OBSERVATION OF INTERFACIAL FRACTURE IN CF/GF MULTI-AXIAL WARP KNITTED FABRIC COMPOSITE MATERIALS SBJECTED IMPACT LOAD

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Abstract

Multi-axial warp knitted fabric (MAWKF) allows the placement of 0, 90 and fiber bundles in any other direction into the fabric structure (0 direction is longitudinal direction). The each plies are linked with knitted yarns. Higher mechanical performance resulted from no crimp of fiber bundle is achieved compared with general textile composite. And this fabric can be treated as one layer, so that stacking process can be reduced, and fabrication cost of composite structures can be reduced.

In this study, concept of "fiber hybrid" was applied and two kinds of fiber bundle, Carbon and Glass, were used in 0/90 MAWKF. Impact properties were investigated for these composites. Fiber hybrid composite compared to composite with one type of fiber realized highest energy absorption capability.

1. Introduction

Hybrid composite is defined as "Composite consist with two or more kind of components" [1]. In hybrid composite, construction components fill in gaps and utilize the advantage and characteristics of each other. In our definition, there are three types of hybrid composite; Fiber Hybrid, Matrix Hybrid, and Interfacial Hybrid. The Fiber Hybrid means using different fibers in one fabric. The Matrix Hybrid means to combine two or more kinds of resin in one composite. The Interfacial Hybrid means to combine two or more types of fiber bundles with different surface treatments. These hybrid technologies improve the mechanical properties of composites and create high performance composites.

Multi-axial warp knitted fabrics produced by warp knitting technology and one of the most attractive features of this fabric is the ability to combine multiple layers of oriented yarn in a single structure, so that the cost can be reduced with omission of the stacking process in case of hand lay-up method for example[2]. The multi-axial warp knitted fabric composite with no crimps can possess higher mechanical properties than general textile composites [3-5].

In this study, impact properties of fiber hybrid multi-axial warp knitted fabric composite materials were investigated. Two kinds of fiber bundle, Carbon and Glass, were used in 0/90 multi-axial warp knitted fabric. One fiber hybrid composite and two standard composite which consist of one type of reinforced fiber were prepared. Here, two types matrix resin, unsaturated polyester and epoxy resin, were prepared. The impact properties of the composites were investigated by using drop weight impact test. Cross section after impact test was observed and the delamination length and delamination strength were forcused. From these result, relationship between fracture mechanisms and energy absorption capability was clarified.

2 Materials and Experiments

Unsaturated polyester (RIGOLAC 150HR BQTNW : SHOWA HIGHPOLYMER) (UP) and epoxy resin (jER828 Japan Epoxy Resins Co., Ltd.) (EP) were used as matrix. Fig.1 shows the Schematic drawing of multi-axial warp knitted fabric composites used in this study. As a fiber hybrid composite, inter-layer hybrid composite (C/G) in which 0 layer and 90 layer were fabricated

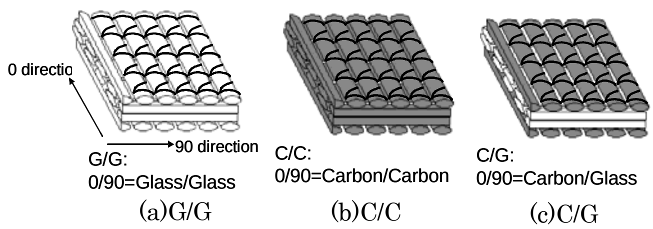


Fig.1 Schematic drawings of specimens of fiber bundle's distribution and cross sectional

by Carbon and Glass fiber bundles respectively was investigated. For the comparison, two kinds of composite with one type of fiber bundle were prepared; Glass or Carbon fiber bundle were used in 0/90 multi-axial warp knitted fabric. One is referred as Glass/Glass (G/G) and the other is Carbon/Carbon (C/C). For the impact test specimen, 2 plies of 0/90 multi-axial warp knitted fabric were stacked by hand-lay-up method with symmetrical stacking sequence $[0/90]_S$. Fiber volume fraction was about 47% in each specimen. Total fiber content and volume ratio of Carbon and Glass fiber were also same. . The specimen geometry was 100×100×1.5mm. In the impact test, the specimen was clamped on all side by a rectangular steel plate with 76mm circular hole and the drop weight load was applied to the center of the specimen using the striker with a hemispherical nose of 12.7mm. Impact test was conducted by using INSTRON Dynatup 9250HV. In case of UP, applied impact energy was 40J, in case of EP, that was 30J.

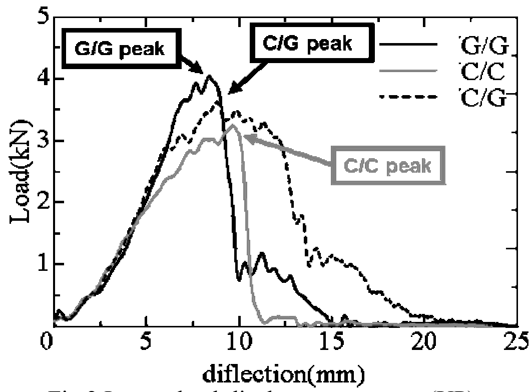


Fig.2 Impact load-displacement curves (UP)

Table 1 Result of impact test (UP)

Impact energy	40J		
properties	Energy to max load (J)	Progressive energy (J)	Total energy (J)
G/G	14.4	8.6	23.0
C/C	15.3	3.7	19.0
C/G	16.9	12.8	29.7

3. Result and Discussion

3-1 Relationship between fracture and energy absorption (Unsaturated polyester)

Fig.2 shows impact load-displacement curves of each specimen. In case of G/G and C/C, load was increased with increase in deflection and reached the maximum load (G/G: 4.0kN at 8.2mm, C/C:3.2kN at 8.7mm). After that, load was dramatically dropped (G/G: 1kN at 8.7mm, C/C: 0kN at 12.4mm). On the other hand, in case of C/G, load was also increased with increase in deflection and reached the maximum load (3.6kN at 8.7mm). After maximum load, however, C/G kept the high load level with increase in deflection (3.2kN until 12.4mm), and finally load was dropped (1kN at 13.6mm). Table 1 shows the result of impact test for each specimen. Total energy “Ut” become higher in order of C/G, G/G, C/C. Ut of inter-layer fiber hybrid composite of C/G was the highest value in all specimens. That is 29% and 56% higher than G/G and C/C. In order to clarify the difference of energy absorption mechanism among each specimen, total energy was divided into two energies; one is energy to maximum load “Um”, the other is progressive energy “Up” after maximum load to final rapture of specimen. There was no difference among specimens for Um, but there was a big difference in Up of each specimen. Up became higher in order of C/G, G/G, C/C. Therefore difference in total energy was resulted from the difference in Up.

In order to clarify the reason for the difference in Up, cross section after impact test of all specimen was observed. Fig.3 shows the Photograph of the cross-section after impact test. From the top surface to the bottom surface, 0/90/90/0 fiber bundles are observed and 0 fiber bundle is oval shapes one, 90° fiber bundle is between 0° fiber bundle. From observation result, there are four kinds of fractures in the specimen after impact test as in Fig.3 (a) ; (1) Delamination between 0 and 90 layer at the impact face, (2) Crack in 0 fiber bundle, (3) Fiber rupture of 90 fiber bundle, (4) Debonding of 0 fiber bundles at the back surface. All specimens have similar fracture. However, there are big differences in length of delamination of each specimen. Length of delamination is also shown in Fig.3 and Table 2. Length of delamination became longer in order of C/G (74.8mm), G/G (31.8mm), C/C (19.8mm).

In addition, delamination of each specimen was observed more microscopically. Fig. 4 shows the result of the observation. In case of G/G, and C/C, crack of the delaminaion was propagated through into 90° fiber-resin interface (Fig.4 (a), (b)). In this case, fracture surface is along the 90° fiber, so surface shape is flat. However, in case of C/G, crack of the delamination was propagated through into 0° fiber-resin interface (Fig.4 (c)). In this case, fracture surface is along the 0° fiber, so surface shape is irregularity. In this case, product of delamination length and 1.57 ($\pi/2$) (Fracture surface shape factor)

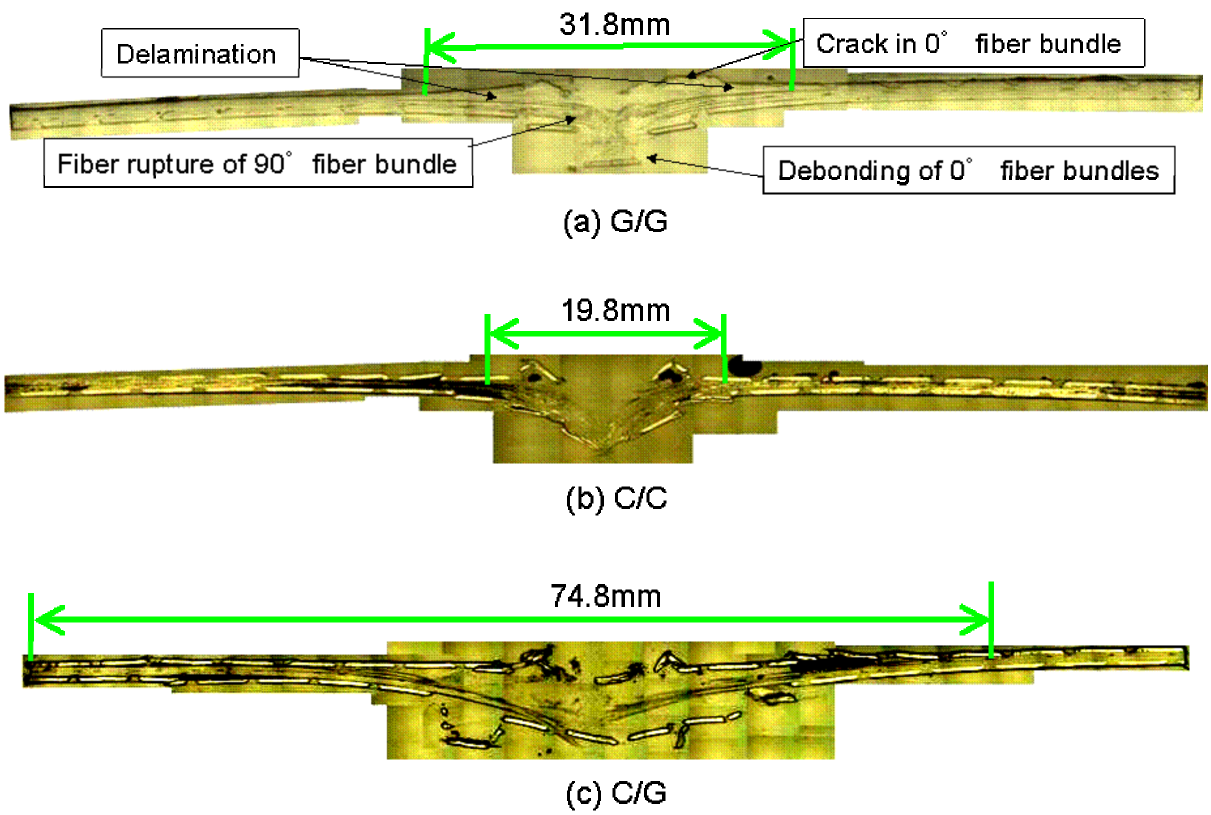
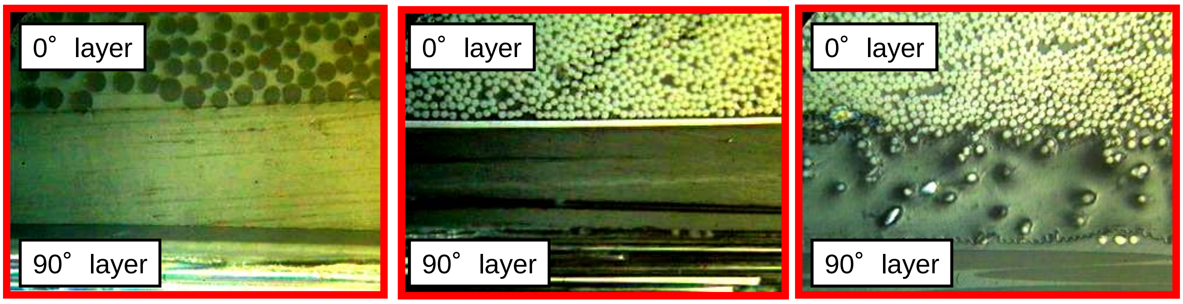


Fig.3 Photograph of the cross-section after impact test (UP)

Table 2 Result of impact test and short span bending test (UP)

specimen	Progressive energy (J)	Delemination length Dle (mm)	Delamination strength Dst (MPa)	Dle×Dst (MPa・mm) "Deleminaion Energy" DE	DE DE×C/C "Delamination Energy Ratio" DER
G/G	8.6	31.8	547	17400	3.19
C/C	3.7	19.8	276	5460	1.00
C/G	12.8	117.4	438	32800	5.97



(a) G/G (b) C/C (c) C/G

Fig.4 Photograph of the delamination of each specimen (UP) is the real delamination length. Therefore delamination length of C/G is 117.4mm (=74.8×1.57). In addition, to clarify the delamination strength, short span bending test was investigated. Results of this test are shown in Table 2. Final fracture of all specimen was delamination, therefore bending strength from this test can be treated as delamination strength. Delamination strength becomes higher in order of G/G(659MPa),C/G(547MPa),C/C(276MPa).

Finally, the product of delamination length and delamination strength was calculated as delamination energy (D.E.), and the value of D.E. were normalized by D.E. of C/C was calculated as delamination energy ratio (D.E.R.) as shown in Table 2. From this result, it can be concluded that delamination energy ratio becomes higher, progressive energy become higher. Especially, in case of fiber hybrid C/G, higher delamination strength and longer delamination length resulted in the highest impact properties.

3-2 Relationship between fracture and energy absorption (Epoxy resin)

Fig.6 shows impact load-displacement curves of each specimen. In this case, impact load of all specimens was increased with increase in deflection (G/G: 4.1kN at 8.4mm, C/C: 1.9kN at 6.4mm, C/G:) and reached the maximum load. And after that, load was dramatically dropped (G/G: 0.5kN at 10.8mm, C/C: 0.0kN at 9.3mm, C/G: 0.0kN at 11.2mm). Maximum load was higher in order of G/G, C/G, C/C.

Table 3 shows the result of impact test for each specimen. Ut becomes higher in order of G/G, C/G, C/C. In this case, Ut of inter-layer fiber hybrid composite of C/G was not highest value in all specimens unlike in case of UP as mentioned in section 3-1. Um becomes higher in order of G/G (12.7J),C/G (12.2J),C/C (5.5J). Up becomes higher in order of G/G (8.3J), C/C (6.9J), C/G (5.7J). Here, D.E.R. was also applied to clarify the energy absorption mechanism. First, cross section after impact test was observed and that results are shown in Fig.7. From observation result, there are three kinds of fractures in the specimen after impact test as shown in Fig.7 (a) ; (1) Delamination between 0 and 90 layer at the impact face, (2) Fiber rupture of 90 fiber bundle, (3) Debonding of 0°fiber bundles at the back surface. Property of terfacial adhesion with EP was better than UP. This is the reason of no crack in 0 fiber bundle in case of EP. All specimens have similar fracture. Delamination length was measured and shown in Fig.7. Delamination length becomes longer

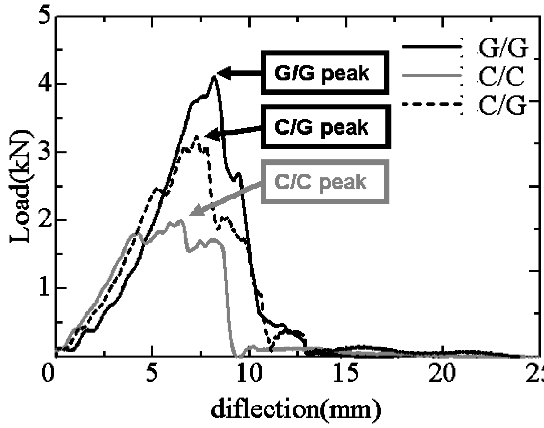


Fig.6 Impact load-displacement curves (EP)

Table 3 Result of impact test (EP)

Impact energy	30J		
properties	Energy to max load (J)	Progressive energy (J)	Total energy (J)
G/G	12.7	8.3	20.9
C/C	5.5	6.9	12.4
C/G	12.2	5.7	17.9

in order of C/G (28.4mm), C/C (26.5mm), G/G (23.5mm).

Second, each cross section was observed more microscopcally. Fig.8 shows the photograph of the delamination of each specimen. From this result, C/C and C/G, crack of the delaminaion was propagated through into 90° fiber-resin interface (Fig.8 (b), (c)). However, in case of G/G, crack of the delamination was propagated through into 0° fiber-resin interface (Fig.8 (a)). Finally delamination length become higher in order of G/G (35.3mm), C/G (28.4mm), C/C (26.5mm).

In addition, delamination strength was investigated by short span bending test. Results of this test are shown in Table 4. Delamination strength becomes higher in order of C/C (1039MPa), G/G (924MPa), C/G (765MPa).

Finally, from previous result, D.E.R. of each specimen was calculated (Table 4). D.E.R. become higher in order of G/G, C/G, C/C. From this result, even in case of epoxy, it can be concluded that delamination energy ratio becomes higher, progressive energy become higher. Therefore this new parameter of delamination energy ratio (D.E.R.) can be applied to different material system.

4. Conclusion

Two type matrix resins were investigated In this study, two kinds of fiber bundle, Carbon and Glass, were used in 0/90multi-axial warp knitted fabric. As a fiber hybrid composite, inter-layer hybrid in which

0 layer and 90 layer were fabricated by Carbon and Glass fiber bundle respectively was investigated.

In case of UP, inter-layer hybrid composite of Carbon in 0 direction and Glass in 90 direction realized highest energy absorption.

In case of EP, inter-layer hybrid composite of Carbon in 0 direction and Glass in 90 direction didn'trealized highest energy absorption.

. In case of UP, there are 4 types fractures. Crack in 0°fiber bundle, Delamination between 0 and 90 layer at impact face, 90 fiber fracture, Debonding of 0 fiber bundle at the back surface. In case of epoxy, there are 3 fractures. Delamination between 0 and 90 layer at impact face, 90 fiber fracture, Debonding of 0 fiber bundle at the back surface. Delamination between 0 and 90 layer at impact face was main fracture.

From relationship between Up and Delamination energy ratio, it can be concluded that delamination energy ratio becomes higher, progressive energy become higher. Delamination energy ratio (D.E.R.) can be applied to different material system.

5. References

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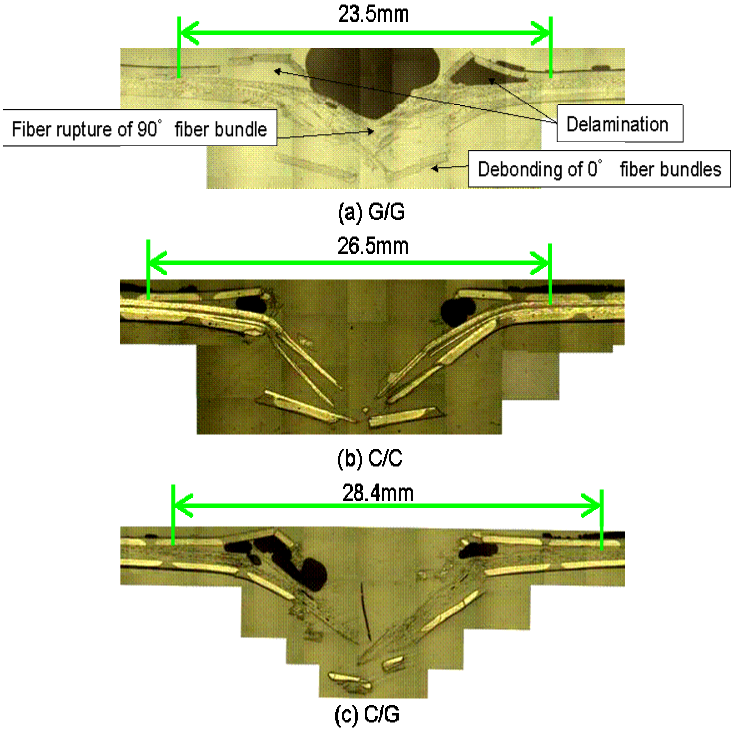

Fig.7 Photograph of the cross-section after impact test (EP)

Table 4 Result of impact test and short span bending test (EP)

specimen	Progressive energy (J)	Delemination length Dle (mm)	Delamination strength Dst (MPa)	Dle×Dst (MPa・mm) "Deleminaion Energy" DE	DE DE×C/C "Delamination Energy Ratio" DER
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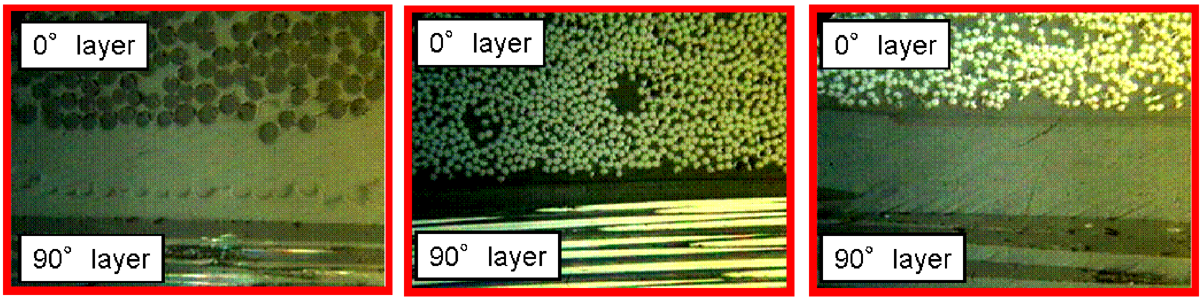

(a) G/G (b) C/C (c) C/G

Fig.8 Photograph of the delamination of each specimen (EP)