Both of static and dynamic 3-point bending tests were examined for comparing the developed chopped tape CF/PP with the conventional CF-SMC. Those fracture mechanisms observed by using the high-speed camera showed the followings.

1. Compression side fracture of the chopped tape CF/PP is small and local, so that the fracture behavior is ductile in comparison to tensile side fracture of CF-SMC.
2. For designing the thermoplastic composites as balanced between high stiffness and high impact-absorbing, it is necessary to distribute the roles of continuous fiber laminate and chopped tape laminate appropriately to its hybrid structure based on their features.

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