MIXED MODE DELAMINATION IN HYBRID LAMINATE UNDER DMMB TEST

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1. Background & Object

A wind power energy system has been developed actively among the renewable energy which is a solution for the global energy problem. A rotor blade is the most part in the wind power system because it revolves and has high weight. The box spar and tail parts are composed of the CFRP and GFRP hybrid laminate composites for the lightweight of the blade. However, CFRP/GFRP hybrid laminates have often damage as like the delamination condition and cracks at the interface of laminates. Due to the delamination or the interfacial crack tip behaviour at the hybrid materials, fracture occurs under mixed mode conditions, especially mode I and mode II. Therefore, there is a need for the evaluation of the mixed mode during the delamination of CFRP/GFRP hybrid laminate interface. This paper shows the results of an experimental examination of the delamination fracture toughness in a CFRP/GFRP hybrid laminate composites. Fracture toughness experiments and estimation are performed by using DMMB(Dissimilar mixed mode bending) specimen. The materials used in the test are a commercial woven type CFRP (Carbon fiber reinforced plastic) prepreg (CF3327) and UD type GFRP(Glass fiber reinforced plastic) prepreg (HD224A). In this study, the effects of the fulcrum location as a loading parameter are evaluated in the viewpoint of energy release rate in mode I and mode II contribution. The fracture experiments were carried out in a small scale universal servo−hydraulic machine(H5KS). And the crack advanced length was recorded with a travel telescope jointed by a stereo microscope.

2. Material & Specimen

Table 1 Specification of CFRP and GFRP

	Fiber weight (g/m²)	Prepreg weight (g/m²)
CFRP	302	475~485
GFRP	203±3	356~375

Table 2 Mechanical properties of CFRP and GFRP laminated composite.

	Unit	CFRP(plain woven)	GFRP(UD)
Elastic modulus, E	Gpa	54.3	43.3
Ultimate strength, σ_u	Gpa	1.527	1.102
Poisson's ratio, ν	−	0.1	0.31
Thickness, t	mm	2.5	3(10ply)
		2.5	2.5(8ply)

➤Prepreg cut in 250 x 250mm

➤10ply lamination, respectively ($CFRP_{10}/GFRP_{10}$)
→ Teflon notch insertion ($CFRP_{10}$/teflon/$GFRP_{10}$)

➤Thermoform in 130℃, 5.7MPa, 60minutes

➤Cut out the specimen size (120 x 22mm)

➤fatigue pre−crack insertion ($K^{max}_f \leq 0.16$MPa, 2Hz, $a_0/L=0.45$)

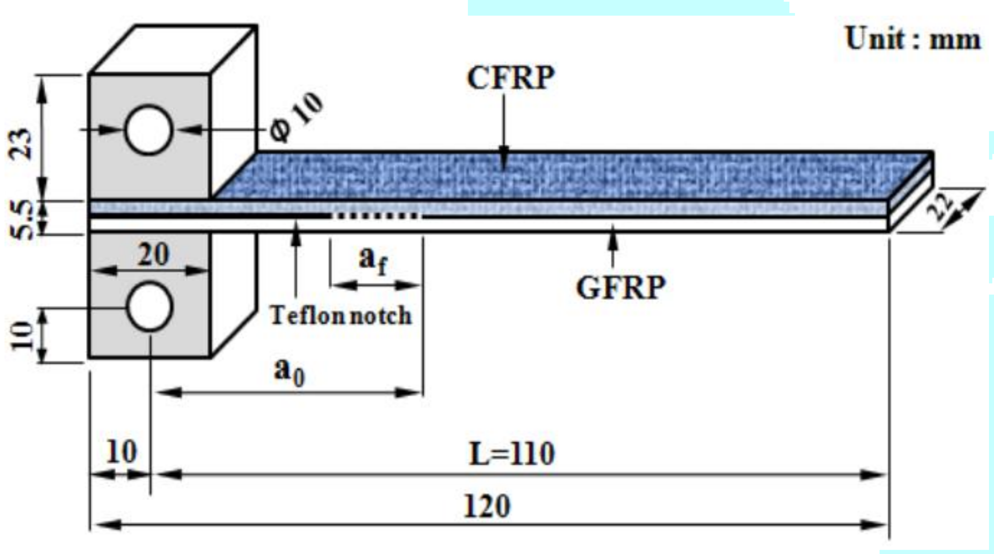

Fig. 1 Geometry of DMMB specimen

3. Experimental method

➤Fatigue pre−crack insertion test

▪Universal dynamic tester(H Co, 50kN)
▪$K^{max}_f \leq 0.16$MPa, 2Hz, $a_0/L=0.45$

➤MMB test

▪Compact tensile tester(Tinus Olsen, H5KS, 5kN)
▪ASTM D 6671, 0.5mm displacement control

➤Crack extension monitoring

▪Assemble stereoscopic microscope(Kyowa Co, x 20) and traveling microscope(N.O.W Co) into crack monitoring system

➤ Energy release rate evaluation is used for the asymmetry delamination and hybrid orthotropic laminate plate formula of Marannano based on Williams analytical expression

$$G_{Total} = G_I + G_{II}$$

The total energy release rate can be divided into two part

$$G_I = \frac{6P_I^2(a+\chi h)^2}{W}\left(\frac{1}{WE_{11}h_1^3} + \frac{1}{WE_{21}h_2^3}\right)$$

$$G_{II} = \frac{6P_{II}^2 a^2}{W^2}\left(\frac{\alpha^2}{E_{11}h_1^3} + \frac{\beta^2}{E_{21}h_2^3} - \frac{1}{h^2(E_{11}h_1+E_{21}h_2)}\right)$$

Where,

$$P_I = \frac{PC}{B} - \frac{\alpha P(B+C)}{\alpha+\beta}\left(\frac{1}{B} - \frac{1}{2L}\right) \quad P_{II} = \frac{P(B+C)}{\alpha+\beta}\left(\frac{1}{B} - \frac{1}{2L}\right)$$

$$\alpha+\beta = 1 \quad \alpha = \frac{E_{11}h_1^3}{E_{11}h_1^3 + E_{21}h_2^3}$$

$$\chi = \sqrt{\frac{E_{11}}{11G_{13}}\left(3 - 2\left(\frac{\Gamma}{1+\Gamma}\right)^2\right)} \quad \Gamma = 1.18\frac{\sqrt{E_{11}E_{22}}}{G_{13}}$$

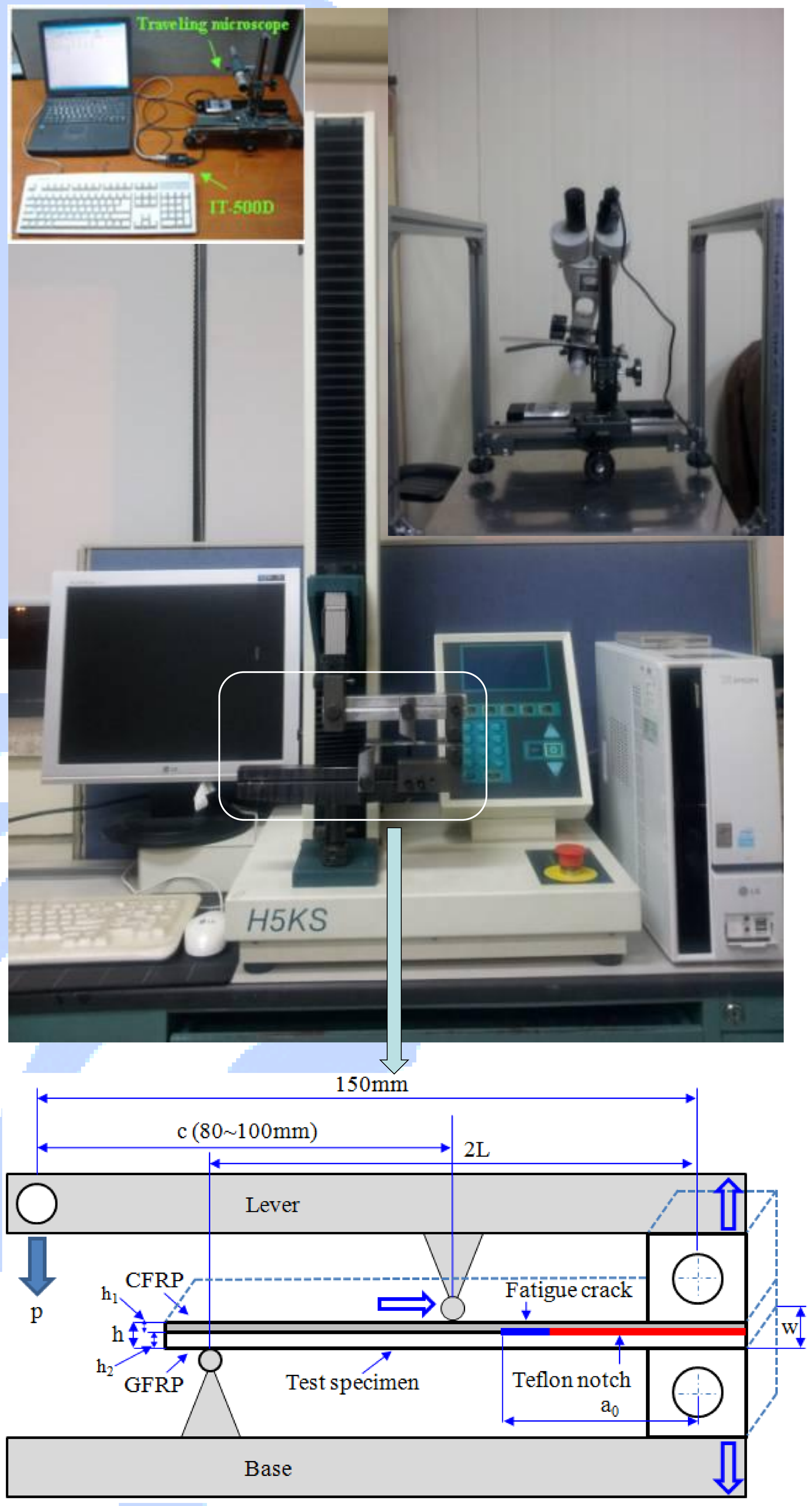

Fig. 2 Overview of MMB experimental apparatus

4. Results & Discussions

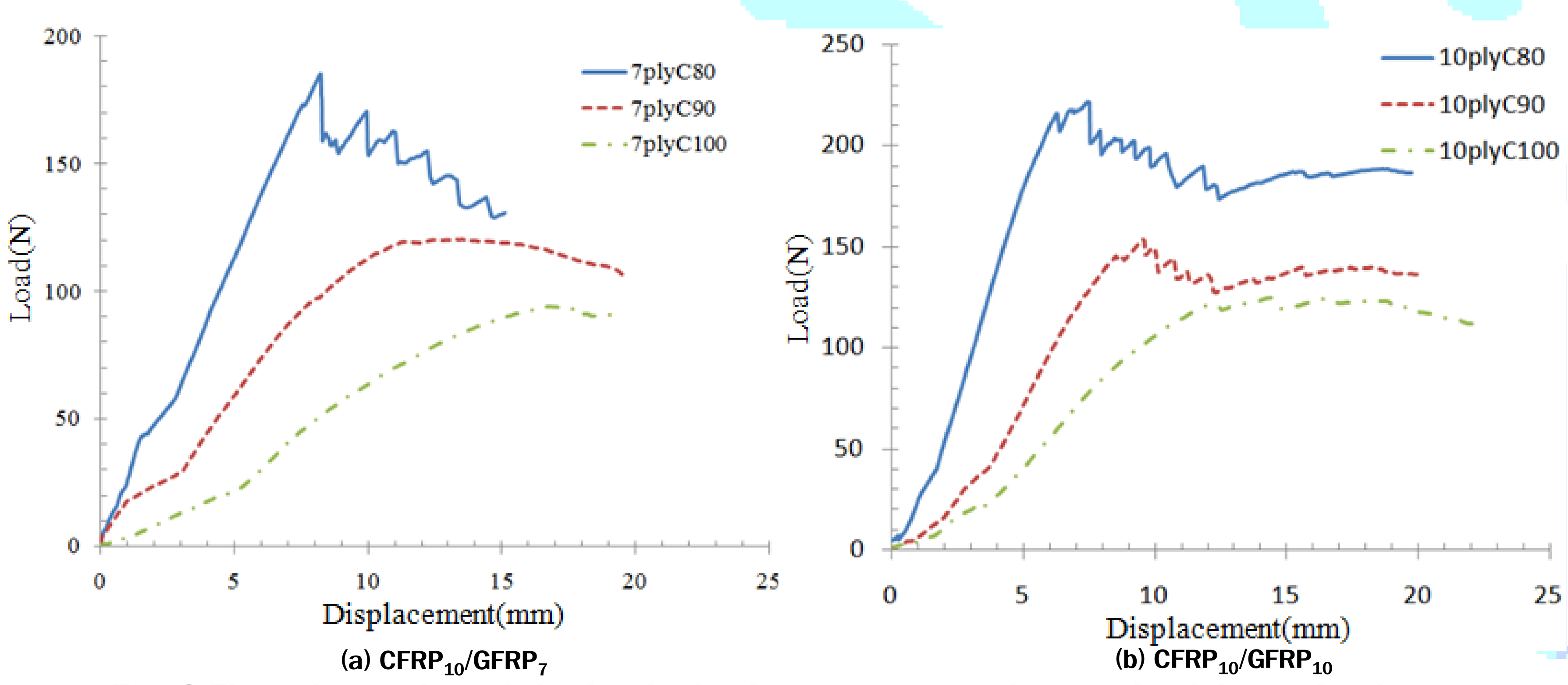

Fig. 3 The relationship of the load−displacement according to the fulcrum loading point under MMB test with mode Ⅰ+Ⅱ.

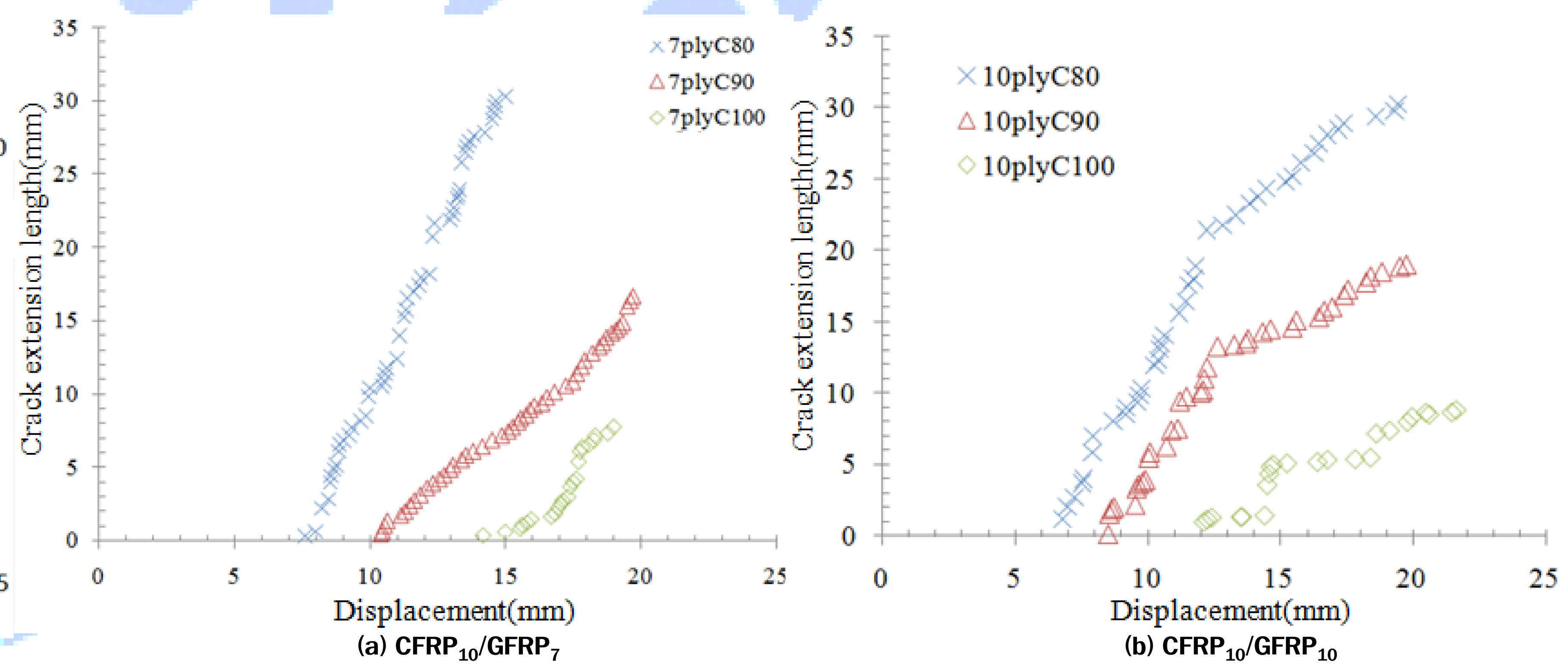

Fig. 4 The relationship of the crack extension length and displacement according to the fulcrum loading point under MMB test with mode Ⅰ+Ⅱ.

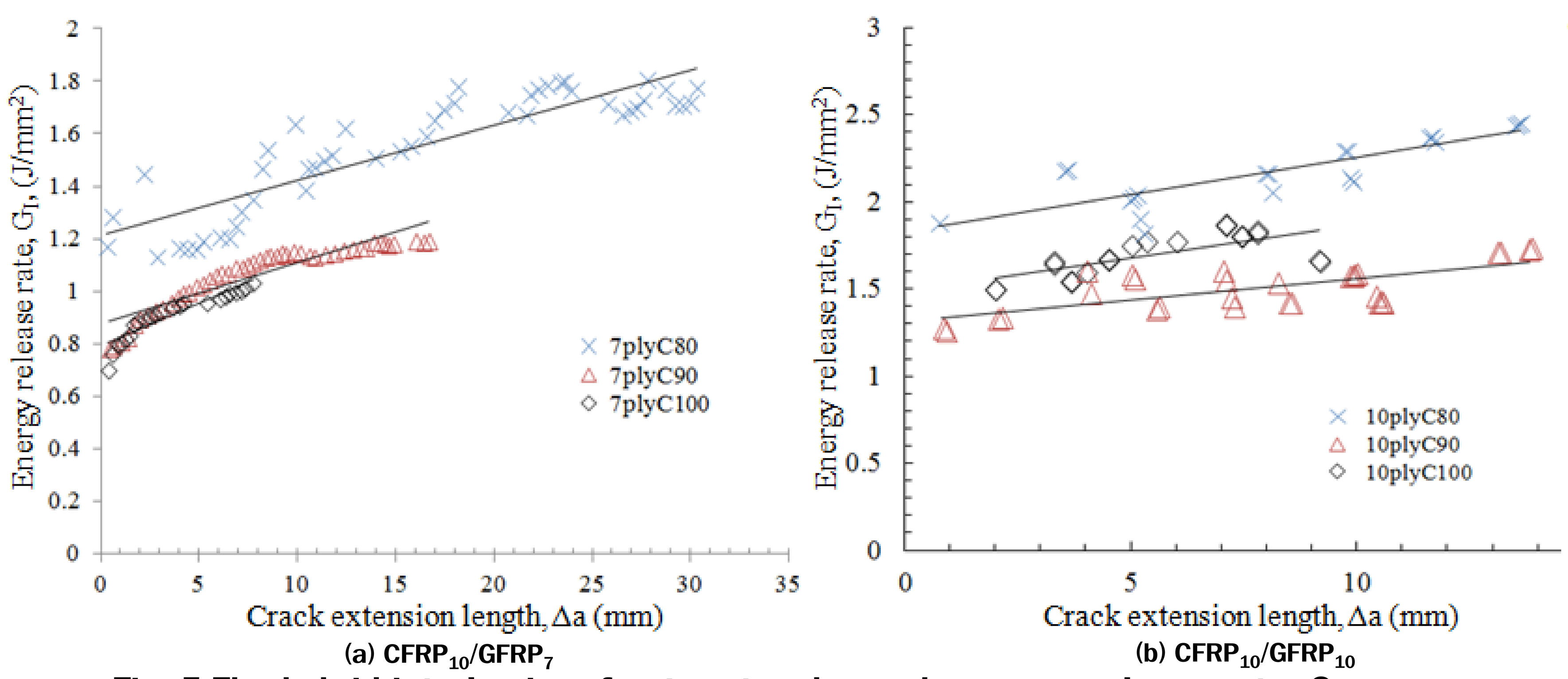

Fig. 5 The hybrid interlaminar fracture toughness by energy release rate, G_I

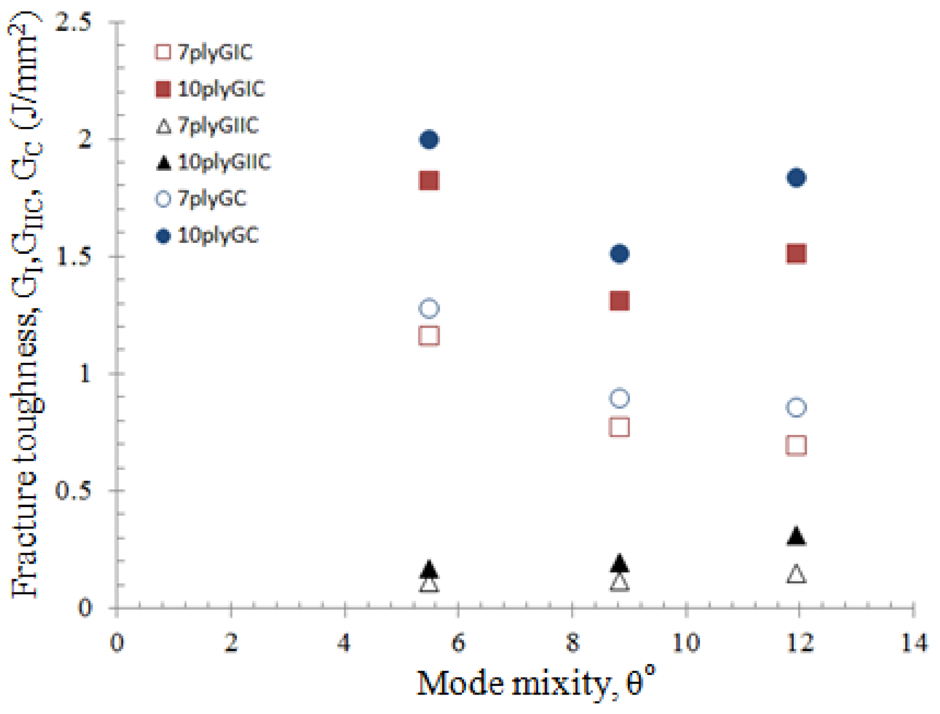

Fig. 6 The variation of the fracture toughness energy release rate curves according to the loading fulcrum ratio.

5. Conclusions

MMB(Mixed Mode Bending) test is performed for the mixed mode delamination fracture phenomenon that occurred in CFRP/GFRP hybrid laminated composite.
The following conclusions could be drawn from this study.

1) G_c for the interlaminar fracture toughness of $CFRP_{10}/GFRP_7$ was 1.28, 0.9 and 0.86 J/mm². And those of $CFRP_{10}/GFRP_{10}$ was 2.00, 1.52 and 1.83 J/mm².
2) The mixed mode delamination fracture phenomenon in CFRP/GFRP hybrid laminated plate was dominated by mode Ⅰ.
3) The mode mixity show a tendency to linearly increase according to the increasing fulcrum ratio.