Effect of Hybridization with E-Glass Powder for Composite Laminates Subjected to Quasi-Static Indentation

M. Ashok Kumar
Dept. of Mech. Engineering, University College of Engineering., Osmania University, Hyd.

A.M.K. Prasad
Dept. of Mech. Engineering, University College of Engineering., Osmania University, Hyd.

D.V.Ravishankar
Dept. of Mechanical Engineering., TKR College of Engineering., Medbowli, Hyderabad

Abstract - The fiber-matrix interface is known to play a major role in the mechanical performance of fiber-reinforced composites. This contribution is mainly related to the ability of the interface to transfer mechanical load from matrix to fiber during loading. A large body of research has found that this stress transfer process affects some quasi-static properties such as strength. This research work deal with effect of rate of indentation in different E glass / epoxy composite laminates hybridized with E glass powder of various proportions, it is also studied that how the fiber orientation will influence the E glass powder percentages during load bearing capacity or in other words how this combination will support the material system in support of load bearing capacity. However it is observed that as the powder percentages are increased load bearing capacity got reduced but in some cases as illustrated in the graphs, powder addition will have different effect in laminated with different fiber orientation.

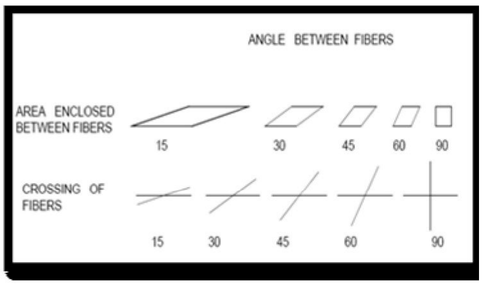
***Keywords*: a)Epoxy resin; b)E-glass fiber; c)Filament winding; d)laminate; e)Indentation; f)E-glass powder**

I. INTRODUCTION

It has been increasing enormously at present; the usage of composite materials in the areas of automotive, aerospace, defense and in sports industries and in many more applications. Composite materials have many advantages over conventional materials because of their superior properties like strength to weight ratio, stiffness to weight ratio, non-corrosive properties, resistance to climatic conditions, high fatigue life, product cost etc., The fiber/matrix interface is known to play a major role in the mechanical performance of fiber-reinforced composites. This contribution is mainly related to the ability of the interface to transfer the mechanical load from matrix to fiber during loading. Researchers in this field have found that this stress-transfer process affects some quasi-static properties such as the strength. However, the importance of the interface becomes largely predominant in the overall behavior of the composite. The composite structures may get damage during manufacturing, maintenance works and during their service. They may be subjected to low velocity impact by the tools also. This local impact is likely to cause damage locally and induce degradation in their strength. The size and type of damage will depends on various parameters like geometries of the support, projectile diameter, size, shape and angle of impact. Extensive studies are taking place concerning the foreign object damage response of composite materials structures. It also observed that low energy impact loading is very important for the laminated composite structures. In such composites, impact induces an internal damage that cannot be detected by a visual inspection but can cause noticeable reduction in strength. It was found that the damage in composite laminate due to quasi-static indentation, which is similar to the low velocity impact, hence it allows using quasi-static indentation tests in order to analyze the impact damage mechanisms. Earlier experimental studies have taken place to characterize the damage due to indentation. Damage zone remains localized beneath the indenter as the tri-dimensional fiber architecture prevents delamination. The aim of this research work is to investigate the influence of fiber angle in the damage of composite laminate, subjected to quasi-static indentation. Damage in the composite laminates results from the interaction between different failure mechanism like matrix cracking, fiber-matrix debonding, delamination between the successive layers and fiber breakage. However in quasi-static indentation mostly the damage may result due to delamination between the layers. For this purpose, static tests were conducted on the composite laminate loaded at the centre by a spherical stainless steel indenter. All the tests were stopped at fixed values of the indenter displacement. Composite laminates with different fiber angles were supported on a square frame. The intensity of the damage caused is observed by the optical light microscope. Specific damages in highly oriented plates along the longitudinal direction formed with two different layers, woven fabric and quasi UD, have been observed. It consists of the development of matrix cracks, starting from non-impacted side, which develop in a conical form through the thickness of the specimen. A comparison between static and dynamic tests was treated. The maximum force attained during the impact tests is greater than the one during the quasi-static tests. The absorbed energy and damage morphology are equivalent for both tests [1].Failure at the interface is modeled by degrading stresses using two interface damage parameters corresponding to interfacial tension and shear failure, while fracture mechanics concepts are introduced by relating the total energy absorbed in the damaging process to the interfacial fracture energy [2].These authors are studying the behavior of composite structures at low-velocity impact. They are trying to give explanation and to simulate the different damage phenomena observed during the experimentation more studies are still required to have better understanding of the damage phenomena developed in these structures during the impact [3-5]. A simple power law equation was assessed, correlating the dent depth with impact energy. It was shown that, if the ratio of the impact energy to the penetration energy is adopted as the independent parameters, the relationship proposed is negligibly affected by the laminate type and thickness [6]. The experimental results demonstrate that the penetration energy is substantially unaffected by the loading speed, so that the formula proposed by these authors for the evaluation of the penetration energy is also effective in static tests [7].

II. MATERIAL PREPARATION

E-glass/Epoxy composite laminates were prepared by passing the E-glass fibers of 1200 TEX, through the resin bath of Epoxy and hardener mixed with E-glass powder maintaining a constant temperature of about 45^0C. The fibers are then wound on a rotating drum with 15 rpm. After complete winding on the drum then it is cut opened and lay on a flat table in the atmospheric condition for about 48 hours to get the tackiness. It is then cut in to required sizes and placed one over the other to obtain the desired thickness of the laminate. All the overlapped layers then compacted between the two parallel flat steel plates with stainless steel spacers of required laminate thickness. The major purpose of lamination is to tailor the directional dependence of strength and stiffness of a composite material to match the loading environment of the structural element laminates are uniquely suited to this objective because the principal material directions of each layer can be oriented according to need. The plates are clamped with nuts and bolts with washers; the clamped setup is then placed in the oven. Maintain the oven temperature of 80^0 C for 4 hours and 120^0 C for next 4 hours so that any entrapped air or volatile gases will be escaped for the first four hours and chemical reaction between the epoxy and hardener will takes place for the next four hours and will lead to permanent set and finally result into a single solid composite laminate. After total curing of 8 hours oven is then switched off so the temperature in the oven may come down to normal temperature. Take out the composite laminate and trim the edges so that the laminate is ready for testing purpose.



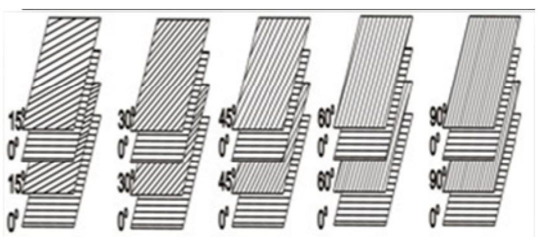


Fig. 1: Angle between successive fibers

Fig. 2: Sequence of angle plies

III. EXPERIMENTATION

Indentation tests were conducted using a load cell based material testing system (UTM) of 100 KN capacities. The prepared angle plied composite laminate of size 100 x 100 mm was centrally placed on a suitable steel frame with a square opening of 50 x50 mm size. The specimen is clamped with a matching flat plate with a square opening of 50 x 50 mm in the middle with bolts and nuts as shown in figure. The clamped composite laminate along with the fixture arrangement was placed on the fixed platen of the testing machine. A spherical stainless steel ball indenter of diameter 8.17mm, fixed to the moving platen of the machine was used for indentation. The test set-up was aligned in such fashion that the indenter fixed to the moving platen makes contact with the specimen under test at its centre point. The tests were conducted with controlled displacement of the indenter (1.0 mm/min). A 10 KN load cell was employed to measure the load applied on the composite plate. Load-displacement data during the indentation process was obtained and recorded as a function of the indentation depth starting from an initial value of 1 mm to a final value of 5.0 mm in steps of 1 mm. Composite laminates with different fiber orientations of (0,15), (0,30), (0,45), (0,60) & (0,90) and with different volume fractions of E-glass powder.

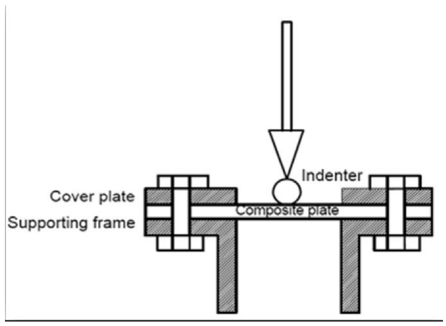


Fig. 3: Schematic diagram of indentation process

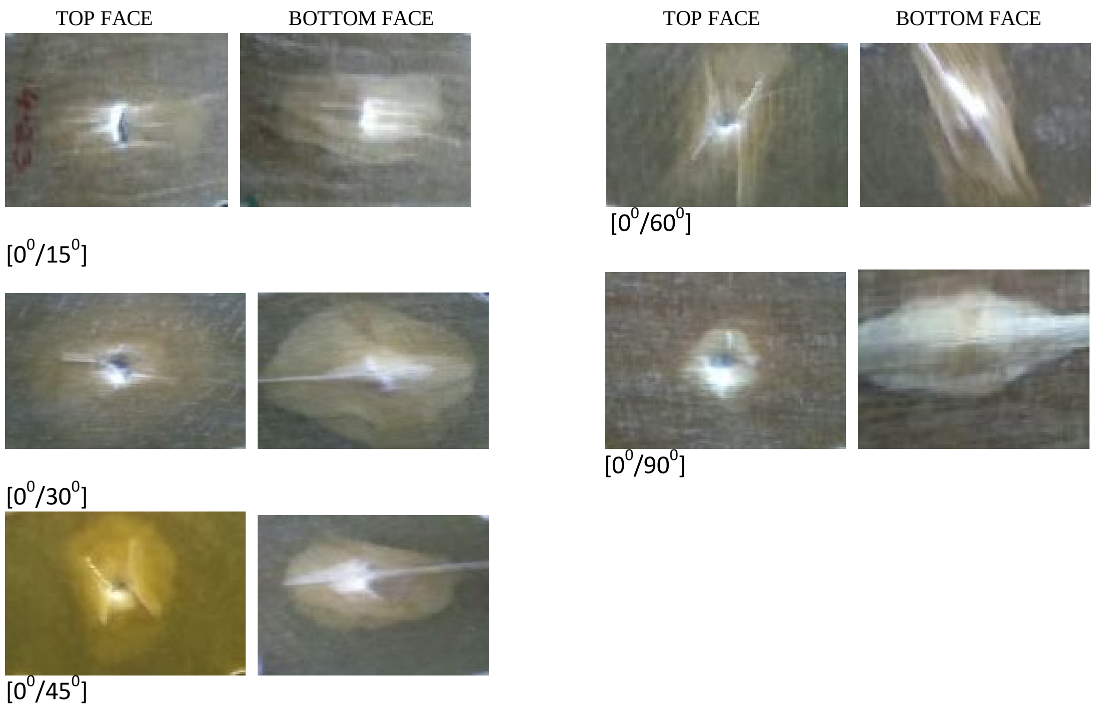


Fig. 4: Laminates after indentation process

E- Glass Powder = 0.5%

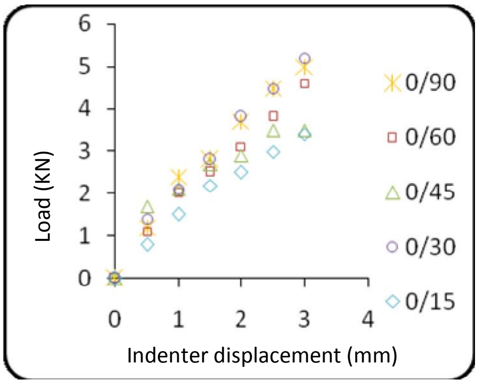


Fig 5: load (KN) vs. Indentation depth

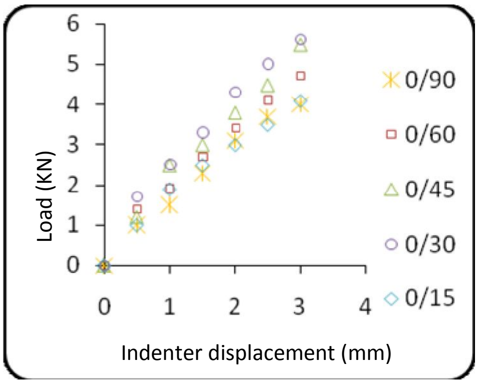


Fig 6: load (KN) vs. Indentation depth

E- Glass Powder = 1.0 %

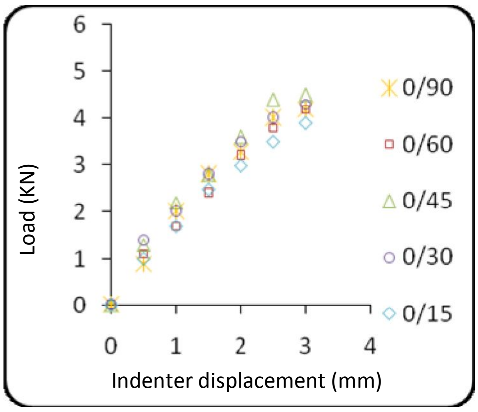


Fig 7: load (KN) vs. Indentation depth

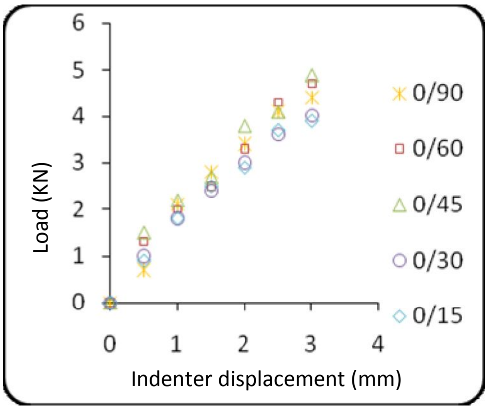


Fig 8: load (KN) vs. Indentation depth

E- Glass Powder = 1.5%

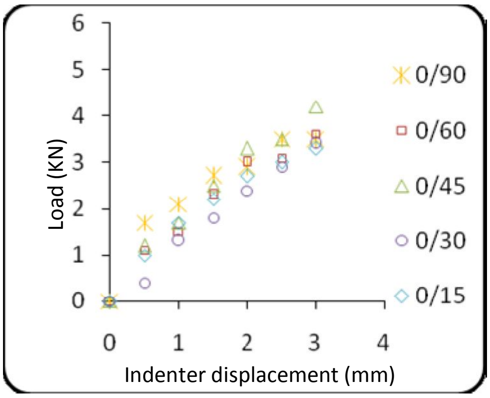


Fig 9: load (KN) vs. Indentation depth

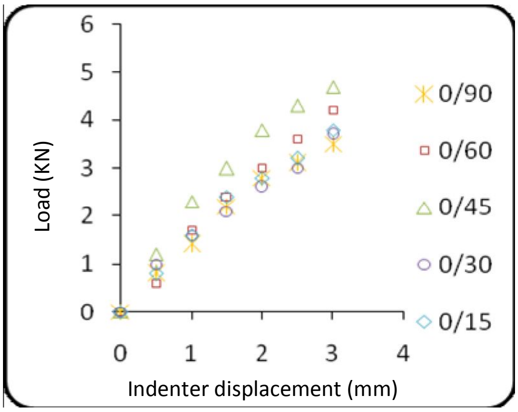


Fig 10: load (KN) vs. Indentation depth

Indenter Rate of loading (ROL)
A-(ROL) = 1.5mm/min
B-(ROL) = 0.5mm/min

Fiber Orientation ($0^0/15^0$)

E-GLASS POWDER = 0.5%

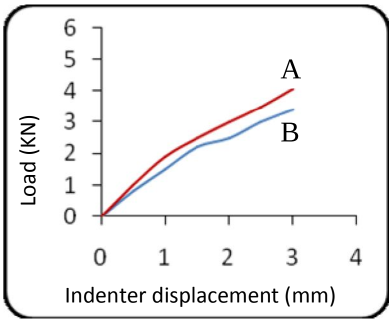


Fig 11: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.0%

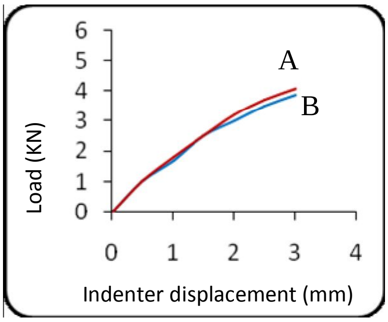


Fig 12: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.5%

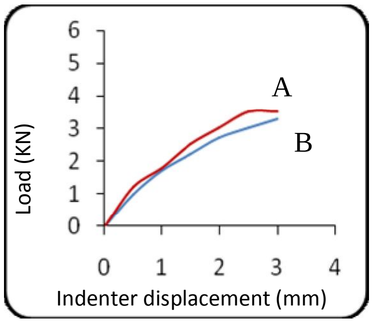


Fig 13: load (KN) vs. Indentation depth (mm)

Fiber Orientation ($0^0/30^0$)

E-GLASS POWDER = 0.5%

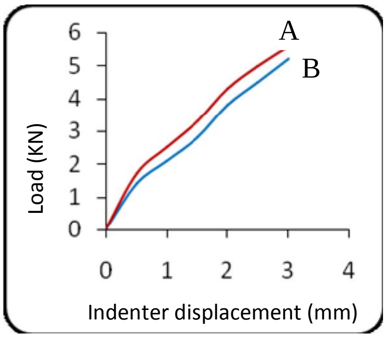


Fig 14: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.0%

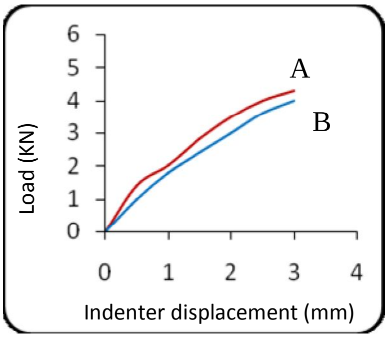


Fig 15: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.5%

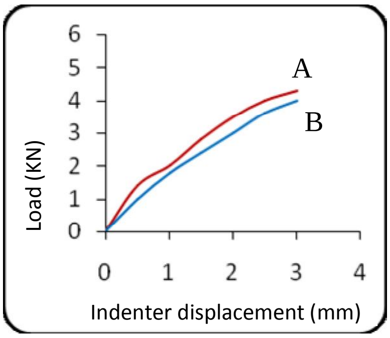


Fig 16: load (KN) vs. Indentation depth

Fiber Orientation ($0^0/45^0$)

E-GLASS POWDER = 0.5%

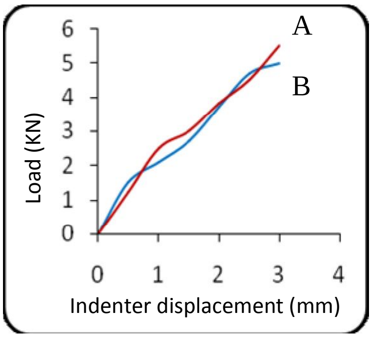


Fig 17: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.0%

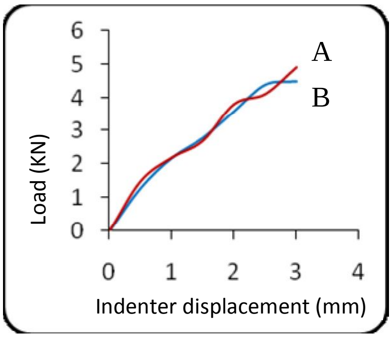


Fig 18: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.5%

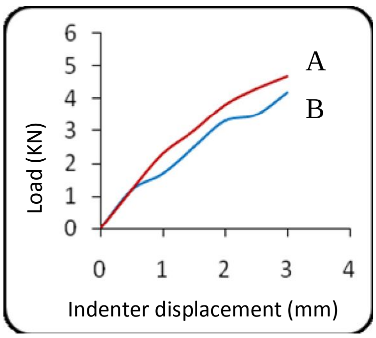


Fig 19: load (KN) vs. Indentation depth (mm)

Fiber Orientation ($0^0/60^0$)

E-GLASS POWDER = 0.5%

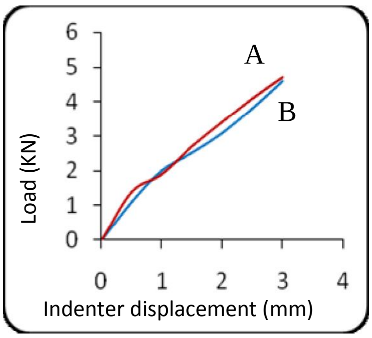


Fig 20: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.0%

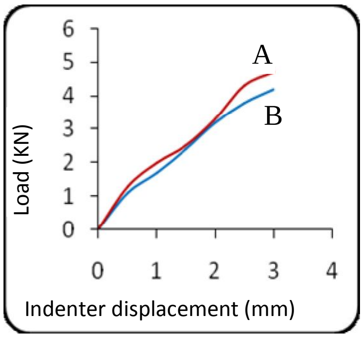


Fig 21: load (KN) vs. Indentation depth (mm)

E-GLASS POWDER = 1.5%

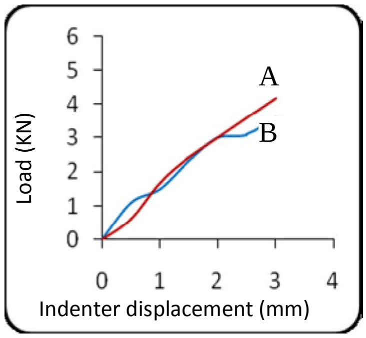
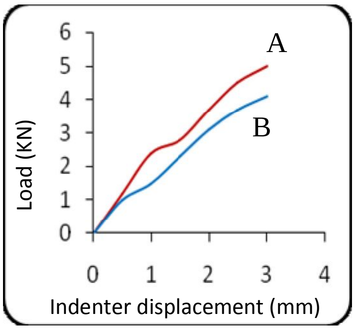
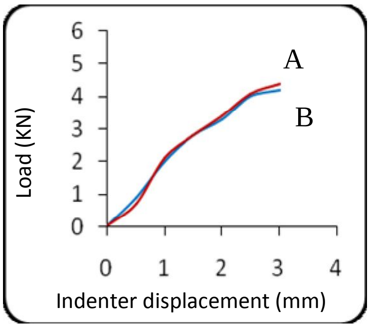


Fig 22: load (KN) vs. Indentation depth (mm)

Fiber Orientation ($0^0/90^0$)

E-GLASS POWDER = 0.5% E-GLASS POWDER = 1.0% E-GLASS POWDER = 1.5%





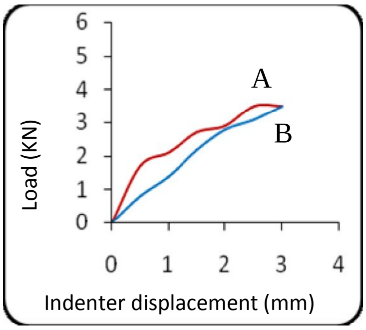


Fig 23: load (KN) vs. Indentation depth (mm) Fig 24: load (KN) vs. Indentation depth (mm) Fig 25: load (KN) vs. Indentation depth (mm)

IV. RESULTS AND DISCUSSIONS

When E-glass powder of 0.5% with a particle size 30 microns is given the following results to the composites with a different fiber orientation with different rate of loading. From graph when a rate of indenter loading of 0.5 mm/min, it is observed that with 1.5 mm indentation depth for the laminate of ($0^0/15^0$) fiber orientation, the load is proportional with increasing the indentation depth. Indentation depth for the laminate of ($0^0/15^0$) the load is proportional increasing with indentation depth. From indentation depth from 1.5mm to 2.0 mm the load is increased gradually and latter it is increased steeply, which show that there is fiber break when the indentation depth increased from 1.5 mm to 2.0 mm. however laminate with ($0^0/15^0$)fiber orientation it has a least load bearing capacity compared to other fiber orientation . The maximum load bearing capacity is 3.4 KN. The laminate with ($0^0/30^0$)shown maximum load carrying capacity of 5.1 KN at a depth of 3mm is uniformly increased with indention depth in ($0^0/30^0$) laminate. The laminate with ($0^0/45^0$) has great fluctuations in the load carrying capacity, it shown the fibers got break for every 0.5mm of indentation depth, and the maximum load taken is same as that of ($0^0/15^0$) laminate. The laminate with fiber orientation ($0^0/60^0$) is shown average load carrying capacity compared to ($0^0/15^0$)' ($0^0/30^0$), ($0^0/45^0$), and ($0^0/90^0$). The laminate with ($0^0/90^0$) is also shown maximum load carrying capacity as that of laminate with ($0^0/30^0$). From graph it is shown that 0.5mm of indentation depth for the laminate with ($0^0/45^0$) shown maximum load carrying capacity and ($0^0/15^0$) shown minimum load carrying capacity. At 1mm of indentation depth ($0^0/90^0$) laminate shown maximum load carrying capacity. At 1.5mm indentation depth laminate with ($0^0/30^0$), ($0^0/45^0$), ($0^0/90^0$) shown maximum load carrying capacity. At 2mm indentation depth maximum load taken is ($0^0/30^0$) and ($0^0/90^0$). At 2.5mm indentation depth laminate with ($0^0/30^0$) and ($0^0/90^0$). At 3mm indentation depth maximum load bearing capacity is for the laminate with ($0^0/30^0$) fiber orientation. From graph when the rate of loading or indentation is 1.5mm/min for all the indentation depth values, laminate with ($0^0/30^0$) is shown maximum load carrying capacity, and laminate with ($0^0/15^0$) is shown minimum load carrying capacity. When the rate of loading is increased from 0.5mm/min to 1.5mm/min. Irrespective of rate of loading the laminate the laminate with ($0^0/60^0$) maintained average load as in the case of 0.5mm/min rate of loading. From graph it is very clear, for all the indentation depth values ($0^0/30^0$) laminate is shown maximum loading carrying capacity and($0^0/15^0$)laminate with minimum load carrying capacity. For 0.5% of E-glass powder, the change in the rate of loading is influenced only the laminate with ($0^0/45^0$) fiber orientation. The maximum load carrying capacity increased from 5.1KN to 5.6KN with the rate of loading increased from 0.5mm/min to 1.5mm/min for the laminate ($0^0/30^0$).Also increased minimum load carrying capacity from 3.4 KN to 4.1 KN for the laminate with ($0^0/15^0$)fiber orientation. From graphs when E-glass powder in the laminates increased to 1% , then the following observations made from the experiments i.e., the rate of indentation 0.5mm/min the laminate with ($0^0/45^0$) shown maximum load carrying capacity, however in general the rate of loading influenced the loading carrying capacity of the laminate. The higher the rate of loading, the load carrying capacity is also high , since all the fibers at different layers will not take part in load carrying then no fibers breakage and hence load carrying capacity will be more, in other works higher is the strain rate. When the rate of loading is 1.5mm/min, there is a steep increase in the load carrying capacity for the laminate with ($0^0/45^0$) with a value of 4.9KNas 4.5KN with a rate of loading 0.5 mm/min. However for both rate of loading ($0^0/45^0$) and ($0^0/60^0$) reached maximum load carrying capacity with minimum load carrying capacity. Hence with 1% E-glass powder in ($0^0/45^0$) shown to be the best. For all the indenter depths from 0.5mm to 3mm for both rate of loading. The laminate with ($0^0/45^0$) carried more load and ($0^0/15^0$) laminate with minimum load baring capacity. In the graphs it is clearly shown that the E-glass percentage is increased to 1.5 still the laminate with ($0^0/45^0$) fiber orientation shown to be the best with small loading fluctuation during loading when the rate of loading is 0.5 mm/min, but in the case of 1.5 mm/min the laminate with $0^0/45^0$is absolutely free from loading fluctuations with a steep increase in the load carrying capacity. However ($0^0/30^0$) laminate is shown to be the minimum load carrying capacity and as usual ($0^0/60^0$) laminate appear to be average loading carrying capacity without any load fluctuations when the rate of loading is 1.5mm/min. The maximum load carrying capacity is same for ($0^0/15^0$) and $0^0/30^0$) laminate for both rates of loading. When the E-glass powder is 1.5% for the laminate with ($0^0/45^0$) is observed to the best load carrying capacity. When the indenter depth is 0.5mmto 2.5mm for ($0^0/90^0$) is the test, when the rate of loading is 0.5mm/min. In the graphs it is shown that the laminate with ($0^0/15^0$)fiber orientation, the load carrying capacity is steeply increasing when E-glass powder is 1% with a maximum load of 4KN for both rate of indenter loadings 0.5mm/min and 1.5mm/min with minimum load carrying capacity 3.1 KN when the rate of loading is 0.5mm/min. In the graphs it is shown that the laminate with ($0^0/30^0$) fiber orientation, the load carrying capacity is uniformly increasing when E-glass powder is 0.5% with a maximum load of 5.6KN with a rate of indenter loadings 1.5mm/min with minimum load carrying capacity 3.2 KN when the rate of loading is 0.5mm/min. From the graphs, it is shown that the laminate with ($0^0/45^0$) fiber orientation the load carrying capacity is more when E-glass powder is 0.5% with a maximum load of 5.6KN for rate of indenter loadings 0.5mm/min, minimum load carrying capacity 4 KN. It is shown that the laminate with ($0^0/60^0$) fiber orientation, the load carrying capacity is higher when E-glass powder is 0.5% with a maximum load of 4.6KN when the rate of indenter loading1.5mm/min and with minimum load carrying capacity 3.5 KN when the rate of loading is 0.5mm/min ,it is shown that the laminate with ($0^0/90^0$) fiber orientation the load carrying capacity is steeply increasing when E-glass powder is 0.5% with a maximum load of 5KN for both rate of indenter loadings1.5mm/min with minimum load carrying capacity 3.2 KN when the rate of loading is 0.5mm/min. It is shown that the laminate with ($0^0/15^0$) fiber orientation, with 0.5%, 1% and 1.5% of E-glass powder, for all the values of indentation depth, the load carrying capacity is proportional is observed maximum when the rate of loading is 1.5mm/min with a maximum load of 4.1KN and minimum load 3KN when the rate of loading is 0.5mm/min with 1.5% of E- glass powder. It is shown that the laminate with ($0^0/30^0$) fiber orientation, with 0.5%, and 1.5% of E-glass powder, for all the values of indentation depth, the load carrying capacity is proportional is observed maximum when the rate of loading is 1.5mm/min with a maximum load of 5.6KN and minimum load 3.3KN when the rate of loading is 0.5mm/min with 1 % of E- glass powder. From the graphs it is shown that the laminate with ($0^0/45^0$) fiber orientation, with 0.5%, 1% and 1.5% of E-glass powder, for all the values of indentation depth, the load carrying capacity is proportional and it is observed maximum when the rate of loading is 1.5mm/min with a maximum load of 5.7KN and minimum load 4.1KN when the rate of loading is 0.5mm/min with 1.5% of E- glass powder.

V. CONCLUSION

1. Irrespective of indenter loading rate the laminate with fiber orientation ($0^0/30^0$) for 0.5% of glass powder and has shown maximum load carrying capacity and minimum for ($0^0/15^0$) laminate for all the values of indenter displacement.

2. When indenter rate of loading is 0.5mm/min and 1.0mm/min the laminate with fiber orientation ($0^0/45^0$) for 1.0% and 1.5% of glass powder has shown maximum load carrying capacity and minimum for ($0^0/15^0$) laminate.

3. For different fiber orientations and glass powder percentages. At higher values of indenter rate of loading the laminates shown maximum load bearing capacity for all the values of indenter displacement.

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