American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-06, pp-289-297
www.ajer.org

Research Paper Open Access

Effect of Unsupported Area of Composite Plates Subjected to Quasi-Static Indentation

M. Ashok Kumar[a], A.M.K. Prasad[b], D.V. Ravishankar[c], M. Paramesh[d]

[a]*Dept. of Mech. Engg., Vignan Institute of Technology & Science, Hyderabad, Telangana, India.*
[b]*Dept. of Mech. Engg., UCE, Osmania University, Hyderabad, Telangana, India*
[c]*Dept. of Mech. Engg., TKR College of Engineering, Hyderabad, Telangana, India*
[d]*Dept. of Mech. Engg., Vignan Institute of Technology & Science, Hyderabad, Telangana, India*

Abstract: E-glass/Epoxy composite circular plates clamped circumferentially were subjected to quasi-static indentation at the center of the specimen with a ball indenter. Damage pattern on surface of the laminated plates with varying degrees of fiber orientation and different unsupported areas was studied. Damage was quantified in terms of the area of opacity of the damaged region. Results obtained on 3 mm thick laminates with a hardened spherical ball indenter of 8.32 mm diameter indicated that damage was directly proportional to the angle θ and inversely proportional to unsupported areas of the specimen plate. Most internal damage was confined to the surroundings of the indentation point.

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

I. INTRODUCTION

Composite materials have wide spread structural applications in Aeronautical, Automotive, and Ship Building and Aero space industry. The volumes on the above sectors as well as the applications areas have been steadily increasing in recent days due to their obvious advantages of high specific stiffness and strength. The damage mechanisms in composites such as delamination fiber breaks and matrix cracking play an important role in every absorption. Prediction of damage assessment is a rather difficult area due to the complexities involved in measuring the energy absorbed in each of the above damaged mechanism. In this context damage inflicted in composite structures subjected to low velocity impact has been very important. This investigation was taken up in the above context. Damage in any composite structure is progressive and cumulative. Damage occurs during manufacturing processes as well as in service usage. These include low velocity impact by hand tools, collision between two structures during assembly etc. Such localized impacts cause local damage but an induced degradation in their strength and are liable to grow under continued usage. The size and type of damage depends on various parameters like Geometry of support, size, projectile diameter and angle of incidence. Extensive studies are taking place in the foreign object damage response of the composite structures. It was found that the damage in composite materials due to Quasi – Static indentation is similar to the one caused by low velocity impact. Several investigators have experimentally studied the damage due to Quasi – Static indentation and characterized the damage. The aim of this research work is to investigate the influence of fiber orientation 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 orientation were supported on a circular steel frame. The intensity of the damage caused is observed by the optical light microscope. Apart from the damage the force carrying capacity is also influencing the angle between the fibers and the depth of indentation increase with the increase in the angle between the fibers. Freitas et al [1] have carried out a numerical study to examine the failure mechanisms in composite specimens subjected to impact loading. Results show that the numerical evaluation of impact with a linear static finite element analysis is not very accurate, but it gives meaningful insights on the major mechanisms of failure. Metals show visible damage caused by impact mainly on the surface of the structures, but for composites the damage is hidden inside the member when subjected to low velocity impact [2]. Wu and Chang [3] studied ballistic impact response of monolithic fibers reinforced composite laminates, where they found that the contact force is dependent on the mass of the projectile, but it has no influence on the amount of the absorbed energy, which is found to be dependent on the initial energy of the impactor. While zhou and Greaves studied damage resistance and tolerance of glass fiber reinforced plates with different thickness [4]. Williams and Vaziri [5] used damage mechanics principles along with matrix and fiber failure criteria ot model damage in low velocity impact. They developed material subroutines for LS DYNA. Load deflection curves and damage patterns compared well with experimental results. Liu [6].carried out an experimental study to obtain the perforation threshold of laminated composite plates with different thickness and bending stiffness. Results show that thickness is more efficient than bending stiffness on the perforation threshold Chen and Sun [7] developed a finite element program to analyze the impact response of composite laminates under biaxial in-plane loads using the program; they solved three cases of in-plane loading. i.e., tensile loading of three times the critical buckling loads of the plate. Compressive loading of 75% of the same critical load, and no initial in-plane loading. N. Rajesh et al studied the behavior of woven glass epoxy laminates were subjected to low velocity impact loading at different energy levels have been investigated using standard instrumented falling weight test, the results shown that the dynamic response of these systems depends on the elastic properties of the fiber materials [8].Ramazan Karakuzu et al. experimented the behavior of glass/epoxy composite plate with different fiber orientations with different impact energies with different masses and observed the following conclusions like the contact force increases by increasing fie angle, the lower impactor mass with higher impact velocity causes greater contact forces, the lower mass with higher velocity causes higher deflection while the lower energy with lower velocity and lower mass with lower energy cause lower deflection. Higher plate thickness cause higher contact force and lower deflection. But contact force and deflection rates decrease y increasing the plate thickness. The overall delaminations area increases by the increasing impact energy; however it does not significantly change by increasing the fiber orientation. The overall delamination area decreases by increasing the plate thickness [9].By this time a number studies have been carried out in this direction, but most of them are concerned with low velocity impact [10].Static tests were carried out on SiC/SiC composite plate loaded at the centre by hemispherical indenter with a fixed displacement and also with complete penetration using various circular support and different indenter diameters. Damage assessment was made using micrograph and post-indentation tensile strength [11].

II. EXPERIMENTAL PROCEDURE

2.1 Material:

E-glass/epoxy composite plates were prepared using a drum winding machine. Laminae were carefully laid up on the surface of the die plate molding tool to a pre-determined layup sequence. After closing the mould with the punch plate and spacers, the assembly was subjected to curing at 160^0C. Laminated composite plates were obtained after curing and trim to the required size.

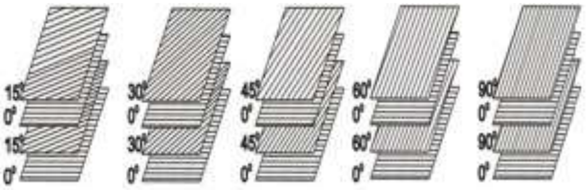
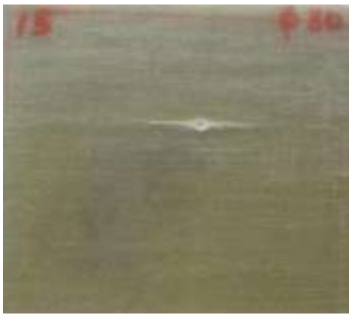


Fig-1: layup sequence of laminae

2.2. Experimental procedure:

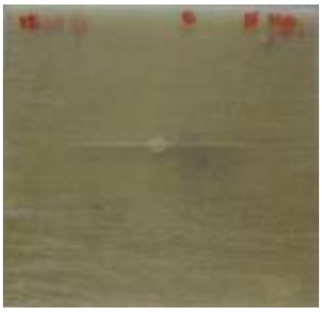
Quasi-static Indentation tests were conducted on a universal testing machine to various specimen plates with different ply orientations and unsupported area placed on a steel supporting frame. A cover plate with a central circular hole of different sizes was placed on top of the composite laminate to obtain different unsupported areas and clamped rigidly using bolts and nuts. The complete assembly along with composite laminate was placed on the bottom support of the testing machine. A spherical stainless steel ball of radius 4.16mm was used for indentation on the composite laminate. The tests were conducted under controlled indenter displacement δ (0.1mm/minute) up to 4mm. Load on the laminate at the central point (P) was quantified with the help of 20kN load cell of the UTM. The load - displacement data were obtained for the chosen ply orientations and unsupported areas of the laminate. From the load displacement curve, stiffness K was evaluated. unsupported diameter=60mm, 80mm, 100mm.

$(0^0/15^0)$



TOP

$(0^0/15^0)$

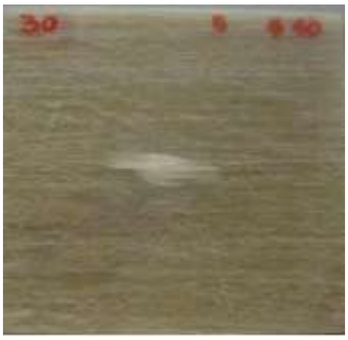


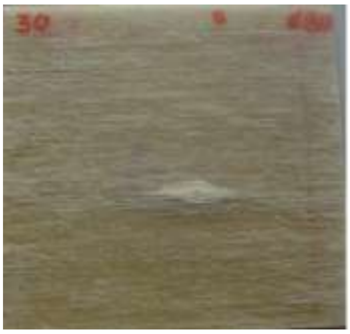
BOTTOM

$(0^0/30^0)$

TOP

$(0^0/30^0)$





BOTTOM

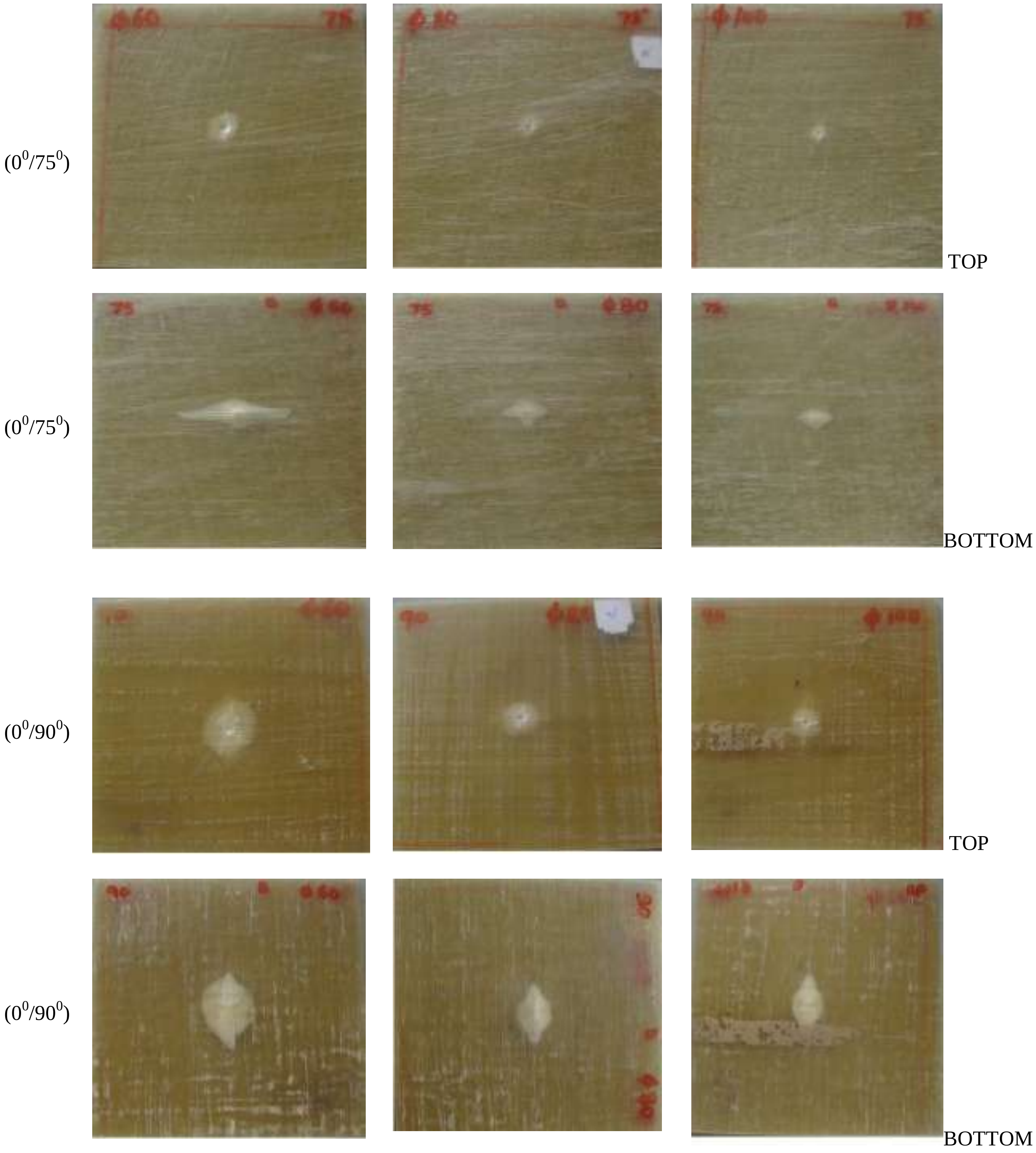


Fig-3: Laminates after indentation

III. RESULTS

3.1 Load-displacement

The load-displacement curves for the specimens indented until the indenter displacement reached a maximum of 4mm was shown in Figs: 4 to 10. These were linear in nature and the apparent damage area on both sides of the specimen was increased with the increase in fiber orientation θ. The load P was proportional to fiber orientation of the laminates. The maximum load when $\theta=15^0$, 30^0, 75^0, 90^0 for unsupported circular diameter of 60mm was 3.3, 3.86, 4.3, 5.52 kN respectively. It was very clear that as the fiber orientation was increasing the load bearing capacity was also increasing. The same trend followed for the unsupported area diameters 80mm and 100mm with decrease in load at the end of 4mm indenter displacement. Irrespective of fiber orientation it was also observed that for small unsupported area diameters the load was higher than large unsupported diameters for the specimen configurations.

3.2 Stiffness - Fiber orientation

K_0 was calculated using the slopes of P-δ curves in different configured specimens and observed that K_0 depends on fiber orientation θ. It shows a non linear relationship with increasing values of K_0 with θ. The global stiffness reflects the ability of the plate to withstand a central load without any loss of stiffness despite some local damage at the point of indentation. There is a progressive increase of K_0 for values of θ from 15^0, 30^0 75^0 and 90^0 and also increases in these values with the decrease in unsupported area diameters as shown fig.11

3.3 Central deflection - Indenter displacement

Under the action of a normal load at the midpoint on a circular plate clamped circumferentially, the deflection at any point of the plate was a function of indenter displacement. The deflection-indenter displacement curve was linear with increasing values of indenter displacement**.** It was observed that the deflection at centre of the plate was directly proportional to indenter displacement and unsupported area diameter as shown in fig.12 to 18.

3.4 Damage development/Apparent damage area - fiber orientation

Composite plate photographs after indentation shown in fig.3 provide a means of quantifying damage area of the indented specimens. The damage on the indented side is a hemispherical cavity with a small convex deformation observed on the back side of the specimens due to compression phenomenon on indented side and tension on back side of the specimen. The size of damage on back side of the specimen was more than the indented side as shown. The photo images disclose that, damage was directly proportion to fiber orientation θ on both the sides, with the damage on the back face being higher than that in the front face. The apparent damage was due to the combined effect of one or more phenomenon like, matrix cracks, fiber-matrix debond and delamination between the angled plies. It was assumed that for small indentation depths, there would have not any fiber breakage. Matrix cracks may take place on the top laminae of the laminate which might be subjected to compression and will result localized buckling. Bottom laminae are in a state of tension and lead to debond or fiber fracture. The mechanism of damage for the top laminae would be matrix crack whereas for the bottom laminae would be delamination.

3.5 Spring back - fiber orientation

Spring-back was defined as the difference between depth of indentation at the centre point at the instance of downward indenter traverse of 4mm and the measured depth of indentation at the same point after the indenter has been retracted back. Experimental results showed that spring back was directly proportional to unsupported area of the laminate and fiber orientation.

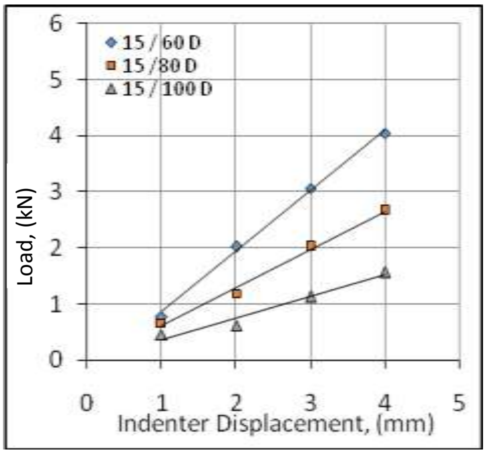


Fig-4: Load vs. Indenter displacement

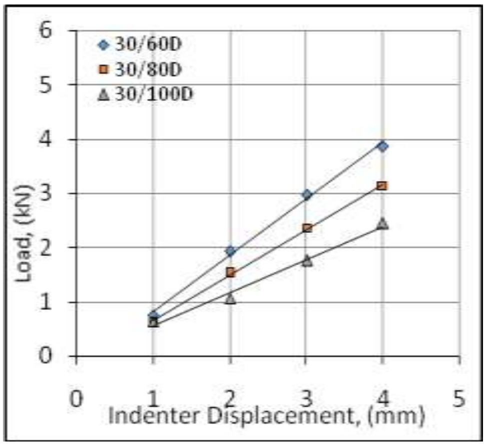


Fig-5: Load vs. Indenter displacement

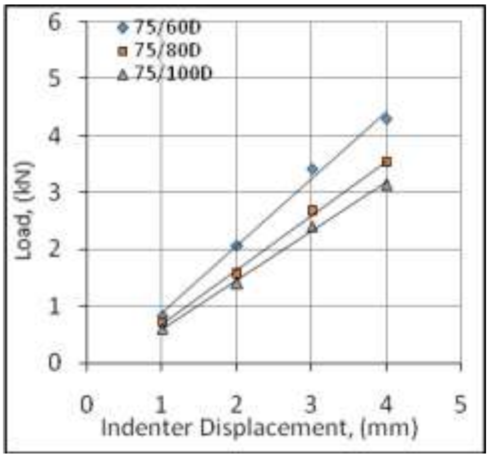


Fig-6: Load vs. Indenter displacement

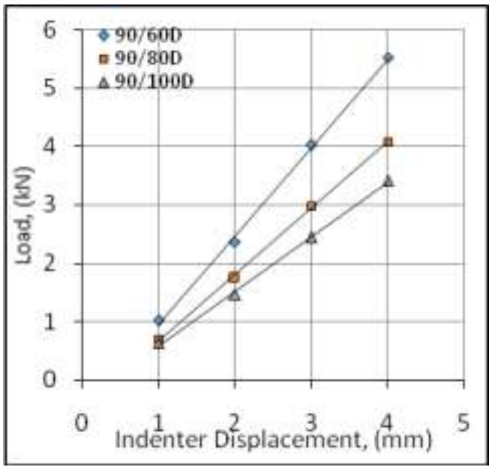


Fig-7: Load vs. Indenter displacement

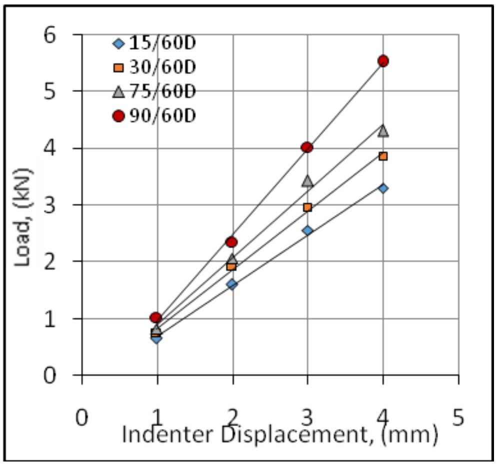


Fig-8: Load vs Indenter displacement

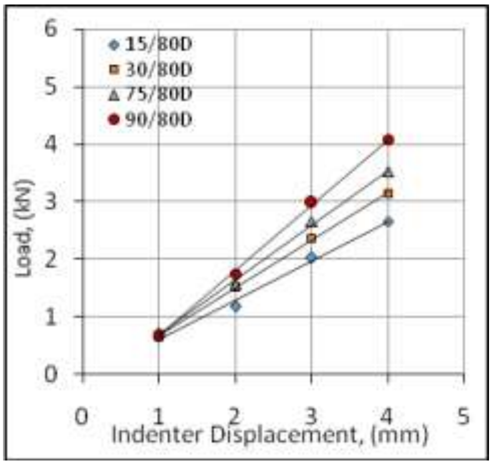


Fig-9: Load vs Indenter displacement

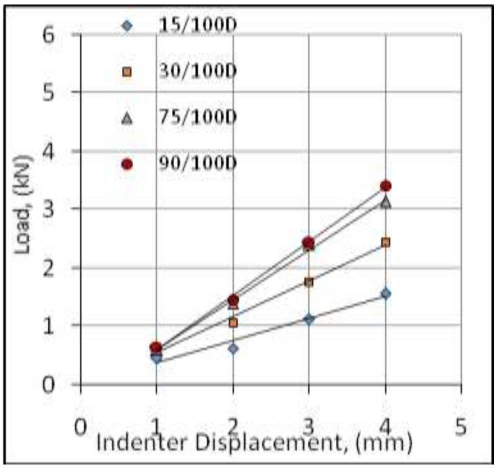


Fig-10: Load vs. Indenter displacement

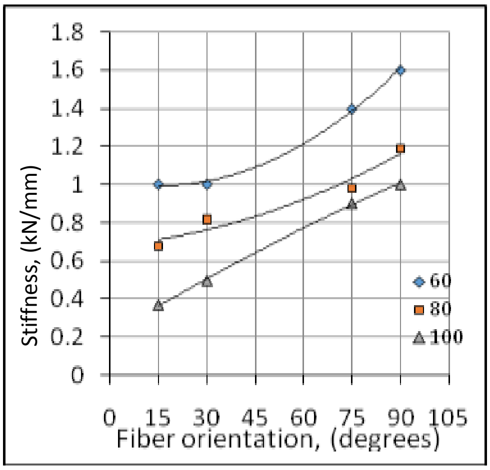


Fig-11: Stiffness vs. fiber orientation

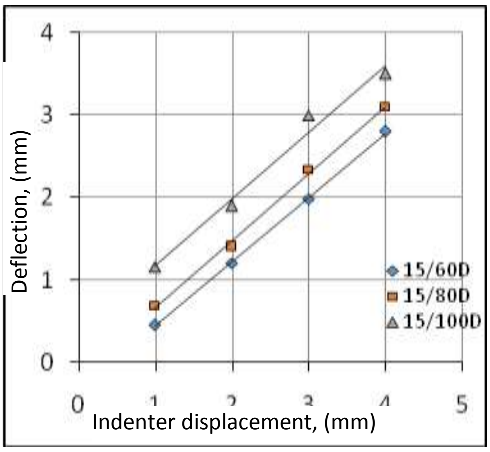


Fig-12: Deflection vs. Indenter displacement

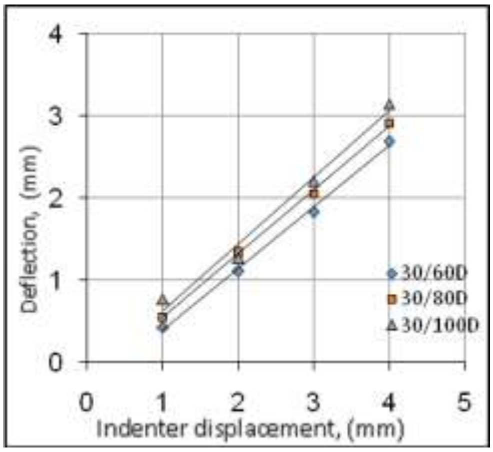


Fig-13: Deflection vs. Indenter displacement

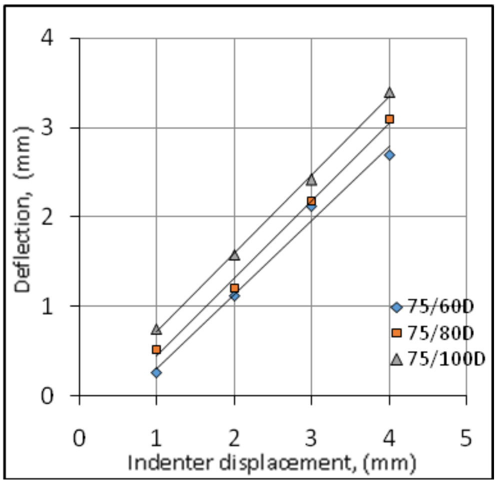


Fig-14: Deflection vs. Indenter displacement

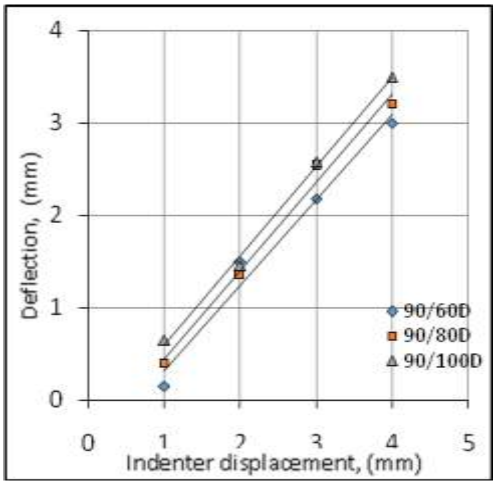


Fig-15: Deflection vs. Indenter displacement

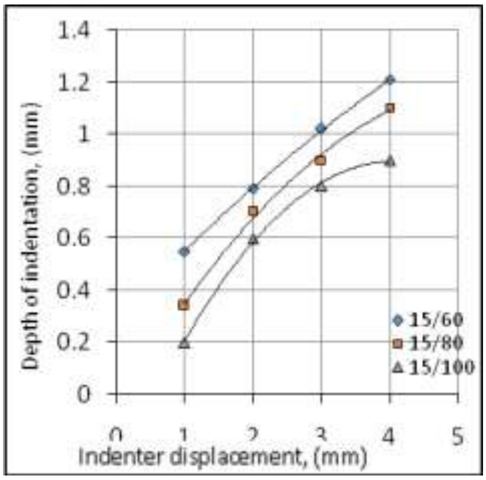


Fig-16: Deflection vs. Indenter displacement

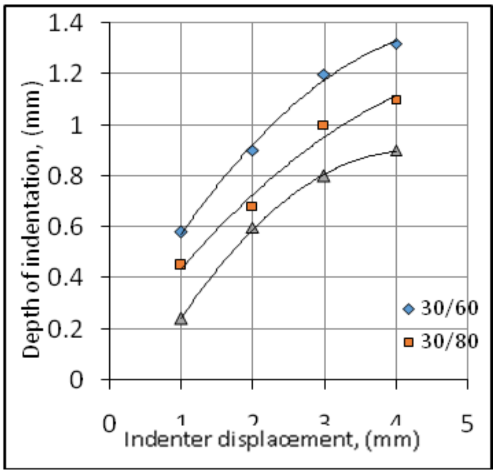


Fig-17: Deflection vs. Indenter displacement

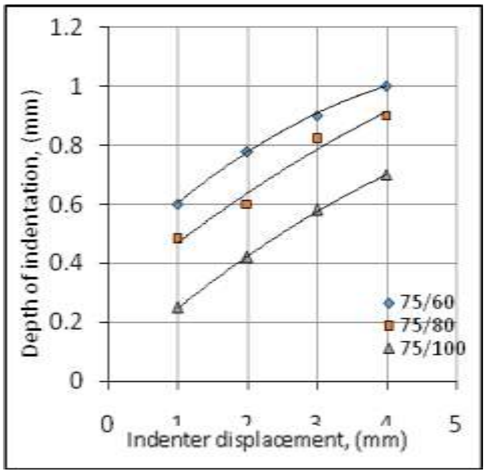


Fig-18: Deflection vs. Indenter displacement

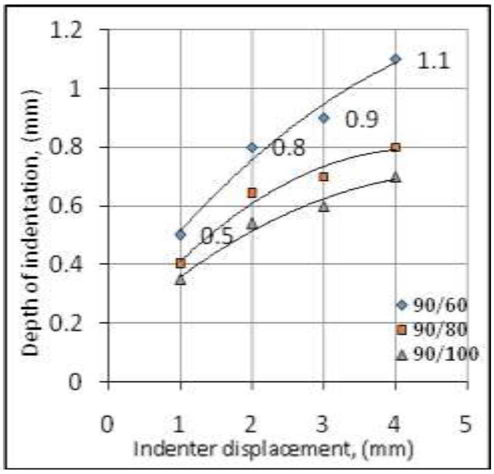


Fig-19: Deflection vs. Indenter displacement

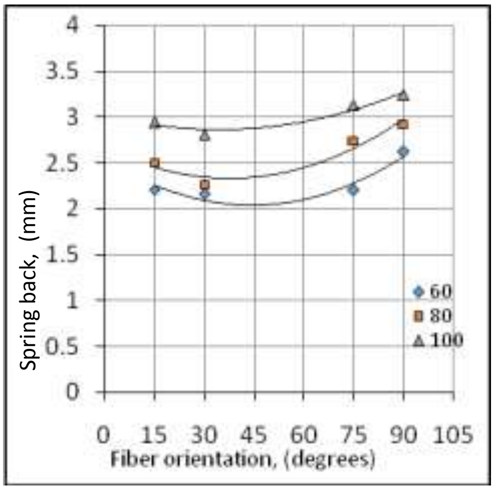


Fig-20: Spring back vs. fiber orientation

IV. CONCLUSION

The size of damage increased with the indenter displacement for given fiber orientation and unsupported area. The damage area was increased with the increase in fiber orientation. Stiffness of specimen for all the values of fiber orientation was gradually increasing with the increase in fiber orientation. It was also observed that for small unsupported area diameters of the specimens, the load was higher than large unsupported area diameters. There is a progressive increase in stiffness values from 15^0, 30^0 75^0 and 90^0 and also increase in these values with the decrease in unsupported diameters of the specimens. The deflection at centre of the plate was directly proportional to indenter displacement and unsupported area diameter of the specimen. Due to increase in stiffness, there was an increase in depth of indentation with decreasing values of unsupported area diameter. Compression phenomenon on indented side and tension on back side of the specimen a led to small convex deformation on the back side of the specimens. Spring back was directly proportional to unsupported area of the laminate.

V. ACKNOWLEDGEMENT

The authors thank CEO, Mr. Shravan and Principal, Dr. M. Venkataramana, of Vignan Institute of Technology & Science, Deshmukhi, for providing necessary facilities at the college to complete this project work.

REFERENCES

[1] Freitas M, Silva A, Reis L. Numerical evaluation of failure mechanisms on composite specimens subjected to impact loading. Composite part B, 2000; 31 (3) 199-207

[2] Richardson MOW, Wiheart MJ. Review of low velocity impact properties of composite materials Composites Part A –ApplSciManuf 1996; 27A (12): 1123-31

[3] Wu E Chang I C Woven glass/epoxy laminates subject to projectile impact Int J Impact Engg 1995 16 (4) 607-19

[4] Zhou G, Greaves IJ. Impact behavior of fiber reinforced composite materials and structures CRC press, woodhead pubs, 2000. 133-185.

[5] Williams KV, Vaziri R. Application of damage mechanics model for predicting the impact response of composite materials. ComputStruct 2001; 79: 997-1011

[6] Liu D. Raju BB, Dang X. Impact perforation re3sistance of laminated and assembled composite plates. IntJ ImpactEngg. 2000: 246: 733-46

[7] Chen JK, Sun CT. Dynamic large deflection response of composite laminates subjected to impact Compos Struct 1985; 4:59-73

[8] N.RajeshMathivanan ,J.Jerald. Experimental Investigation of Woven E-Glass Epoxy Composite Laminates Subjected to Low-Velocity Impact at Different Energy Levels. Journal of Minerals Characterization &Engg Vol. 9 No.7, PP.643-652, 2010.

[9] RamazanKarakuzu ,Emre Erbil , Mehmet Aktas. Damage prediction in glass/epoxy laminates subjected to impact loading. Indian Journal of Engineering &Materials Sciences. Vol. 17, June 2010. PP. 186-198.

[10] Guan Z, Yang C. Low velocity impact and impact process of composite laminates J compos Mater 2002; 36 (7): 851-71

[11] Berdoyes.I; Thebault.J.Bouillom.E. Improved SiC/SiC and C/C materials applications parts International proceedings of European congress on advanced materials and processes. EUROMAT 2005 Prague, Czech Republic 5-8 September 2005