Effect of fiber type on the translaminar fracture toughness of epoxy-based laminated composites

H. Taghibeigi, A. Zeinedini, A. Akhavan-Safar (INEGI, Portugal), L.F.M. da Silva

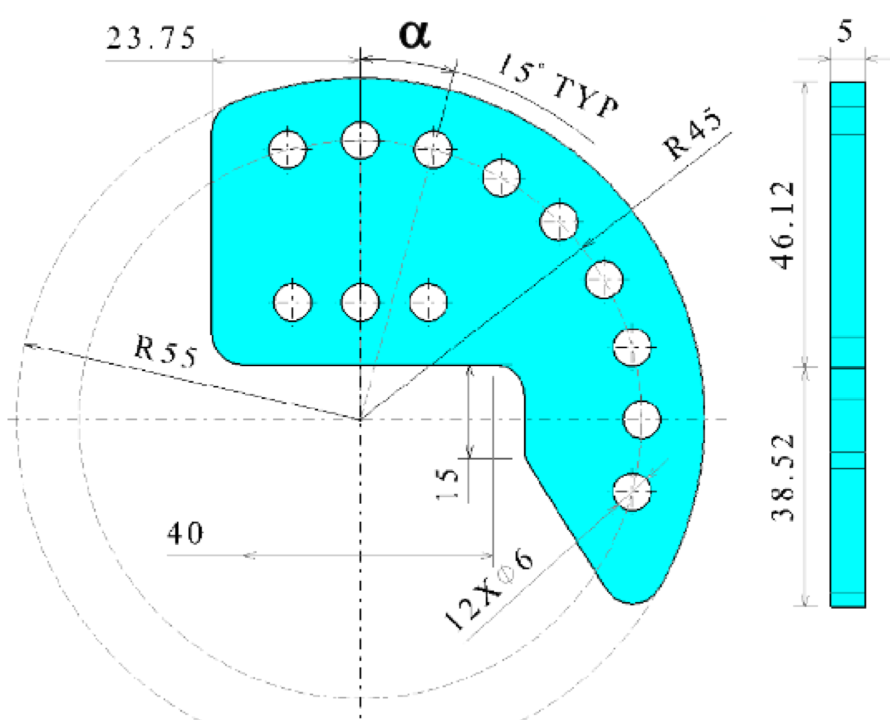
Advanced Joining Processes Unit

Introduction

Different damage modes may occur in the laminated composites [1]. To the best knowledge of the authors, no study has been conducted on the comparison of translaminar fracture toughness of different laminated composites subjected to modes I and II loading conditions [2]. Hence, modes I and II translaminar fracture toughness of carbon, E-glass, and Kevlar epoxy-based laminated composite systems were investigated using the practical data and a finite element analysis.

Experimental methodology

In this study, CTSs (compact tension specimens) with the dimensions of 60 mm×37.5 mm were considered as shown in Fig. 1. Arcan test configuration was used to measure modes I and II translaminar fracture toughness (TFT) of laminated composites reinforced by Carbon, Kevlar, or E-glass fibers (see Fig. 2). In Fig. 2, different samples tested under modes I and II loading states have been displayed.



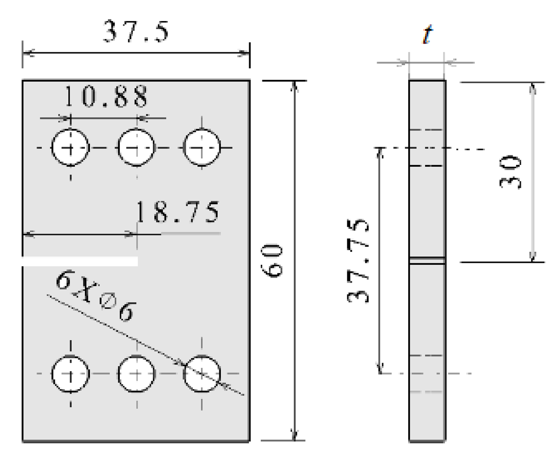


Figure 1 –The draft of Arcan fixture and the CTS sample

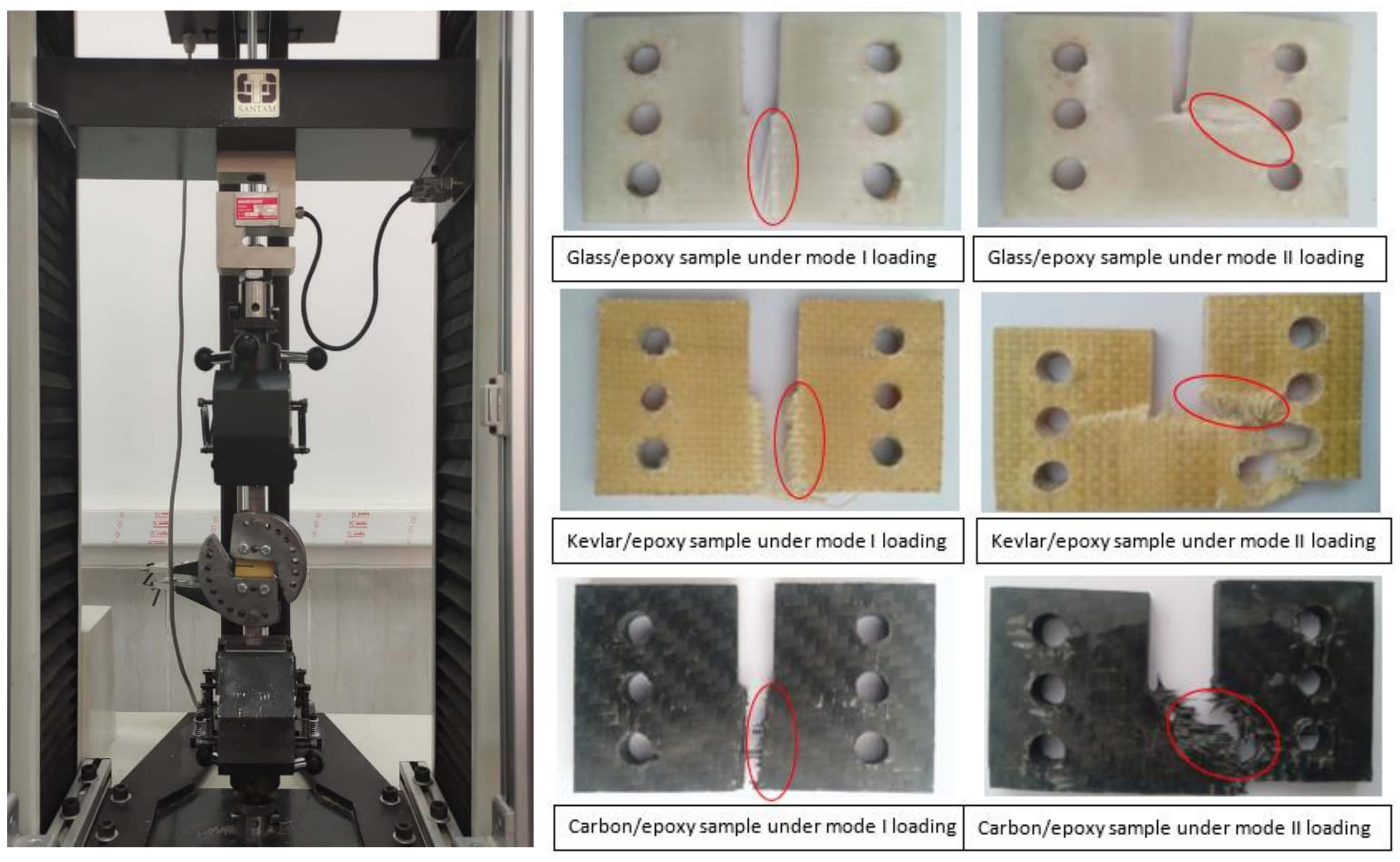


Figure 2 – The test setup used to measure the translaminar fracture toughness (left) and the tested samples (right)

Finite element analysis

Due to the lack of a data reduction method to determine the translaminar fracture toughness of the CTS specimens, in this study, a finite element based approach was used to calculate the fracture toughness of the tested specimens. The simulated composite sample was shown in Fig. 3.

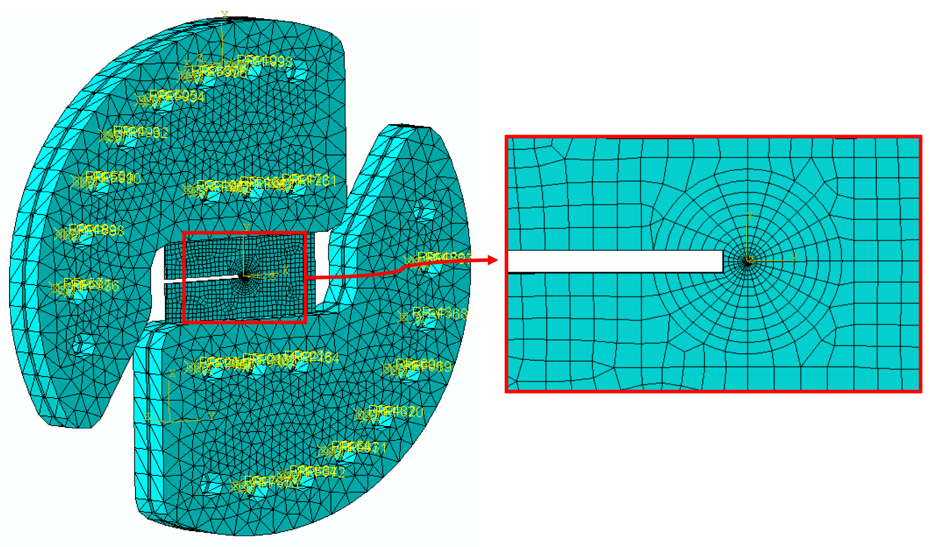


Figure 3 - The simulated CTS samples in Abaqus and the detail of the pre-crack tip area

The translaminar critical strain energy release rate and TFT of a laminated composites system is determined as follows [2]:

$$G_c = \frac{P_c^2}{2t}\gamma\delta e^{\delta a}\Big|_{a=a_0} \longrightarrow K = \sqrt{GE}$$

The compliance-crack length curves of different laminated composites systems under mode I and II loading conditions have been shown in Figs. 4a and b.

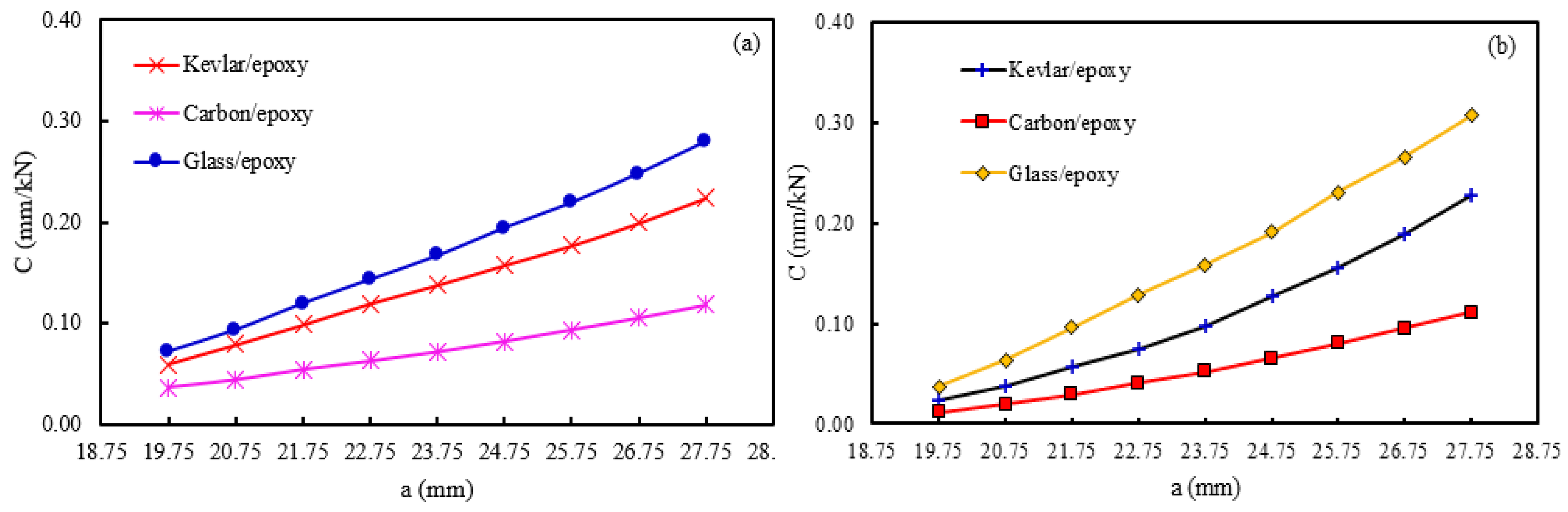


Figure 4 – The compliance calibration curves for different composite systems under (a) mode I and (b) loading conditions determined by the finite element analysis

Results

Fig. 5 shows the typical load-displacement curves obtained for different laminated composite systems.

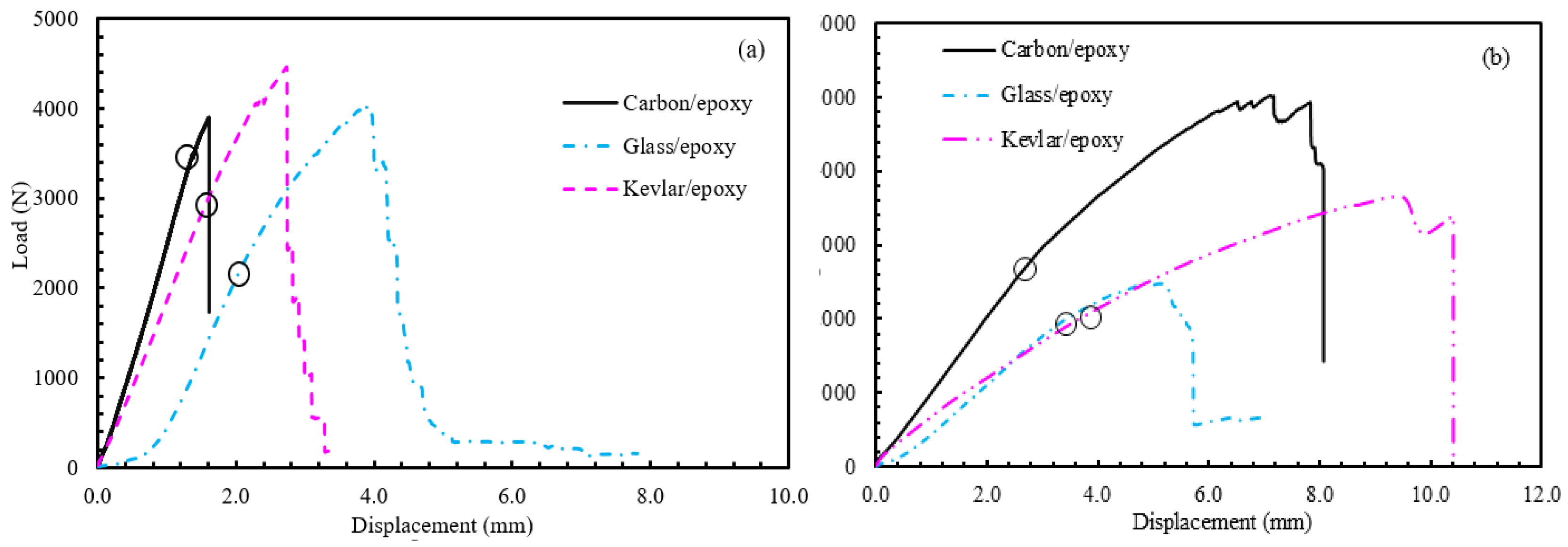


Figure 5 – The influence of fiber type on the representative load vs displacement curves obtained from the (a) mode I and (b) mode II translaminar fracture tests

The results obtained for modes I and II TFT of the composite systems have been listed in Table 1. As tabulated, the biggest value of TFT under both loading states was determined for the carbon/epoxy laminates. On the other hand, the E-glass/epoxy laminates has the smallest value of TFT and under both loading states. The strength of fibers used to reinforce the composites is the main reason that explains the mentioned expressions.

Table1 – The NL load, the related translaminar fracture toughness of different laminated composite systems under mode I and II loading states

Loading condition	Materials	P_{NL} (N)	$K_{C\text{-}NL}$ (MPa√m)
Pure mode I	E-glass	2226.4±146.7	13.19
	Carbon	3501.4±178.2	27.95
	Kevlar	2934.7±165.0	17.04
Pure mode II	E-glass	1862.9±227.1	12.27
	Carbon	2706.1±108.3	24.00
	Kevlar	1991.4±92.3	12.85

Conclusions

Some important conclusions can be stated as follows:

- The carbon/epoxy system has the best performance and highest TFT under both mode I and II loading condition.
- The crack deflection of all composite systems under mode I loading condition is similar to the brittle materials.
- Among the tested materials, the fiber bridging is widely observed in the Kevlar/epoxy system under mode I loading state. On the other hand, under mode II loading condition, the fiber bridging is mainly happened in the Carbon/epoxy system.

References

[1] *Akhavan-Safar, A., et al, Mode II fracture energy of laminated composites enhanced with micro-cork particles*, J Braz. Soc. Mech. Sci. Eng. 2021.**43:** p. 490.

[2] Laffan, M.J., et al., *Translaminar fracture toughness testing of composites: A review*, Polym. Test. 2012. **31**: p. 481–489.