Effect of specimen width and crack length on the fracture properties of glass/epoxy laminated composites

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Abstract

This paper investigates the effect of width of the specimen and crack length on the fracture properties of glass/epoxy laminated composites. Three different widths namely 30, 40 and 50 mm were considered. The gauge length of the specimen was taken in such a way that it was four times the width of the specimen, and five different crack length to width ratios (a/D) were taken into consideration namely 0, 1/8, 2/8, 3/8, 4/8. The tensile test was conducted in INSTRON 8862 universal tensile machine under displacement control mode. All the tensile tests were conducted at a strain rate of 1 mm/min.
Keywords: Apparent fracture toughness; Crack length; specimen width.

1. Introduction

The application of composite materials increased widely in nuclear, automobile, aerospace, marine, biomedical and other engineering areas due to their superior qualities like lightweight than metals, higher resistance to corrosion, durability, design flexibility, higher performance at elevated temperatures and it also offers the facility to fiber orientation. The size effects are defined as the change in mechanical or fracture properties of a material with the change in the size of the specimen.

Li et al. (2015) investigated the effect of width of the specimen on tensile properties of aligned short carbon fibre reinforced epoxy laminated composite. The tensile test results revealed that tensile strength increases with specimen width up to 25 mm. Xue et al. (2015) studied the tensile properties of UACS/Al laminates with different slit angles through experimentally and numerically by using finite element simulations. From the tensile test results, it was found that the higher tensile strength was obtained with smaller slit angles. Bhagat and Singh (2013) investigated the effect of specimen width, length, crack length and crack length to width ratio on stress intensity factor in both mode-1 and mode-II. It was found that the stress intensity factors in both Mode-I and Mode-II increase with an increase in crack length, and decrease with increase in size factor. Kawai et al. (2018) studied the specimen size effect and notch diameter to width ratio on the tensile strength of unidirectional carbon/epoxy laminated composites. It was found that by using scale-sensitive notch size effect law, it was possible to measure the opening fracture toughness for splitting failure of unidirectional carbon/epoxy laminated composites. Wisnom and Hallett (2010) studied the effect of thickness of the specimen, hole diameter and scaling techniques (sub-laminate level and ply-level) on tensile and compressive strength properties of carbon/epoxy composites. Wisnom (1999) presented a review of the effect of specimen size which is used for testing. It was found that the strength of the specimen decreases with increase in the volume of the specimen. It was found that size effect is the more considerable factor in both flexural and tensile tests. Kawai and Mitani (2016) investigated the effect of the size of specimen and length of a notch on the tensile properties of woven fabric carbon/epoxy composite laminates. Tensile tests were conducted on three different specimen sizes with unnotched specimens and double-edged notched specimens. It was concluded that tensile strength of specimen depends on the specimen size and notch size. It was found that the ratio of notched to an unnotched strength of specimen decreases with increasing length of the notch. It was found that for a given notch length the notched strength ratio increases with decreasing specimen size. A notch-size effect law introduced by using Neuber interpolation method. Bazant et al. (1996) studied the effect of specimen size on the nominal strength of notched samples laminated with graphite/epoxy composites. Tensile tests were conducted on four different specimen sizes with two different layups namely cross-ply and quasi-isotropic. Double-edged notches prepared with the cross-ply layup and single-edged notches are prepared with the quasi-isotropic layup. It was found that there is size effect on the nominal strength of the specimen and it agrees with size effect law proposed by Bazant. Different fracture parameters like fracture process zone, fracture energy, and effective length are calculated by using size effect law parameters. Johnson et al. (1998) conducted the tensile tests on composite laminates to study the specimen size effect on mechanical properties. Evaluated the effect of specimen size concerning ultimate stress and strain, delamination and first-ply failure strain. It was found that tensile strength of the specimen increases with increasing specimen size. Mahmoud et al. (2003) conducted the tensile tests on bidirectional, chopped and unidirectional Kevlar and glass/polyester

Nomenclature

a	crack length
L	gauge length of the specimen
D	width of the specimen
P	maximum load or failure load
t	thickness of the specimen
Do	constant depending on both specimen geometry and fracture process zone
B	constant characterizing the solution according to plastic limit analysis based on strength concept.
f_u	reference strength of the material (laminate), introduced to make constant *B* dimensionless.
σ_N	nominal strength
α	Relative size effect
g_N	coefficient introduced to make σ_N matches with maximum stress in the specimen determined by bending Theory.

laminated composites to evaluate the effect of arrangements of fibres and volume fraction of fibres. Effect of fibre orientations and length of crack on stress intensity factor and stress energy factor calculated. From the results, it was found that with the increase of crack length nearly there is no effect of stress intensity factor, but with the increase of crack orientation, there is a decrease in stress intensity factor. It was found that all the behaviors of bidirectional, chopped and unidirectional composites increases with the increment of the volume fraction of fibre. Castrodeza et al. (2005) conducted tests on SE(B) and C(T) specimens to investigate the influence of crack direction on fracture toughness of unidirectional fibre metal laminates. Notches were introduced parallel and perpendicular to the fibre direction in both SE(B) an C(T) specimens. Xu and Waas (2017) calculated the fracture toughness of woven textile composites by using single edged notch tensile specimens (SENT). The stress intensity factor was calculated by using both available stress intensity factor solutions and finite element method. The critical energy release rate is determined by using cohesive zone model, size effect law, and linear elastic fracture mechanics.

Even though several researchers presented the effect of specimen geometry, the fracture properties and size effect on glass/epoxy composites under different specimen geometry and different crack lengths are not available.

2. Size effect law:

The effect of specimen geometry on the nominal strength of geometrical alike quasi-brittile materials commonly follows the size effect law (Bazant, 1984, 1993);

$$\sigma_N = B f_u (1+\alpha)^{-1/2}, \alpha = \frac{D}{Do} \quad \textbf{(1)}$$

$$\sigma_N = g_N P / BD$$

3. Experimental program

3.1 Material used for testing

The glass/epoxy laminated composites are prepared by hand layup method. Diglycidyl Ether of Bisphenol A (DGEBA) type epoxy resin was utilized as a matrix, and triethylene tetra amine (TETA) was utilized as hardener. The epoxy resin and a hardener was supplied by Hindustan Ciba Giegy Ltd. The epoxy resin and hardener are mixed in 10:1 weight ratio as per suppliers recommended standard.

3.2 Glass/epoxy laminate preparation

The fabrication of glass/epoxy composite laminates is done by using hand layup method. Eight layers of woven fabric E-glass fibres were fabricated by taking 50:50 weight fraction of glass fibre and epoxy. The plates of sizes

400 mm X 400 mm were fabricated, after that the plates are allowed for curing at room temperature for three days by applying the load of 20 kg over it. After completion of curing the specimens of required sizes were cut with the help of hand cutting machine.

3.3 Preparation of specimens

The specimens were cut from 400 mm X 400 mm fabricated glass/epoxy composite laminate in three different sizes. The shape and geometry of the specimen shown in Fig. 1. The dimensions of the three different sizes as shown in Table 1.

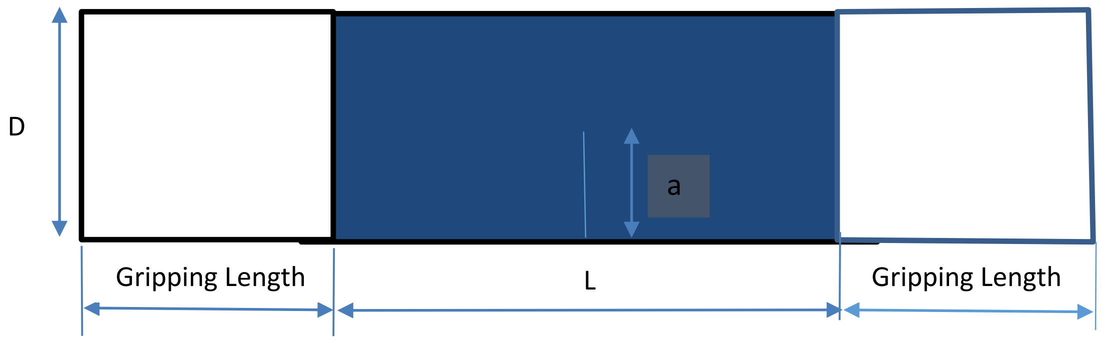


Fig. 1 Geometry of the specimen

Table 1. Dimensions of test Geometry (in mm)

	D	L	Gripping Length	t	Crack length (a)				
					(a/D)=0	(a/D)=1/8	(a/D)=2/8	(a/D)=3/8	(a/D)=4/8
Size-1	50	200	50	3.46	0	6.25	12.5	18.75	25
Size-2	40	160	50	3.46	0	5	10	15	20
Size-3	30	120	50	3.46	0	3.75	7.5	11.25	15

The crack was introduced with the help of hacksaw blade as shown in Fig. 2. (a). Five different crack length to width of the specimen ratios (a/D) were maintained namely 0, 1/8, 2/8, 3/8, 4/8.

Fig. 2. (a) Introducing a crack with hacksaw blade; (b) Specimen after introducing a crack

3.4 Tensile testing

The tensile test was performed in INSTRON 8862 Universal testing machine (UTM) shown in the Fig. 3(a) to evaluate the tensile properties. Three samples were tested for each (a/D) ratio. A total of 15 specimens were tested per each width. The samples were tested at a loading rate of 1 mm/min.

Fig. 3. (a) INSTRON 8862 universal testing machine; (b) Specimen under testing.

In order to determine the size effect law parameters by using linear regression of experimental results, we introduced the below terms

$$D = X$$

$$\sigma_N = Y^{-1/2}$$

$$Bf_u = E^{-1/2}$$

$$Do = \frac{E}{F} = \frac{1}{F(Bf_u)^2}$$

The size effect law in Equation. (1) can be represented in the form

$$Y = E + FX$$

Table 2. Nominal strength (in Mpa) and fracture parameters for different tested geometry

σ_N	30	40	50	Bf_u (MPa)	Do (mm)
(a/W) = 0	246.4	219.1	192.3	0	0
(a/W) = 1/8	148.5	134.9	133.5	180.23	57.65
(a/W) = 2/8	126.9	109.1	107.6	185.85	23.83
(a/W) = 3/8	89.9	82.2	81.7	106.94	66.05
(a/W) = 4/8	71.5	66.0	64.7	86.12	61.84

A linear regression analysis was conducted by plotting width versus nominal strength for different (a/D) ratios by taking width on x-axis and nominal strength on y-axis as shown in Fig. 4.

The size effect law parameters were obtained from the slope E and the vertical intercept F of the plots are as follows:

Linear regression curves for different (a/D) ratios:

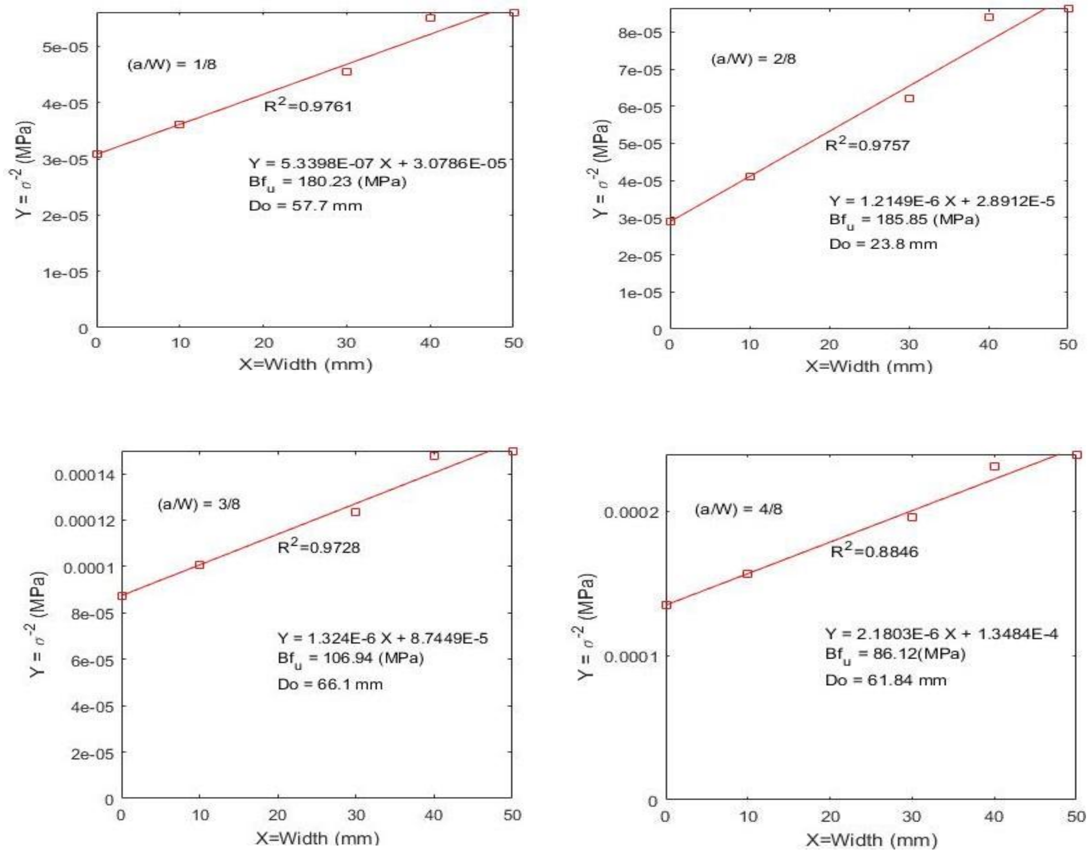
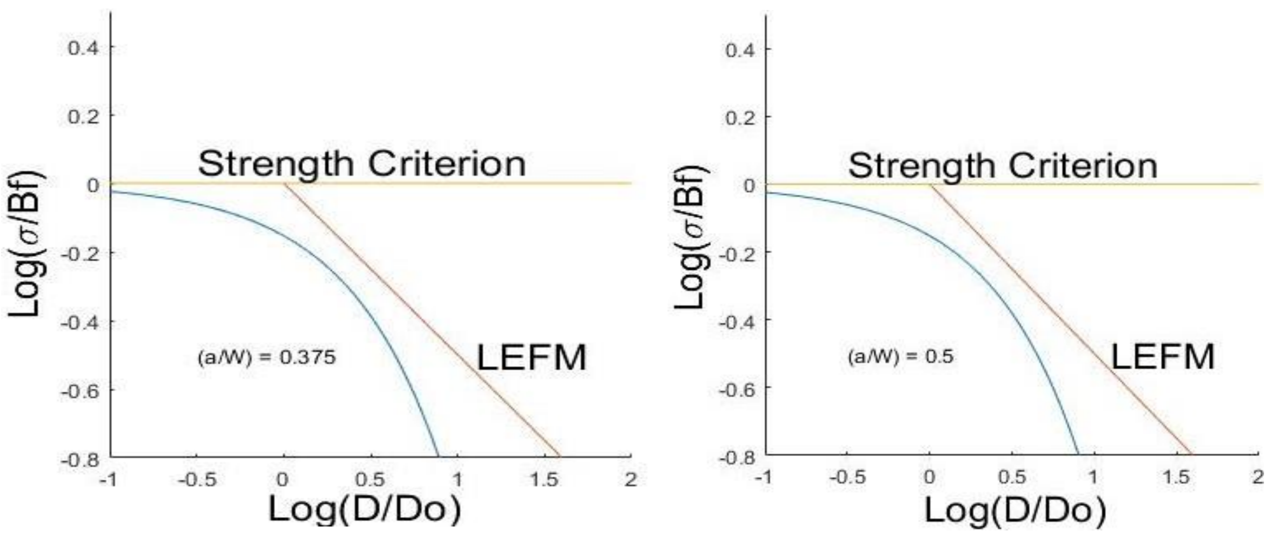


Fig. 4. Linear regression plots for determining size effect parameters

Fig. 5 represents the size effect plots at different (a/D) ratios ranging from 1/8 to 4/8. the plot between logarithm of nominal strength versus logarithm of characteristic dimension coincides with size effect law proposed by Bazant, which is transition between strength criterion and linear elastic fracture mechanics.

Size effective curves for different (a/D) ratios:



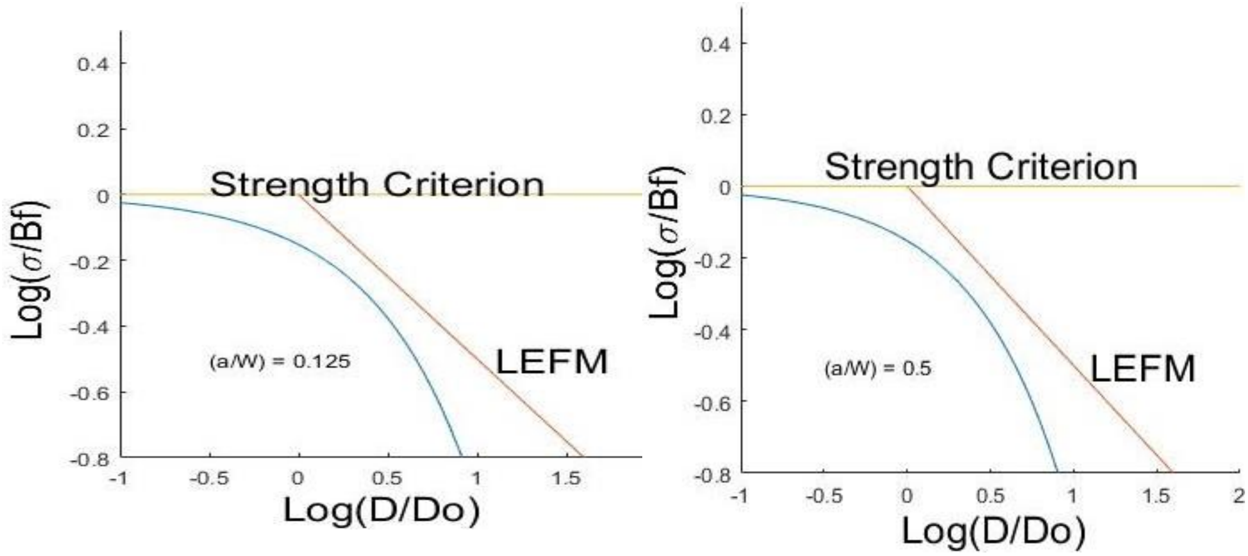


Fig. 5. Size effect curves for different (a/D) ratios

4. Conclusions:

1.Tensile tests was conducted on five different (a/D) ratios namely 0, 1/8, 2/8, 3/8,4/8 at a strain rate of 1 mm/min.
2.The nominal strength of the glass/epoxy composites increase with decrease in width of the specimen.
3.The present tests with different widths shows that the nominal strength of glass/epoxy composite laminates with different (a/D) ratios exhibits a significant size effect.
4.The size effect observed coincides with the size effect law suggested by Bazant, according to which curve of the logarithm of nominal strength versus logarithm of characteristic dimension exists a smooth transition from strength criterion to inclined asymptote of slope -0.5.

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