EXPERIMENTAL INVESTIGATION OF SIZE EFFECT AND FRACTURE CHARACTERISTICS OF TWO DIMENSIONAL COMPOSITE LAMINATE

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Keywords: Composite material, Fracture mechanics, Tensile testing, Size effect

ABSTRACT

Designing of large composite structure is a difficult task because the size effect factor is often overlooked in the studies of composites.

This study is about how size of structure affects the strength of the structure. These studies contribute and analyze the size effect experimentally. Tensile tests are performed on the single edge notched tension specimens which are made of glass fiber (reinforce) and polyester resin (matrix). Geometrical similar specimens are considers for testing. Results of test show that strength of specimen is decrease while increasing the size of specimen and from the from linear regression analysis size effect is measure. Bazant's size effect law allows to measure fracture characteristics of composite material accurately.

The main conclusion of the study is to find fracture energy and fracture process zone. This can accomplished neither by LEFM nor stress strain approaches which does not count size effect.

1. Introduction

When two or more than two materials which have different properties, are combined and form a material of different properties is known as composite material. Composite material have some magnificent properties and because of its properties, the use of composite material is becoming wider and wider. Applications of composite material include in nuclear energy, air, marine and ground transportation, wind energy, sports equipment etc. However, it is difficult to design large composite structure because Stress Strength approach and LEFM approach cannot predict the strength of the composite material.

For finding material properties it is necessary to use the specimen of specific size. Then a basic question arises: does the size of specimen affect the value of measured property? And the answer of this question introduces the term "size effect". It must be noted that according theories of elasticity and plasticity, the strength of structure does not depend upon size but in reality it does and this phenomenon is known as size effect.

Bazant [2] suggest the term size effect and he also suggest that the fracture energy release is the main reason behind the size effect. Further bazant and kazami [3,4,5] determines the fracture characteristics in different composite material. They suggest that size effect is intermediate between the elasticity (ductility or max. size effect) and plasticity (brittleness or zero size effect). Thus the size effect plot (log σ_N Vs. log D) shows that for smaller size specimen, max. size effect occurs means results are completely differ from linear elastic fracture mechanics and the specimen behaves like ductile material and for larger specimen, minimum size effect occurs means the results are almost same as Linear elastic fracture mechanics and large structure behave like brittle structure.

This study only deals with the size effect occur when width of the specimen is varied but if the thickness is varied how different type of size effect occurs, is not investigated here. Size effect method is use for measuring fracture characteristics of composite specimen and this is the simplest method to measure fracture characteristics because this method only require peak load and for testing material simple testing machine without controller can be use.

2. Test description

2.1 Material

Tests were conducted on the specimens manufactured by hand lay-up process. A polyester based resin was chosen for matrix material and glass fiber of E class was selected for the reinforced material. The material was following ASTM standard procedure of tensile testing under the uniaxial load. Material properties of composite material are shown in **Table1**.

Table 1
Properties of fiber glass reinforced composite

Property	Sign	Value
Fiber volume ratio	V_f	0.66
Laminate Thickness	t (mm)	1 mm
Longitudinal modulus	E_1 (GPa)	48.015
Transverse modulus	E_2 (GPa)	23.81
In-Plane shear	G_{12} (GPa)	4.94
Major poisson ratio	υ_{12}	0.2541
Minor poisson ratio	υ_{21}	0.1215

2.2 Specimen characteristics

Following bazant size effect tests were conducted on single edge notched tension specimens of 1 mm thickness. Specimens were selected of three different sizes and specimens were scaled in two dimension. The width of specimen was taken in the ratio of 1:2:4. And the length to width (L/D) ratio was taken as 2.25 for all specimens. The notch size was taken as D/5. The notch was made by wire cutting and the radius of crack tip was 0.1 mm. Specimens were prepared with 38 mm of gripping section. Gripping section was not scaled because the failure occurs away from gripping section. **Table 2** shows geometrical specifications of SENT specimens and **fig. 1** shows the schematic design of specimens.

Table 2
Specification of SENT specimen.

Size	Width (mm)	Gauge length (mm)	Total length (mm)	Crack length (mm)	Thickness (mm)
Small	15	33.7	109.7	3	1

Medium	30	67.5	143.5	6	1
Large	60	135	211	9	1

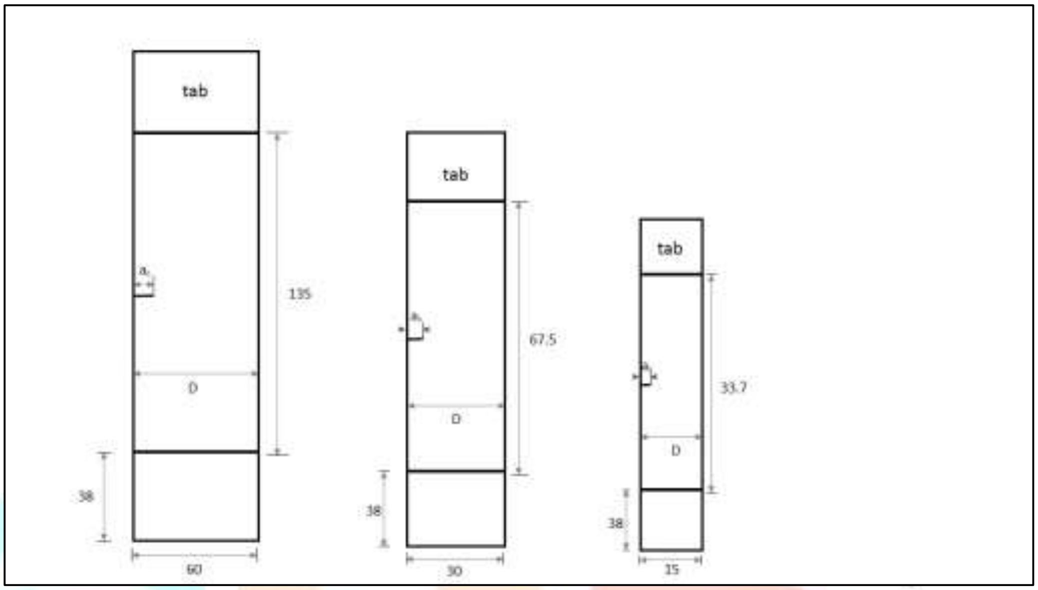

Fig. 1 geometry of single edge notch tension specimens (units: mm)

2.3 Testing

Tests were performed on uni-axial servo hydraulics UTM (Universal Testing Machine) with a 20 ton capacity at a constant crosshead rate. The feed rate, 5 mm/min was constant for all specimens. 20 mm/min was taken as a home rate for all specimens. Load and displacement data were recorded in software. From that data load-displacement curve plotted.

3. Test results

After completing tests load displacements data were analyzed. Fig. 2 shows comparison of load displacement curves of all SENT specimens. It is important to note that, for the largest size specimen load displacement curve is almost linear but for smaller size specimen load displacement curve is nonlinear means the large size specimen behaves like brittle material and small size specimen behaves like ductile material.

Fig.2 shows that the failure of specimen occurs quickly after the peak load. Damage consisting of micro cracks in between ply, delamination between plies observed before the max. load and the fiber breakage and fiber pull-out can be observed after the max. load.

Table 2 shows the test result and nominal stress values. From the Table 2 it can clearly see that the strength of the structure is decreases while increasing the size of specimen.

Table 2

Tensile test results of SENT specimens

Thickness (mm)	Width (mm)	Load (N)	Nominal Strength (MPa)
1	15	1234.95	82.35
1	30	20589.6	68.6

1	60	4205	53.1

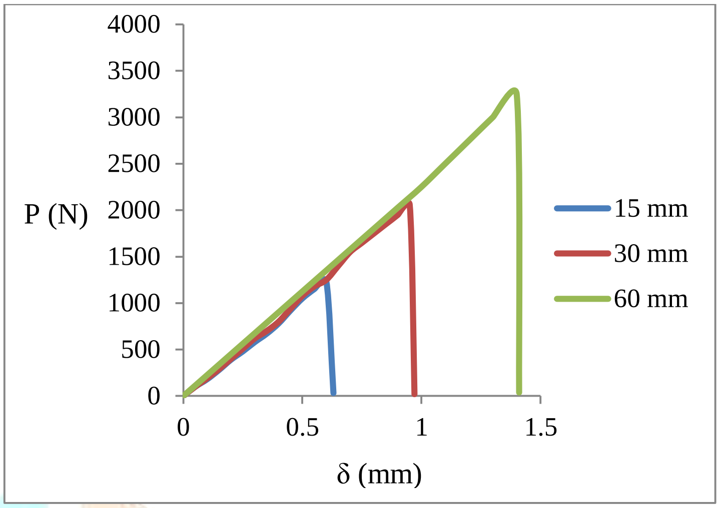

Fig. 2 SENT Specimens of 1 mm thickness

4. Discussion

4.1 Observed size effect and analysis of size effect by size effect law

Bazant size effect law is a relationship between the strength of the specimen and size of specimen. Eq. (1) shows the relationship between σ_N (nominal strength) and D (width).

$\sigma_N = \frac{\sigma 0}{\sqrt{1+\frac{D}{D0}}}$ ……………………………(1)

Where, σ_N is nominal strength of specimen, D = width of the specimen, σ_0 and D_0 are the constant depending upon geometry and fracture process zone of material. This parameters (σ_0, D_0) can be determine by linear regression of eq.(1). Define following

D = X;

$A = \sigma_0^{-2}/ D_0$ ……………… (2)

$B = \sigma_0^{-2}$ ...………………. (3)

$\sigma_N^{-2} = Y$;

So, the eq. (1) became Y = A*X + B………………. (4)

Following calculation shows the linear regression analysis of SENT specimens of 1mm thickness. Linear eq. can be derived from the stress (σ_N) for the known value of width (D). Further that linear eq. is used for calculating the parameters (σ_0 & D_0).

Y = 4.306 X + 82.93

Linear regression analysis which was conducted on SENT specimens of 1 mm thickness and represented in fig. 3. From that following parameters estimated. A = 4.306 $(GPa)^{-2}$ $(mm)^{-1}$ and B = 82.93 $(GPa)^{-2}$ and from eq. (2) and (3) σ_0 = 109.81 MPa and D_0 = 19.26 mm.

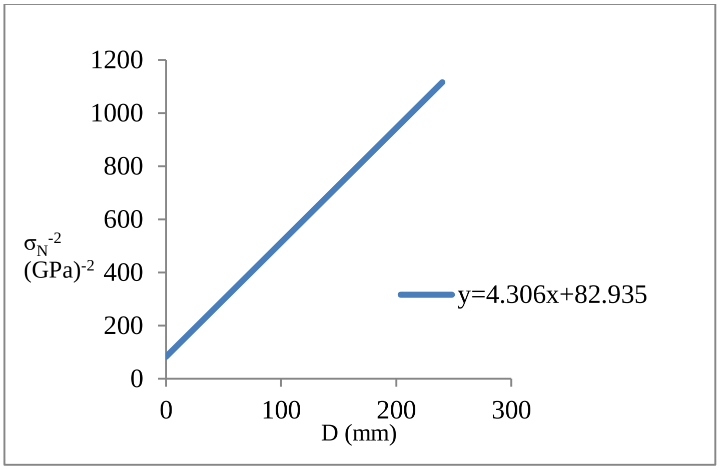

Fig.3 linear regression analysis of SENT specimen

Furthermore, result data were fitting by Size effect law. Fig 4 shows the measured size effect. Which clearly shows that smaller size specimen shows more size effect than larger size specimen.

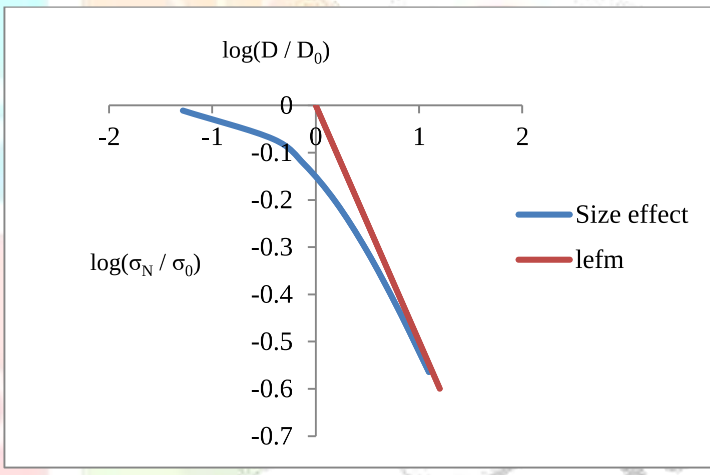

Fig.4 measured size effect

4.2 Determination of fracture energy and fracture process zone by estimation from measured size effect

The parameters of size effect A and B are directly related to fracture energy of structure and fracture process zone length. And the relationship between them is shown below.

$A = g(\alpha_0) / E^* G_f$ & $B = C_f\, g'(\alpha_0) / E^* G_f$ …………………………(5)

Where, $g(\alpha_0)$, E^* and $g'(\alpha_0)$ are the known factors.

$E^* = \sqrt{\frac{2E1E2\sqrt{\lambda}}{1+\rho}}$ ……………………(6)

$\lambda = E_2 / E_1$; $\rho = \frac{\sqrt{E1\ E2}}{2\ G12} - \sqrt{\upsilon 12\ \upsilon 21}$

Measured value of G_f = 21.94 N/mm and C_f = 1.964 mm

5. Conclusion

1 This investigation shows the significant size effect of geometrical similar SENT specimen.
2 Measurements of size effect are uses for measuring the fracture characteristics. The size effect method of measuring fracture characteristics is the simplest one because it only requires maximum load.
3 Results show that the ductility of specimen is decreased while increasing the size of specimen.

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