FUNDAMENTAL RESEARCH ON REPAIR OF CARBON FIBER REINFORCED THERMOPLASTICS

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1 Introduction

To reduce energy consumption and CO_2 emission in transport sector, lightening the weight of automobile is efficient, especially for early promotion of electric vehicles [1]. For this purpose, CFRPs (carbon fiber reinforced plastics) have long been candidate materials, but their application has been limited in some specific areas. The reasons are well known as their higher cost, slower cycle time, difficulty in recycling and so on.
In order to break through current situation, Japanese government started national R&D program to develop innovative technologies concerning CFRTP (carbon fiber reinforced thermoplastics) since 2008FY. And following items have been developed.

(1) Continuous and discontinuous CF/PP sheets and tapes,
(2) Ultra high cycle molding,
(3) Jointing,
(4) Repair and recycling.

The objective of this paper is to introduce repair technologies of the national program above.

2 Fracture Mechanism of CF/PP

Fracture of CF/EP (carbon fiber reinforced epoxy) is known to be brittle as shown in Fig.1 due to delamination [2]. But in the case of flexural test of CF/PP (carbon fiber reinforced polypropylene) as shown in Fig.2, fracture starts from the compressive side, besides local kink and debonding spread without large delamination. Then, melting of matrix resin due to heat should be effective for recovery of mechanical properties [3]. In this study, to investigate the recovery of flexural modulus, flexural strength and impact energy absorption, flexural fractured specimens are molded by heat press with and without additional CF/EP or CF/PP sheets.

3 Experiments

3.1 Materials

Matrix of CFRP is EP produced by WEST SYSTEM. Matrix of CFRTP is PP produced by LION IDEMITSU COMPOSITES CO. Carbon fiber is TR3110M produced by Mitsubishi Rayon Co. Then, quasi-isotropic CFR(T)P laminates in which pieces of carbon fiber cloth are accumulated as $[0/45/0/45]_s$ are prepared (Fig.3). 5 *mm*×15 *mm* of CF/EP and CF/PP sheets are used in repairing as patches.

3.2 Repair methods

Candidate repair systems are, for example, magnetic heating, induction, adhesive bonding, ultrasonic welding, spin/vibration, welding, inert gas welding and so on [4].
In this study, CF/EP is repaired with CF/EP patch, and the bonding type is adhesion (Fig.4). In the case of CF/PP, flexural fractured specimens are repaired with/without patches [5]. When repairing with patch, the way is same as the case of CF/EP. When repairing without patch, CF/PP is repaired only by heat press. Jigs for thermal repair of CF/PP are shown in Fig.5.

3.3 Results and Discussions

3.3.1 Experimental Results of Fresh Materials

Figs.6 and 7 are stress-strain behaviors of each fresh material from flexural test. CF/EP shows brittle fracture with delamination after maximum stress (Fig.6). On the other hand, in the case of CF/PP, local debonding between fiber and resin is observed after maximum stress, and then stress-strain relationship shows plastic deformation similar to metals. Due to this fracture mechanism, CF/PP has higher energy absorption ability than CF/EP (Fig.7).

3.3.2 Experimental Results of Repairing

The repaired specimens are loaded till their maximum stresses, which are 2.0% of strain for CF/EP specimen, 2.2% and 3.7% of strain for two CF/PP specimens without patch respectively. Figs.8, 9 and 10 show each stress-strain behavior and Tables 1, 2 and 3 show mechanical properties of each.

In the case of CF/EP (Fig.8), fresh material shows brittle feature and repairing with patch does not appear to be effective.

In the case of CF/PP repaired only by heat press (Fig.9), initial stiffness is recovered as well as energy absorption ability.

In the case of CF/PP repaired by heat press with patch (Fig.10), mechanical properties are perfectly recovered, and the strength is rather higher than fresh material. It is of course by the contribution of increased V_f, but the more important technical merit is an excellent matting and adhesion between matrix material and reinforcing material. It must become an advantage of CF/PP in practical application.

Moreover, the appearance of repaired CF/PP is almost as same as fresh material comparing to CF/EP (Figs.11 and 12).

4 Conclusions

In this study, fundamental research about repair of CFRTP is performed. After comparing fracture mechanisms between CF/EP and CF/PP, each optimal repairing method is shown. Based on existing knowledge, following conclusions can be obtained from previous experiments.

(1) CF/PP has high energy absorption ability because that large delamination does not occur in its fracture process.

(2) The high energy absorption ability of CF/PP can be recovered by heat press molding because local debonding between fiber and resin can be welded by heat and pressure.

(3) Repairing with patch can further strengthen the material because of an increase in V_f.

(4) The appearance of repaired CF/PP is almost as same as fresh material.

Acknowledgement

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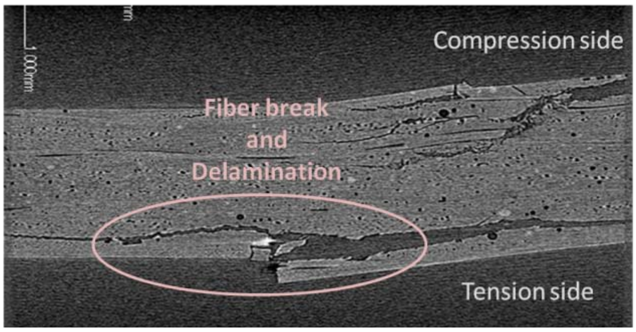

Fig.1 Fracture mechanism of CF/EP by flexural test.

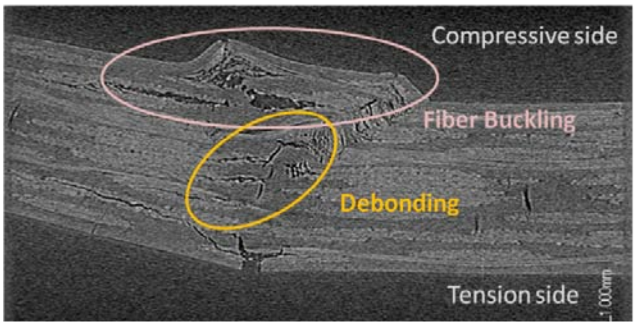

Fig.2 Fracture mechanism of CF/PP by flexural test.

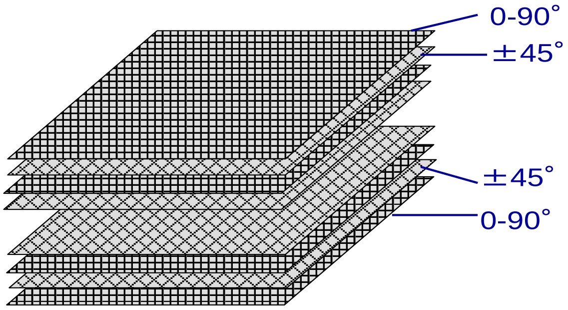

Fig.3 Fiber orientation of quasi-isotropic CF/EP and CF/PP.

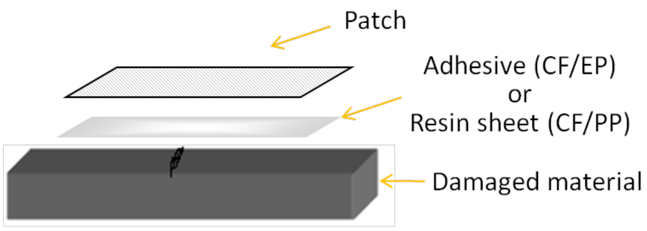

Fig.4 Repairing way of CF/EP or CF/PP with patch.

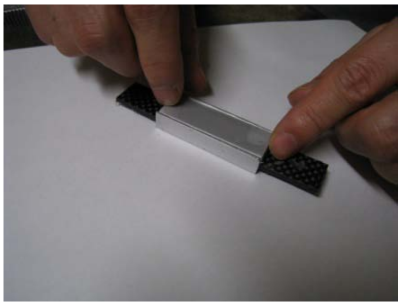

Fig.5 Jigs for thermal repair of CF/PP.

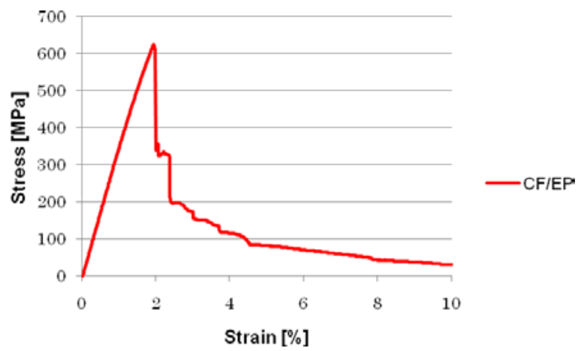

Fig.6 SS curve of fresh CF/EP (V_f=34%).

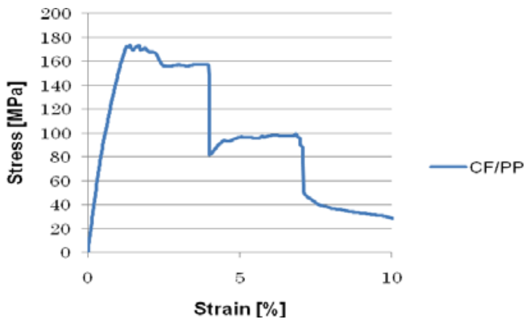

Fig.7 SS curve of fresh CF/PP (V_f=29%).

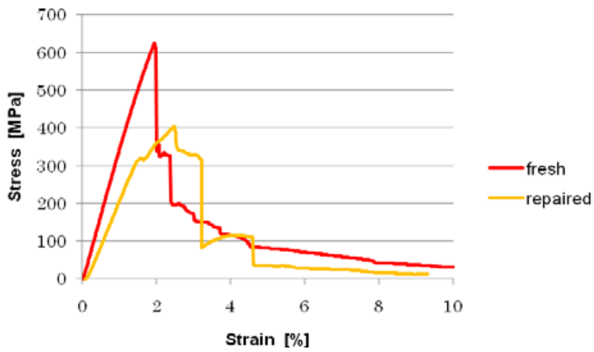

Fig.8 SS curve of fresh and repaired (patched) CF/EP.

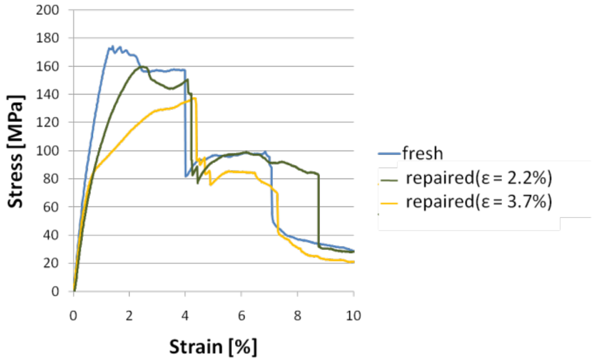

Fig.9 SS curve of fresh and repaired (without patch) CF/PP.

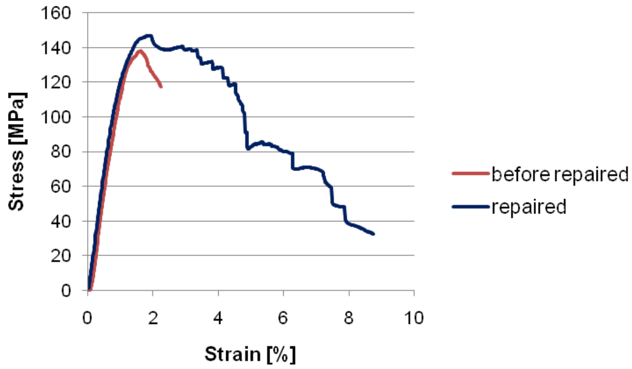

Fig.10 SS curve of original and repaired (patched) CF/PP.

Table 1 Mechanical properties of fresh and repaired CF/EP.

	Flexural modulus [GPa]	Flexural strength [MPa]	Flexural strain at ult. load [%]
Repaired material	22.5	405	2.48
Fresh material (Average)	35.5	590	2.00

Table 2 Mechanical properties of fresh and repaired (without patch) CF/PP.

	Flexural modulus [GPa]	Flexural strength [MPa]	Flexural strain at ult. load [%]
Repaired material (ε =2.2%)	16.0	160	2.50
Repaired material (ε =3.7%)	17.2	137	4.34
Fresh material (Average)	19.6	170	1.83

Table 3 Mechanical properties of original and repaired (patched) CF/PP.

	Flexural modulus [GPa]	Flexural strength [MPa]	Flexural strain at ult. load [%]
Repaired material (ε =2.2%)	14.4	147	1.87
Original material (ε =2.2%)	16.0	138	1.61

Fig.11 Repaired CF/EP with patch.

Fig.12 Comparison between the fracture material and the repaired material in case of CF/PP. (Left: overall view, Right: side, Center: closeup of fracture part)