

EFFECT OF FIBER DISCONTINUITY ON THE MECHANICAL PROPERTIES IN FIBER REINFORCED COMPOSITE LAMINATES

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1 Introduction

In fabricating complicated laminated composite structure by using prepregs, there may be fiber discontinuity in the structure which may influence the mechanical response of the structure. The fiber discontinuity also may act as a source of stress concentration and damage. In this regard, it is very important to understand the effect of fiber discontinuity on the mechanical properties of laminated structure in order to establish an efficient design methodology of laminated composite structure which uses prepregs. In the present study, the effect of fiber discontinuity size on the mechanical properties in CFRP laminate is investigated experimentally. The damage initiation and growth near the fiber discontinuity are also discussed.

2 Experimental methodology and Analysis

2.1 Specimen and Tensile tests

A material system used was T700SC/2592 carbon/epoxy system. Laminate configurations were unidirectional [0₈]. To introduce fiber discontinuity in the laminates, cut prepregs are stacked. In stacking prepregs we cared to not have gap between the cut prepregs. Five kinds of laminates are prepared: (a) a laminate without fiber discontinuity (a normal unidirectional laminate), (b) a laminate with 2-ply thick fiber discontinuity at the center of the laminate, (c) a laminate with 4-ply thick fiber discontinuity, (d) a laminate with 6-ply thick fiber discontinuity and (e) a laminate with 8 (all) cut prepregs. Fig.1 shows the schematics of the laminates used. We refer the specimens as (a) continuous specimen, (b) 2-ply discontinuous specimen, (c) 4-ply discontinuous specimen, (d) 6-ply discontinuous specimen and (e) all-ply discontinuous specimen. Also, there was resin rich region in fiber discontinuity. Specimen size is 200mm long, 10mm wide and 1.2mm thick. The

crosshead speed was 1.0mm/min. To measure both strains in the longitudinal and transverse directions, two biaxial strain gages put on specimens. The strains were measured at two points; one is the center of the specimens which is just above fiber discontinuity and the other is 20mm distant from fiber discontinuity in the longitudinal direction. The gage length is 2mm. Fig.2 shows schematic of the position of the strain gages.

We also observed specimen edge face under tensile loading in 6-ply discontinuous specimen. Tensile loading was stopped on the way, and we observed it by optical microscope. Three single strain gages that gage length is 2mm were put on specimen. Also two single strain gages that gage length is 5mm were put on specimen. As shown in Fig.2.

2.2 FEM analysis

Finite element method program ABAQUS was used. 1/8 models of the specimens were made by a solid element of three dimensions as shown in Fig.3. The resin rich region that existed in fiber discontinuity was modeled as a rectangle part which had thickness of the discontinuity layer and the observed length. The material properties used in the analysis are shown in Table 1 and Table 2. Table 3 shows length of X-direction of resin rich region. Also the displacement was given to the right edge so as the strain of the overall X-direction to be 1%.

3 Results and Discussion

3.1 Tensile test

Fig.4 shows stress-strain curves of (a) 2-ply discontinuous specimen, (b) 4-ply discontinuous specimen and (c) 6-ply discontinuous specimen. The strain away from fiber discontinuity show almost linear stress-strain relation until a certain stress. The strain rapidly increases at a stress point, and after that, stress-strain curve shows almost linear stress-strain relation. The strain at the center of the

specimens (fiber discontinuity site) shows nonlinear stress-strain relation at relatively low stress range. After the strain away from fiber discontinuity rapidly increased, the stress-strain curves of both points almost coincide with each other. The nonlinear stress-strain relation at the fiber discontinuity site implies that damages initiate and progress around the fiber discontinuity in the relatively low stress range. The coincidence of the stress-strain curves from the two points after the sudden increase in the strain implies the delamination development and progress between the continuous and discontinuous layers.

Next, Fig.5 shows stress-strain curves of 6-ply discontinuous specimen, and Fig.6 shows result of edge surface observation. Stress-strain curve on fiber discontinuity site shows nonlinear stress-strain relation on 100MPa (A in Fig.5). It is considered that this corresponds to the generation of debonding on resin rich layer and fiber edge of fiber discontinuous layer as shown in Fig.6 (a). The Strain on 4mm distant point from fiber discontinuity rapidly increased on 400MPa (B in Fig.5). It is thought that this corresponds to the delamination between continuous and discontinuous plies as shown in Fig.6 (b).

3.2 FEM analysis

Fig.7 shows distribution of stress in X-direction on straight line CD in Fig.3. Vertical axis are normalized by applied stress of specimen. The distance from the center of the specimen (point C in Fig.3) is taken as a horizontal axis. Fig.7 shows the normalized stress in the interface (point D in Fig.3) increase by fiber discontinuous layer thick. If interface debonding is assumed to occur when interface tensile stress was reached at a stress point, it corresponds to experimental result that specimen stress where interface debonding is generated decline by fiber discontinuous layer thick.

Fig.8 shows distribution of shear stress τ_{XY} between fiber continuous layer and fiber discontinuous layer. The distance from the center of the specimen (point A in Fig.3) is taken in a horizontal axis. The shear stress increase and the shear stress at with distance from the center of the test piece, and dropped at the interface. Also shear stress rises by fiber discontinuous layer thick. It is thought that this shear stress exerts dominant influence on delamination. In this regard, it can qualitatively explain that stress at discontinuous behavior of stress-strain curves decline by fiber discontinuous layer thick.

4 Conclusion

The damage initiation and growth behavior near fiber discontinuity in CFRP laminates under tensile loading was investigated experimentally. The following conclusions were obtained.

- (1) The nonlinear behavior initiation of strain on fiber discontinuity site corresponds to interface debonding of fiber discontinuity.
- (2) The discontinuity behavior away from fiber discontinuity corresponds to delamination between continuous and discontinuous plies.
- (3) Initiation stress of nonlinear and discontinuous behavior decreased with the thickness of fiber discontinuous layer. FEM result qualitatively agree with this result.

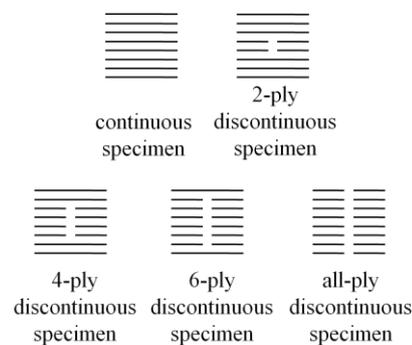


Fig.1 Schematic of the laminates used in this study

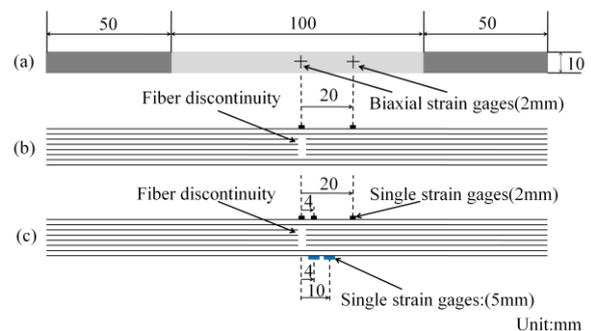


Fig.2 Schematic of tensile specimen

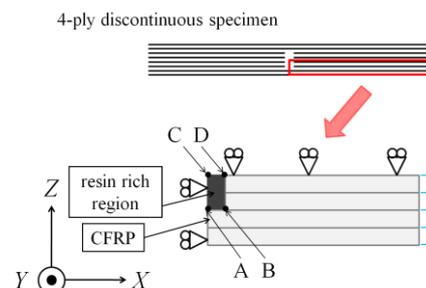
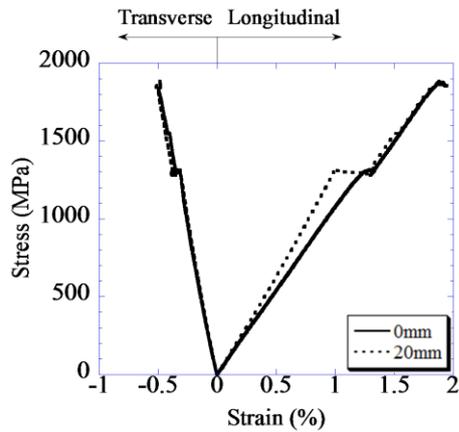
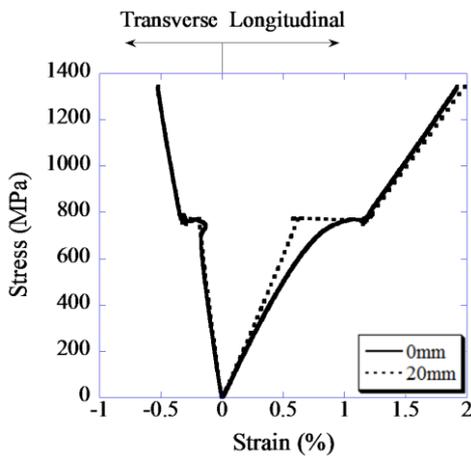


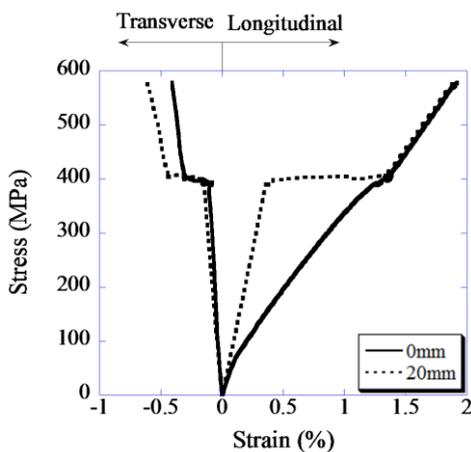
Fig.3 Finite element analytical model of 4-ply discontinuous specimen



(a) 2-ply discontinuous specimen



(b) 4-ply discontinuous specimen



(c) 6-ply discontinuous specimen

Fig.4 Stress-strain curves of (a) 2-ply discontinuous specimen, (b) 4-ply discontinuous specimen and (c) 6-ply discontinuous specimen

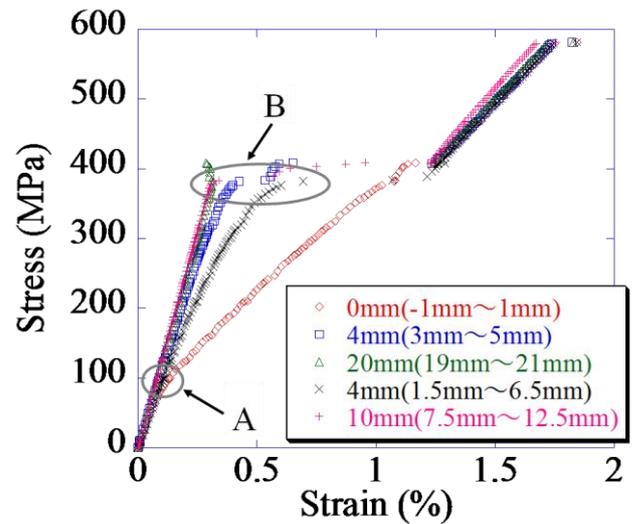


Fig.5 Stress-strain curve for 6-ply discontinuous specimen

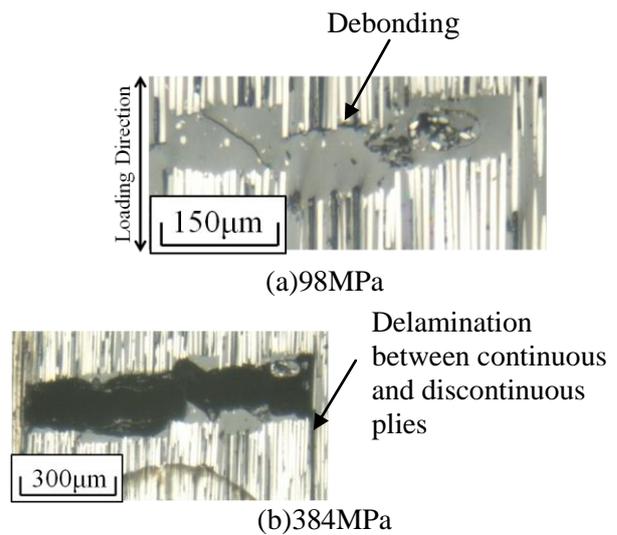


Fig.6 Damage progress process around fiber discontinuity in the 6-ply discontinuous specimen at (a) 98MPa and (b) 384MPa

Table 1 Material properties of CFRP used in the analysis

$E_x=130.0\text{GPa}$	$\nu_{yz}=0.50$	$G_{yz}=3.18\text{GPa}$
$E_y=9.53\text{GPa}$	$\nu_{xz}=0.34$	$G_{xz}=4.73\text{GPa}$
$E_z=9.53\text{GPa}$	$\nu_{xy}=0.34$	$G_{xy}=4.73\text{GPa}$

Table 2 Material properties of resin rich region used in the analysis

$E=3.0\text{GPa}$	$\nu_{yz}=0.3$	$G_{yz}=1.15\text{GPa}$
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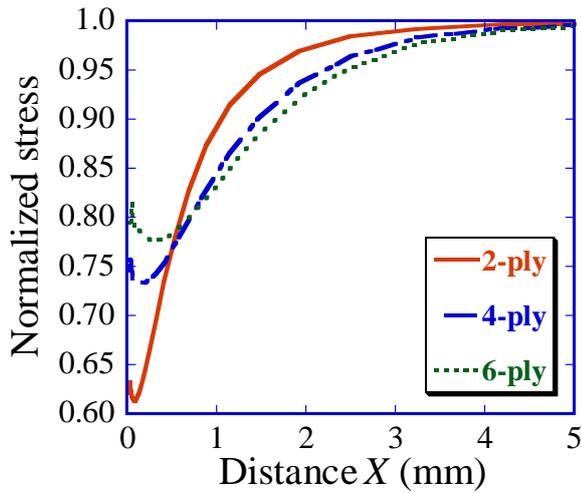


Fig.7 Normalized stress in X-direction along the laminate mid-ply as a function of the distance from the specimen center

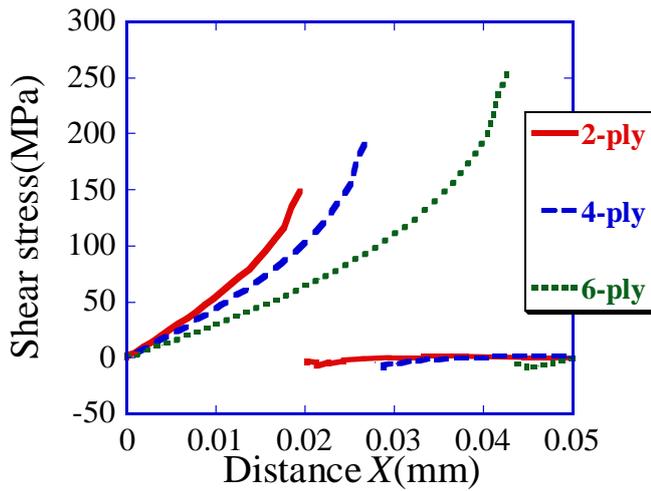


Fig.8 Shear stress, τ_{XY} , along the interface between the continuous and discontinuous plies as a function of the distance from the specimen center

Table 4 Stress and longitudinal strain at fracture

Number of discontinuity ply	Fracture stress (MPa)	Fracture longitudinal strain (%) (Measured point : distance from fiber discontinuity)
0	2770	2.02(0mm) 2.00(20mm)
2	1910	1.94(0mm) 1.94(20mm)
4	1340	1.92(0mm) 1.93(20mm)
6	550	1.89(0mm) 1.88(20mm)
8	80	0.38(0mm) 0.068(20mm)

Table 3 Length of the resin rich region in X-direction

Specimen	Length (mm)
2-ply discontinuous specimen	0.020
4-ply discontinuous specimen	0.027
6-ply discontinuous specimen	0.043