Influence of Filler Materials on Pinned Joints of Woven Glass Fiber Reinforced Epoxy Composites

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Abstract: Fiber reinforced composite materials have been gaining wide application in aircraft submarine and spacecraft constructions, to strengthen bridges and other civil engineering structures. Joints are formed using mechanical fasteners and load sharing in these joints depends on the number, size, and material of the bolts and the stiffness of the joining members. Therefore, suitable revealing methods for the failure strength would help in selecting the appropriate joint size in a given application.

The objective of the present work is to determine the bearing or failure load of filler added woven glass fiber/epoxy composites through single and double serial pinned joints with different parameters by experimental methods. The effect of the distance from free edge to the diameter of first hole (E/D) ratio, the width of plate to diameter of hole (W/D) ratio and the effect of filler materials on Titanium dioxide (TiO_2) and Zinc Sulphide (ZnS) on bearing load are experimentally investigated using laminated woven glass fiber composite plate with single and double serial pinned joints.

Keywords: Polymer Matrix Composites, Pinned joints, Fillers, Failure load.

INTRODUCTION

Advanced glass composite materials with anisotropic properties created an innovative need for new test specimens and test procedures. A composite is a system that is created by the synthetic assembly of two or more materials: including selected filler or reinforcing element and a required resin as binder to obtain specific characteristics and properties. The behavior and properties of this interface will control the properties of the composites. We can find excellent applications of composite materials in many structures and industries had increased because of their outstanding behavior.

The decent knowledge regarding the material properties and its behavior under loading conditions is much required. Alaattin Aktas [1] analyzed failure mode and failure load of woven glass fiber epoxy composite plates with one and two serial pinned joints experimentally and numerically. For analysis two variables are considered for investigation. A good correlation was found between experimental results and numerical predictions. Alaattin Aktas *et al.* [2] conducted failure load and failure mode of glass-epoxy composite plates. The distance from the free edge of plate to the diameter of the first hole (E/D) ratio (2, 3, 4, 5), and the width of the specimen to the diameter of the holes (W/D) ratios (2, 3, 4, 5). Ramazan Karakuzu *et al.* [3] studied on the effects of geometrical parameters such as the edge distance-to-hole diameter ratio (E/D), plate width-to-hole diameter ratio (W/D), and the distance between two holes-to-hole diameter ratio (M/D) on the failure loads and modes in woven glass fiber reinforced vinylester composite plates with two serial pin-loaded holes. Marie-Laure Dano *et al.* [4] worked on Stress and failure analysis of mechanically fastened joints in composite laminates. They reviewed on single mechanically fastened joints in fiber-reinforced plastics. The Finite Element model used to account contact at the pin-hole interface, progressive damage, large deformation theory, and a non-linear shear stress-strain relationship. H. J. Lin *et al.* [5] examined failure strength of a woven-glass-roving composite for circular hole. Two types of circular holes, drilled and moulded-in were considered. Failure experiments on (0, 90), and (f 45) S woven-roving composites are conducted on samples with four various size of hole diameters. The Hashin strength criteria and a material degradation model were used analysis of strength and numerical results are obtained. A.Nanda Kishore *et al.* [6] obtained failure modes and loads for multi-pin joints in un-directional glass fiber-epoxy composite laminates by finite element analysis and correlating the results with the experimental work. In multi-pin joints, the effect of variation in pitch-to-diameter ratio (P/D), side width-to-diameter (S/D) and edge-to-diameter (E/D) ratios plays important role in composite laminates.

In the present work an attempt has been made to evaluate the effect of filler materials on pinned joints of woven glass fiber reinforced polymer composites.

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Table 1: Composite Combinations

Sl. No.	Filler	Volume fraction	Representation
1		Glass Fabric 60% + Epoxy 40%	GE
2	ZnS	Glass Fabric 59%+ Epoxy 40% + ZnS 1%	GEZ1
3		Glass Fabric 58%+ Epoxy 40% + ZnS2%	GEZ2
4		Glass Fabric 57%+ Epoxy 40% + ZnS3%	GEZ3
5	TiO_2	Glass Fabric 59%+ Epoxy 40% + TiO_2 1%	GET1
6		Glass Fabric 58%+ Epoxy 40% + TiO_2 2%	GET2
7		Glass Fabric 57%+ Epoxy 40% + TiO_2 3%	GET3

MATERIALS AND EXPERIMENTATION

Materials

The type of Glass Fiber mat selected was Mat – 2 (330GSM). The matrix material used was a medium viscosity epoxy resin (LAPOX L-12) and a room temperature curing polyamine hardener (K-6). This epoxy resin was selected since it provides good resistance to alkalis and has excellent adhesive properties**.** In the present work, two fillers materials have been used i.e. Titanium dioxide (TiO_2) and Zinc Sulphide (ZnS). These fillers can improve mechanical properties including fire and smoke performance by reducing organic content in composite laminates.

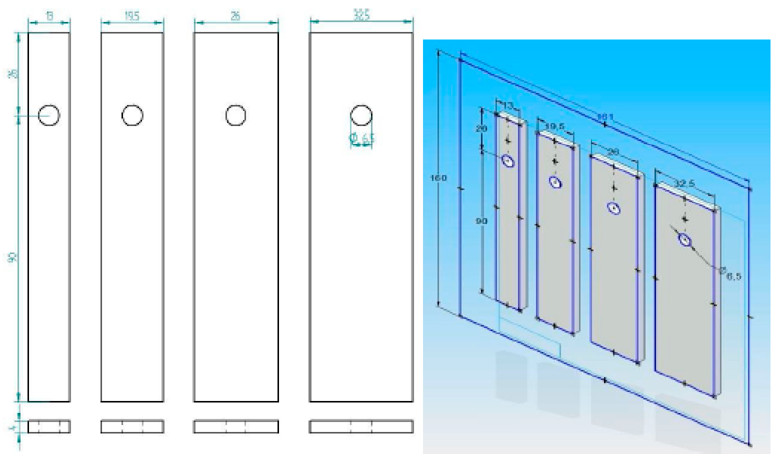

Figure 1: Dimensions of single pinned specimens (E/D ratio varied).

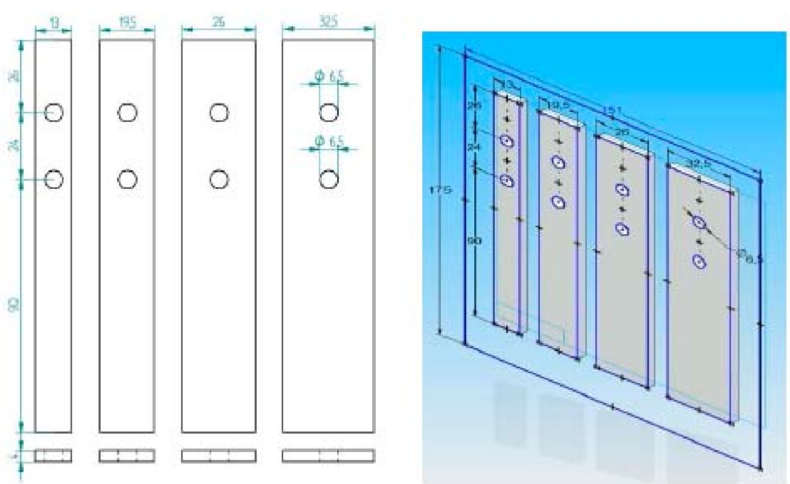

Figure 2: Dimensions of serial pinned specimens (E/D ratio varied).

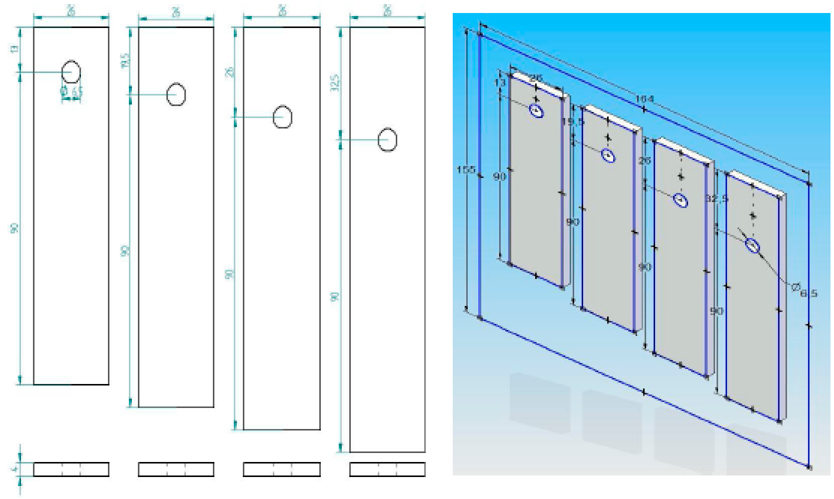

Figure 3: Dimensions of single pinned specimens (W/D ratio varied).

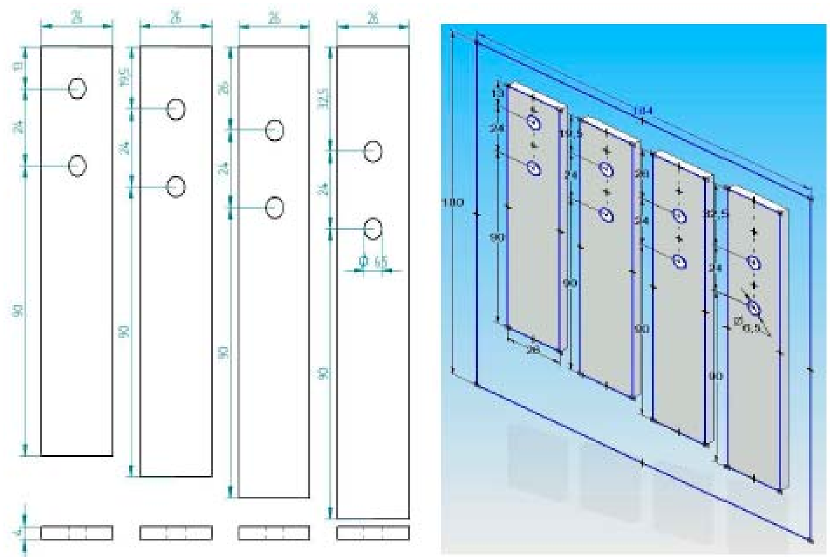

Figure 4: Dimensions of serial pinned specimens (W/D ratio varied).

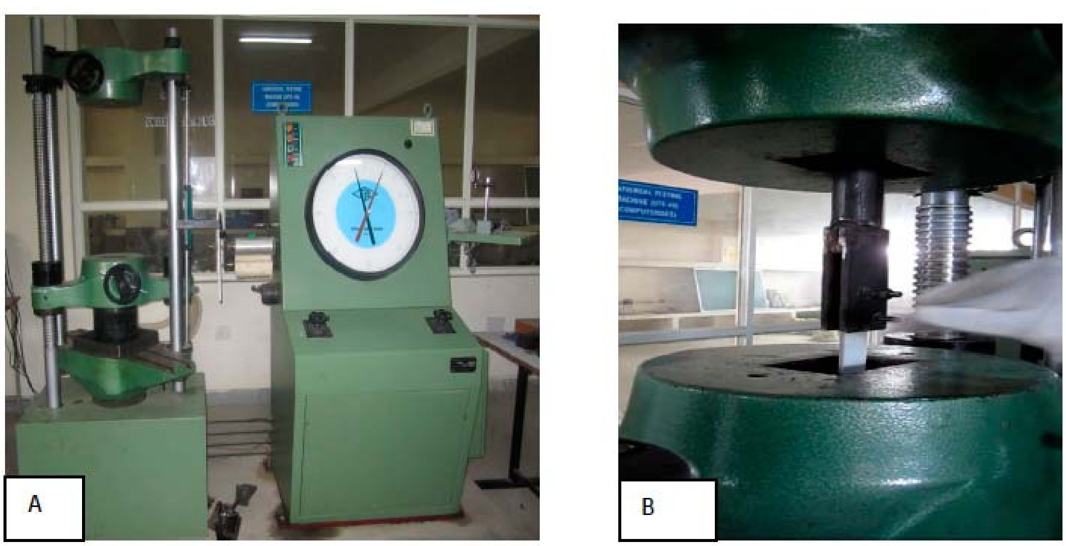

Figure 5: (**A**) shows Universal testing machine (**B**) Experimental setup.

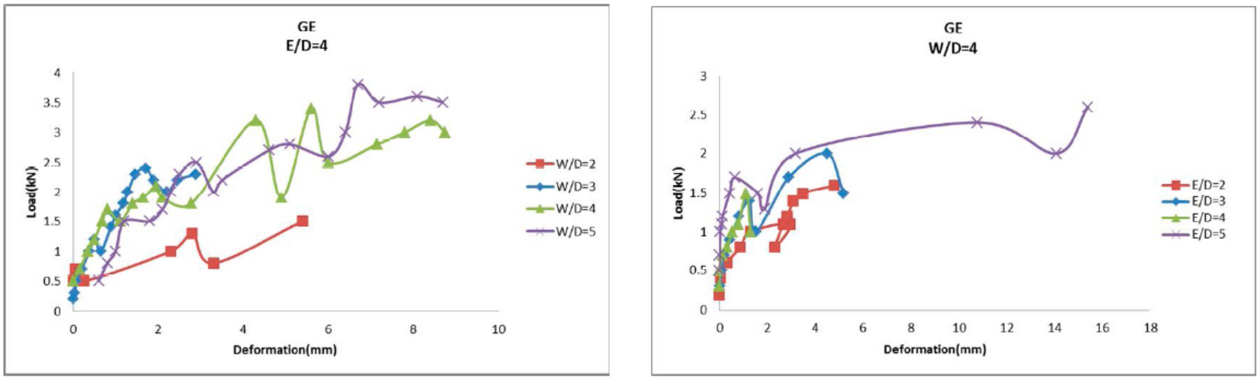

Figure 6: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (without filler material).

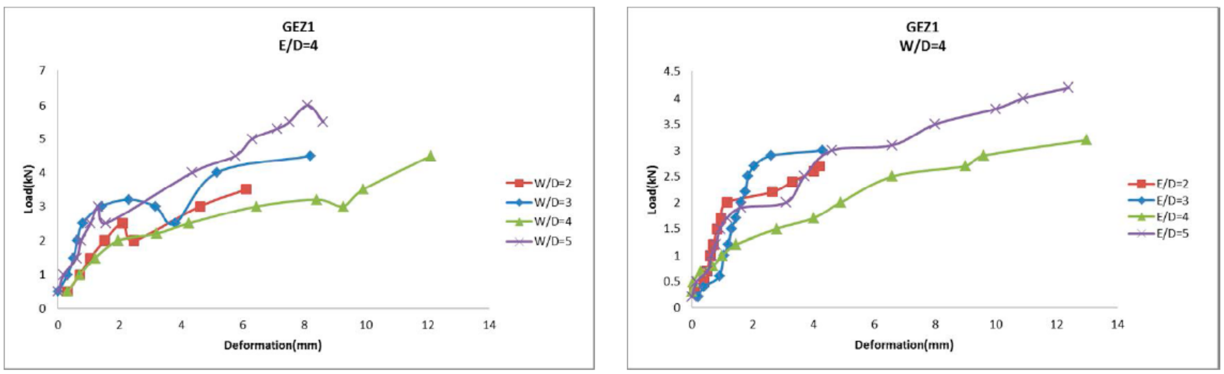

Figure 7: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 1% ZnS filler material).

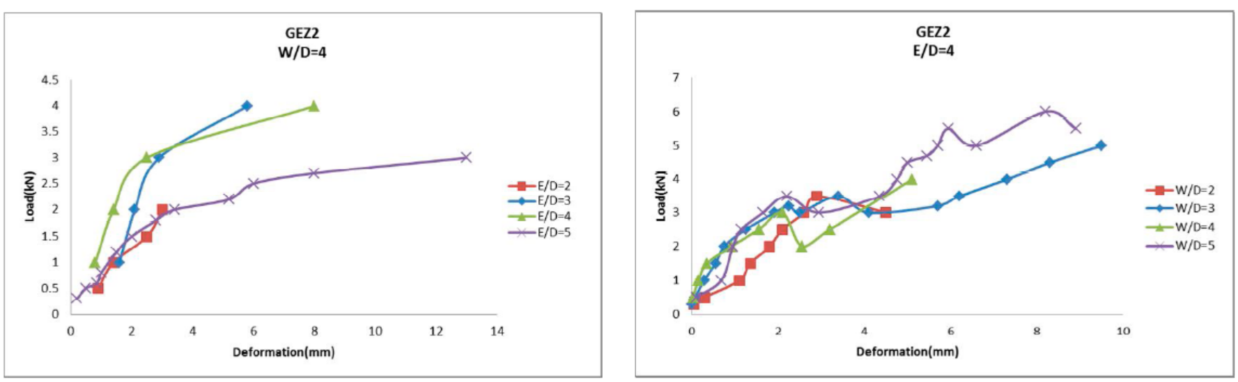

Figure 8: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 2% ZnS filler material).

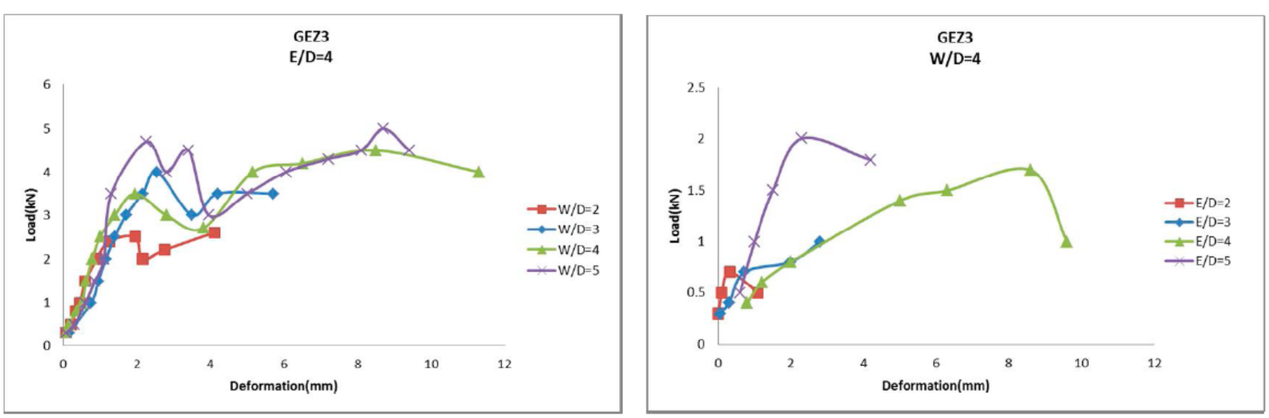

Figure 9: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 3% ZnS filler material).

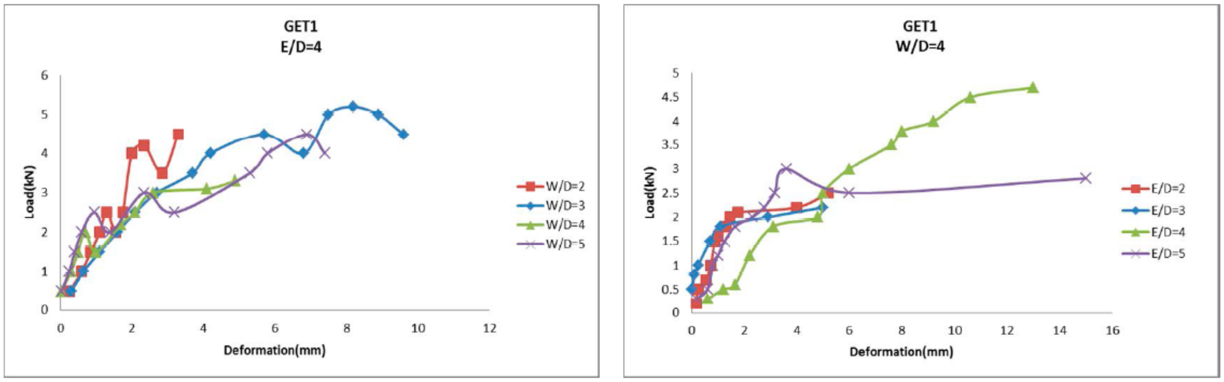

Figure 10: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 1% TiO_2 filler material).

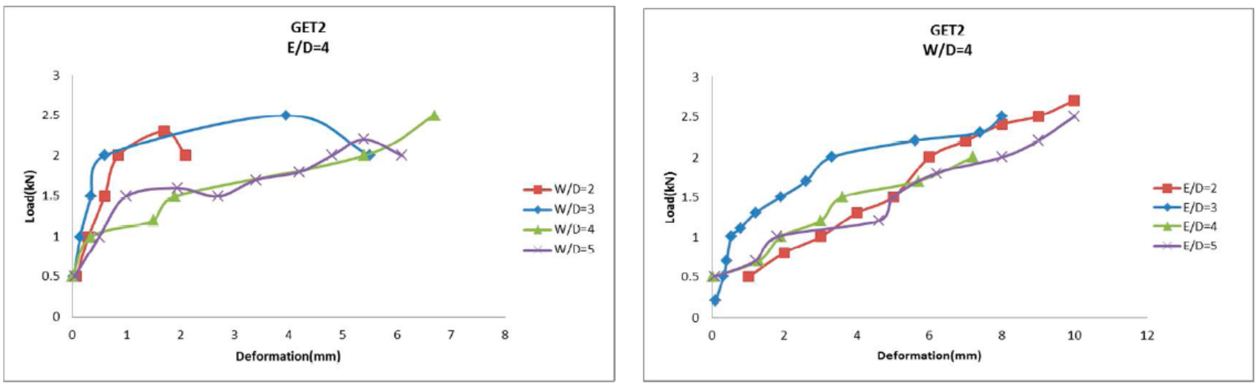

Figure 11: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 2% TiO_2 filler material).

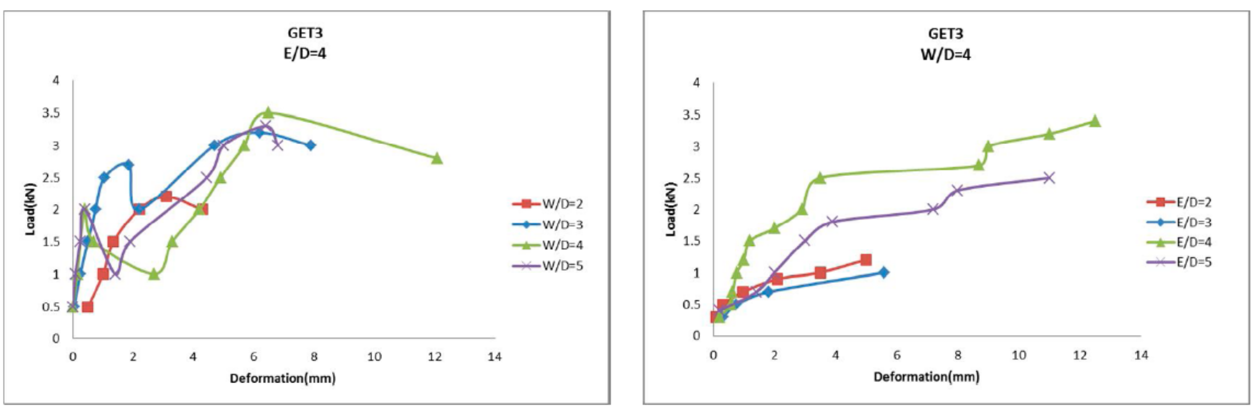

Figure 12: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 3% TiO_2 filler material).

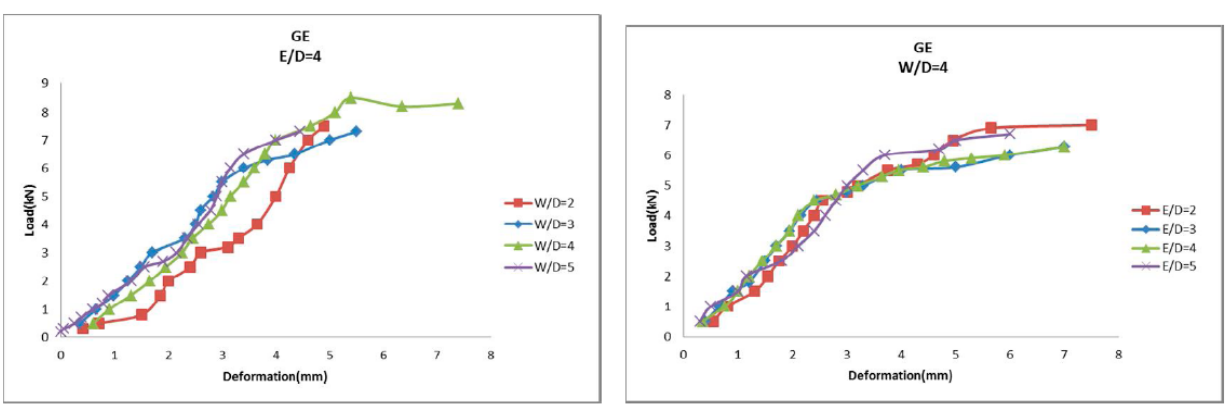

Figure 13: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (without filler material).

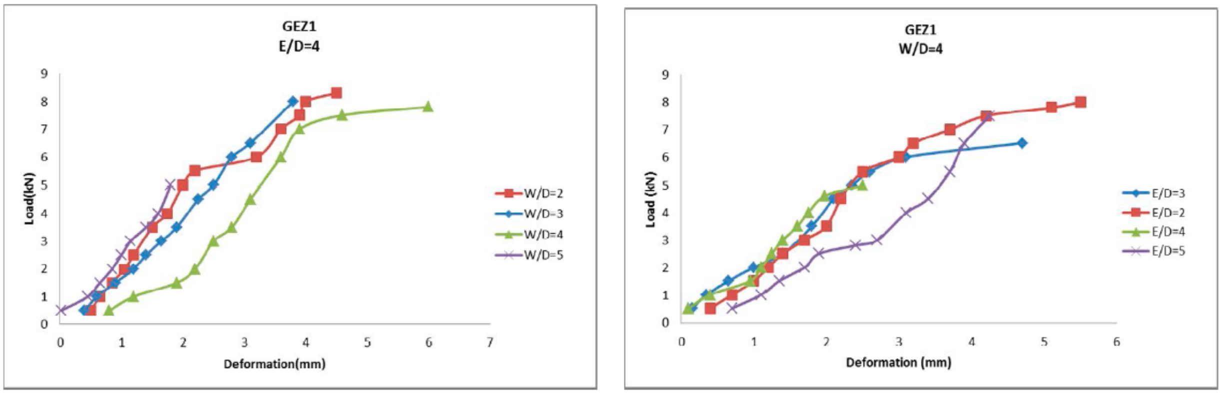

Figure 14: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 1% ZnS filler material).

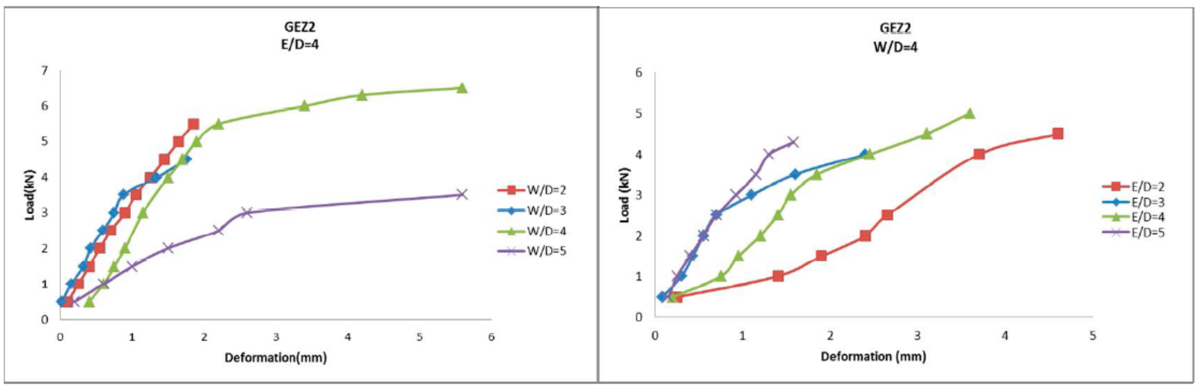

Figure 15: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 2% ZnS filler material).

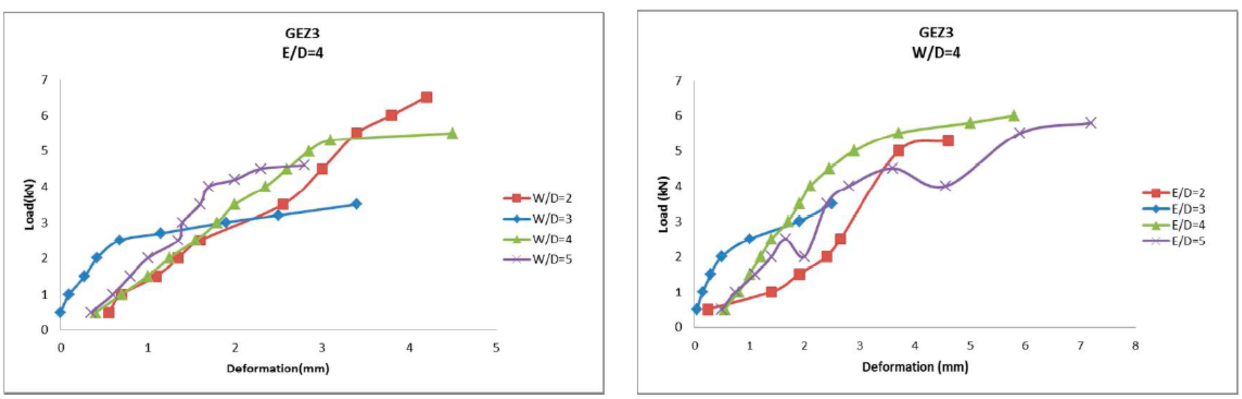

Figure 16: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 3% ZnS filler material).

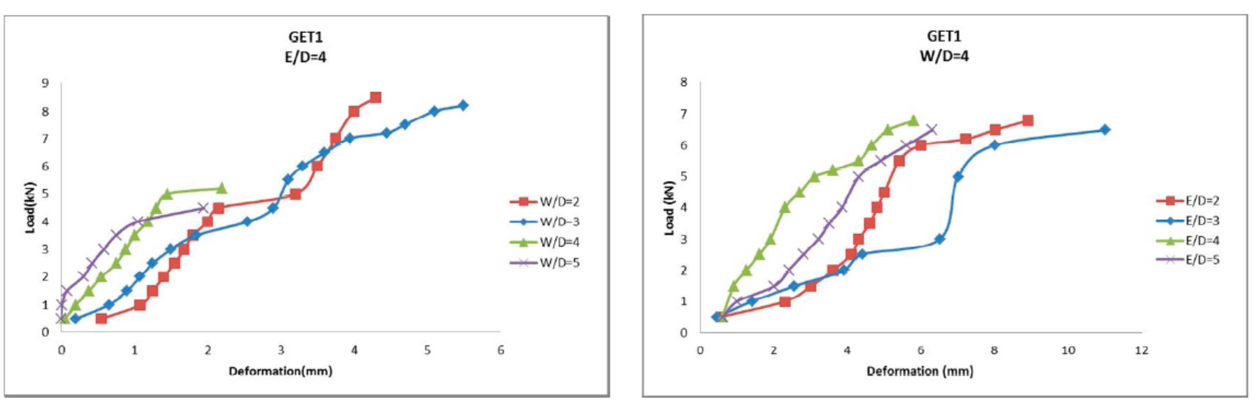

Figure 17: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 1% TiO_2 filler material).

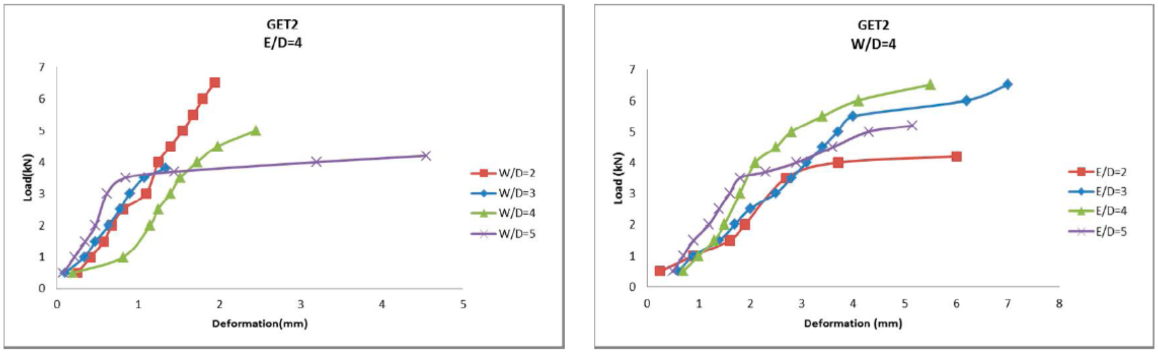

Figure 18: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 2% TiO_2 filler material).

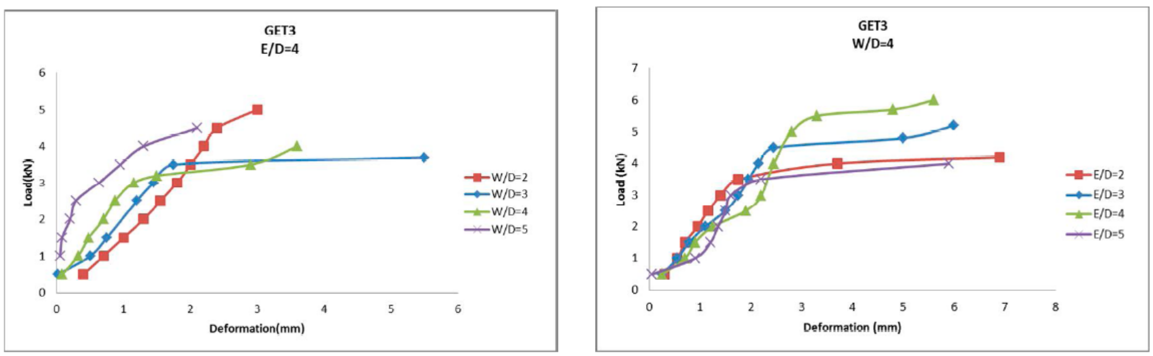

Figure 19: Load v/s Deformation for single pinned specimens by varying W/D & E/D ratios (with 3% TiO_2 filler material).

Specimen Preparation

Fabrication of the composites is done through the Hand-lay-up technique. The required proportion of constituents were added to attain required volume fraction. The constituent involves the woven fabric E-Glass fibers, epoxy of L-12 grade, K6 hardener and filler materials. The various proportions are as shown in following Table **1**. Experimentations were carried-out on all varieties of specimens in accordance with ASTM D953 standards. The dimensions of the specimens are shown in Figures **1**, **2**, **3** & **4**. Figure **5A** shows the universal testing machine which is used for testing and Figure **5B** shows the experimental set up to carry out the test.

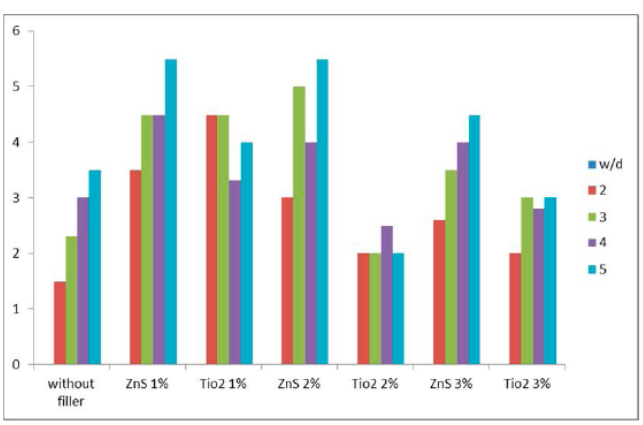

Figure 20: Comparison of failure load for different compositions of single pinned specimens with varied W/D ratio.

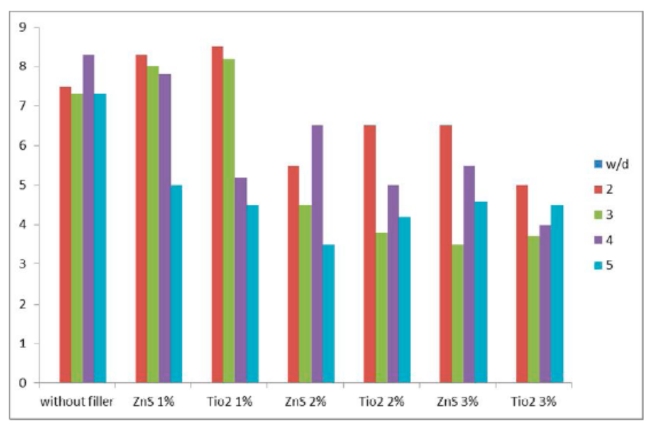

Figure 21: Comparison of failure load for different compositions of serial pinned specimens with varied W/D ratio.

DISCUSSIONS

The failure strength of ZnS and TiO_2 filled composite is compared with that of unfilled composite separately. From the above figures the following discussions can be obtained,

1) As shown in Figure **20**, For single pinned joint when (E/D)=4, the failure strength increases as

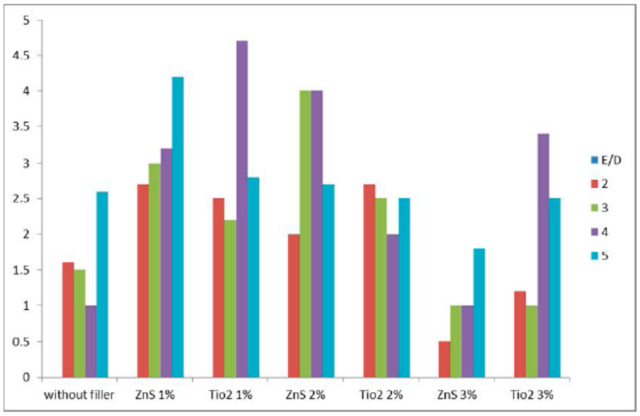

Figure 22: Comparison of failure load for different compositions of single pinned specimens with varied E/D ratio.

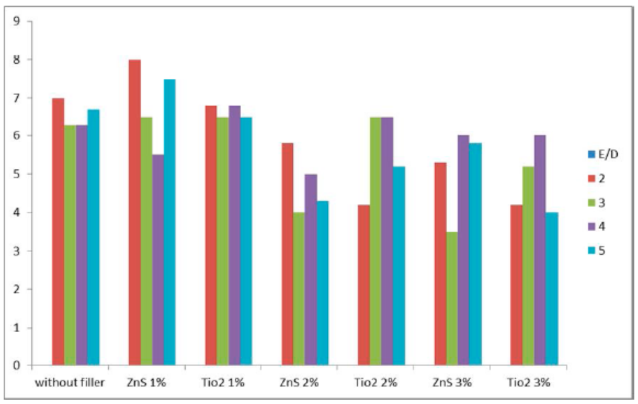

Figure 23: Comparison of failure load for different compositions of serial pinned specimens with varied E/D ratio.

(W/D) ratio is equal to 2, 3, 4 & 5 and ZnS filler is equal to 0%, 1%, 2% & 3%. Also the failure strength increases as (W/D) ratio is equal to 2, 3, 4& 5 and TiO_2 filler is equal to 0% & 1%.

a) Maximum value (5.5 kN) of failure strength is observed for composite with single pin, (E/D) = 4, (W/D) = 2 and 1% TiO_2.

b) Maximum value (5 kN) of failure strength is observed for composite with single pin, (E/D) = 4, (W/D) = 3 and 2% ZnS.

c) Maximum value (4.5 kN) of failure strength is observed for composite with single pin, (E/D) = 4, (W/D) = 4, and 1% ZnS.

d) Maximum value (5.5 kN) of failure strength is observed for composite with single pin, (E/D) = 4, (W/D) = 5, and 1% & 2% ZnS.

2) For single pinned joint when (W/D)=4, the bearing or failure strength increases as (E/D) ratio is equal to 2, 3, 4 & 5 and ZnS filler is equal to 0%, 1% & 2%.. Also the bearing/failure strength increases as (E/D) ratio is equal to 2, 3, 4& 5 and TiO_2 filler is equal to 0%, 1% & 2%.

a) Maximum value (2.7 kN) of failure strength is observed for composite with single pin, (W/D) = 4, (E/D) = 2 and 1% ZnS & 2% TiO_2.

b) Maximum value (4 kN) of failure strength is observed for composite with single pin, (W/D) = 4, (E/D) = 3 and 2% ZnS.

c) Maximum value (4.7 kN) of failure strength is observed for composite with single pin, (W/D) = 4, (E/D) = 4, and 1% TiO_2.

d) Maximum value (4.2 kN) of failure strength is observed for composite with single pin, (W/D) = 4, (E/D) = 5, and 1% ZnS.

3) For double serial pinned joint when (E/D)=4, the bearing/failure strength increases as (W/D) ratio is equal to 2 & 3 and ZnS filler is equal to 0% & 1%. Also the bearing/failure strength increases as (W/D) ratio is equal to 2 & 3 and TiO_2 filler is equal to 0% & 1%.

a) Maximum value (8.3 kN) of failure strength is observed for composite with double serial pinned joint with (E/D) = 4, (W/D) = 2 and 1% ZnS.

b) Maximum value (8.5 kN) of failure strength is observed for composite with double serial pinned joint with (E/D) = 4, (W/D) = 3 and 1% TiO_2.

4) For double serial pinned joint when (W/D)=4, the bearing/failure strength increases as (E/D) ratio is equal to 2 & 3 and ZnS filler is equal to 0% & 1%,. Also the failure strength increases as (E/D) ratio is equal to 2 & 3 and TiO_2 filler is equal to 0% & 1%.

a) Maximum value (8 kN) of failure strength is observed for composite with double serial pinned joint with (W/D) = 4, (E/D) = 2 and 1% ZnS.

b) Maximum value (6.5 kN) of failure strength is observed for composite with double serial pinned joint with (W/D) = 4, (E/D) = 3 and 1% TiO_2.

c) Maximum value (7.5 kN) of failure strength is observed for composite with double serial pinned joint with (W/D) = 4, (E/D) = 5 and 1% ZnS.

CONCLUSION

From the experimental results, and observations made during experimentation, the following conclusions are obtained -

- Since TiO_2 is harder than ZnS, TiO_2 filled composite behaves as more brittle compared to ZnS filled composite. Hence we can observe that the failure strength of TiO_2 filled composite is greater than that of ZnS filled composites.
- In single pinned joints, the failure strength increases as (W/D) or (E/D) ratio increases.
- In double serial pinned joints, the failure strength increases as (W/D) or (E/D) ratio is equal to 2 & 3.
- As the secondary filler (ZnS or TiO_2) increases, the number of layers of glass fiber decreases. Due to this, failure strength decreases as ZnS & TiO_2 increases as 1%, 2% & 3%.

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