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Comparative Study of Experimental and Simulated Results of Compression Test on Epoxy Based E-Glass / Carbon Fiber Reinforced Polymer Composite Laminates

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***Abstract* - In this study, compressive strength and contraction of Polymer Composite Laminates made of E-Glass / Carbon bi-woven fabric reinforced in Epoxy resin matrix has been evaluated experimentally. Composite laminates were fabricated using hand lay-up technique for different ply orientations of 0^0,30^0,45^0,60^0 and stacking sequence of $(0^0/30^0/45^0/60^0)_{2S}$ for 2 and 3 mm laminate thickness. The laminates were subjected to vacuum bag moulding (Wet Lay-up), followed by post curing process at elevated temperatures. The specimen preparation and compression testing were carried out as per ASTM standards using Instron Universal Testing Machine. The Experimental results were validated with FEM analysis by LS-DYNA using LS-PREPOST as the prime post processor and the results of both experimental and FEM show admirable agreement with one another.**

***Keywords*-- Carbon fiber, E-Glass fiber, Epoxy, Vacuum Bag Moulding, LS-DYNA.**

I. INTRODUCTION

Composite Materials also termed Composites are solid materials that marks when two or more dissimilar materials, each of its own characteristics, are combined to form a new material whose properties are superior to the original materials made for specific application. The name composites more specifically refer to structural materials within which a fibrous material is embedded. Composite materials are heterogeneous engineered materials made of two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct on a macroscopic level within the finished structure. Composites are combinations of two materials in which one of the material(s), called reinforcements, in the form of fibers, sheets or particles are embedded into other material(s) called matrix, when combined together become stronger, stiffer and perform better when compared to each of the distinct components.

Composites are of greatest use in the aviation industry where their stiffness, lightness, and heat resistance makes them the materials of choice in reinforcing the engine cowls, wings, doors, and flaps of aircraft.

Composite materials are also used in the making of sports racquets and other sports equipment, cutting tools and in certain parts of automotive engines. The most extensive application has been in satellite systems, military aircraft, radomes, helicopters, commercial transport vehicles, civil engineering, consumer goods and general engineering services.

A. Functions of Fibers and Matrix

The main functions of the fibers in a composite are:

- To carry the load. In a structural composite, 70 to 90% of the load is carried by fibers.
- To provide stiffness, strength, thermal stability, and other structural properties in the composites.
- To provide electrical conductivity or insulation, depending on the type of fiber used.

A matrix material fulfills several functions in a composite structure, most of which are vital to the satisfactory performance of the structure.

The important functions of a matrix material include the following:

- The matrix material binds the fibers together and transfers the load to the fibers. It provides rigidity and shape to the structure.
- The matrix isolates the fibers so that individual fibers can act separately. This stops or slows the propagation of a crack.
- The matrix provides good surface finish quality and aids in the production of net-shape or near-net-shape parts.
- The matrix provides protection to reinforcing fibers against chemical attack and mechanical damage (wear).

B. Epoxy

Epoxy is a very versatile resin system, allowing for a broad range of properties and processing capabilities. It exhibits low shrinkage as well as excellent adhesion to a variety of substrate materials.

Epoxies are the most widely used resin materials and are used in many applications, from aerospace to sporting goods. There are varying grades of epoxies with varying levels of performance to meet different application needs. They can be formulated with other materials or can be mixed with other epoxies to meet a specific performance need. Epoxies are cured by chemical reaction with amines, hydrides, phenols, carboxylic acids, and alcohols. The curing (cross linking) reaction takes place by adding a hardener or curing agent. Cure rates can be controlled through proper selection of hardeners and/or catalysts. Each hardener provides different cure characteristics and different properties to the final product. The curing goes faster with increased temperature. The higher the cure rate, the lower the process cycle time and thus higher production volume rates. Epoxy-based composites provide good performance at room and elevated temperatures. Epoxies are inherently strong, fairly flexible and have excellent adhesion. Epoxies have good strength, bonding, creep properties and chemical resistance.

C. Glass fibers

Glass fibers are prepared by mixing ingredients such as silica sand, limestone, folic acid and other compounds. The mixture is heated to melting temperature of about 1260°C and the molten glass is made to pass through fine holes of platinum plate. The glass strands thus formed are gathered, cooled and wound. The fibers are drawn and woven into various forms to increase the directional strength of composite materials. Glass fibers are predominantly used fibers in reinforced polymers as they are economical, easy to produce, have high strength, stiffness and easily mouldable with plastics. Different types of glass fibers like E, S, C and quartz, can be manufactured by adding varied chemicals to silica sand. Their high strength, durability, low dielectric constant and relatively low cost have made them very useful in automotive, submarine and motorboat applications. E-Glass fibers (Electrical grade) are good insulators, have relatively high energies to failure, provide the composites with good Impact resistance compared to other fibers. But S-Glass has the highest Impact strength and predominantly used in aerospace and military applications.

The main restraint of glass fibers is their low modulus and is widely used as the reinforcing material for the following reasons:

- Inexpensive and easily available
- Manufacturing using simple and economical method
- Possess high tensile strength and high resistance to corrosion

Fiberglass materials are used in boat hulls, marine structures, pressure vessels, automobile body panels, aircraft wings and fuselage, radar housings, welding helmets, swimming pool items, rooftops and flow pipes.

D. Carbon Fibers

Carbon fibers have high elastic modulus exhibiting high stiffness at low elongation. Carbon fibers are not moisture absorbent and resist chemical actions. Their fatigue strength is excellent and do not get stressed and corroded easily. But carbon fibers are relatively expensive compared to glass fibers. Carbon fibered composites are ideally suited for applications where strength, chemical inertness, stiffness, weightlessness, high damping and fatigue characteristics are the inevitable requirements. They can also be used at elevated temperatures without many consequences. Their properties make it an ideal choice of reinforcing materials used in aerospace, automobiles, civil engineering, military and various competitive sport applications.

Carbon fibers are used as a reinforcing material due to:

- Good Physical strength, toughness and impact resistance.
- Good vibration damping strength, lightweight, dimensional stability
- Low abrasion rate, low coefficient of thermal expansion.

E. Polymer Matrix Composites

Polymer Matrix Composites are the most commonly used, advanced composite materials comprising of a fibrous material of thin diameter (e.g., fiberglass, graphite, carbon, Kevlar, boron etc.) reinforced into polymerized resin (e.g., epoxy, polyester etc.) to enhance the required properties of composites to desired levels for specific applications. Polymer Matrix Composites have widespread usage due to their low cost, high strength and simple fabrication methods. Polymer Matrix

Composites are advantageous, mainly due to the following properties*:*

- Possess high tensile strength, stiffness and fracture toughness
- Possess good abrasive resistance

The major disadvantages are

- Thermal resistance is low
- Coefficient of thermal expansion is high.

Properties of Polymer Matrix Composites are determined by Properties of the fibers, Orientation of the fibers, Concentration of the fibers, Stacking sequence of fibers, Aspect ratio of fibers and Properties of the matrix.

Polymer composite properties can be weighed using rule of mixtures. Polymer Matrix Composites are widely used in aerospace structures, automotive components, boat hulls, radio controlled vehicles, sport equipment (golf clubs, ski's, tennis racquets, fishing rods), bullet proof jackets, brake/clutch linings, medical devices etc.

II. FABRICATION OF LAMINATES FOR COMPRESSION TESTING

Composite panels using reinforced materials of bi-woven glass and carbon fabrics as facings have been prepared using Vacuum Bagging technique. The specimens were cut to the requisite size and shape, glued to the facings using an adhesive resin made of epoxy **LY 556** resin and **HY 951** hardener mixture, blended to 100:10 ratio by weight. The surfaces were thoroughly cleaned to be free of oil, dirt or unwanted materials before bonding at normal temperature and pressure. The coupons were cured for about 24 hours to get sufficient strength. Specimen thicknesses have been maintained at 2 mm / 3 mm only throughout the experiments for glass and carbon fibered composites. Test laminates of 300 mm X 300 mm were initially fabricated to prepare test specimens by Vacuum bag moulding followed by curing at room temperature.

The fabric used was E-glass fiber and Carbon fiber of 300 gsm in the form of rolls. The fabric roll was spread on the flat surface and required dimension of 300 mm x 300 mm was marked using the marker pen on the spread fabric and cut using a scissor manually. Required number of layers of fabric was cut to get the required thickness of laminates. The resin and the hardener of required quantities were taken in a previously weighed empty bowl. They were mixed properly in the bowl using a paintbrush. The mixture was used immediately in the preparation of the laminate which otherwise would form gelation. A highly polished flat mould was cleaned and wiped dry followed with acetone PVA wax for about 20 minutes to dry. The wax is applied in order to form a thin film.

A small quantity of resin system was coated on the mould surface and then a layer of the fabric already cut was placed on that. The resin system was applied on the fabric to wet it and then the next layer of fabric was placed. he same procedure was followed till the required number of layers were placed ensuring adequate impregnation.

The Mylar sheet was stuck on the topmost ply and specimen was rolled using roller. The same procedure is repeated for making other composite laminates also. A flexible film of Polyvinyl Acetate (PVA) was glued over the wet lay-up and vacuum is drawn by having the edges sealed. An advanced method of vacuum bagging is used for better consolidation of fibers and to reduce voids by placing a release film on the laminate, covered by a bleeder ply of fibreglass cloth so that excess resin can be squeezed out from the laminate. A peel ply of a non-woven fabric was kept on the bleeder ply and the vacuum bagging was straddled over the entire assembly. Evacuating the bag at atmospheric pressure eliminates cavities and forces out surplus resin from the laminate. The laminates were left at room temperature curing for 24hours and then the laminates were kept in oven for post curing to improve the properties. In the same way, laminates were prepared for different ply orientations like 0^0, 30^0,45^0 and 60^0 and the stacking sequence of $[0^0/30^0/45^0/60^0]_{2S}$ and were cut to the required size and shape as per ASTM standards to undergo compression tests.

III. COMPRESSION TESTING OF COMPOSITE LAMINATES (EXPERIMENTAL)

The most difficult of the intrinsic test properties to be measured are the compressive test properties. Slight specimen geometric variations can cause eccentricity of the applied load and consequently enhances the prospect for failures to occur due to geometric instability. So complex loading fixtures and specimen configurations have been developed for compressive strength measurements. The Compression tests are carried out to describe the compression properties of the FRP Composite Laminates. With a complete deflection curve it is possible to determine the core compressive strength and the maximum contraction modulus. These tests were conducted according to **ASTM D 1621** standards with a test speed of 5mm/min. The experimental results for Epoxy based E-Glass and Carbon fibered composite laminates of 45^0 orientation under compression loading is depicted below.

Fig 1: Specimen under Compression Test

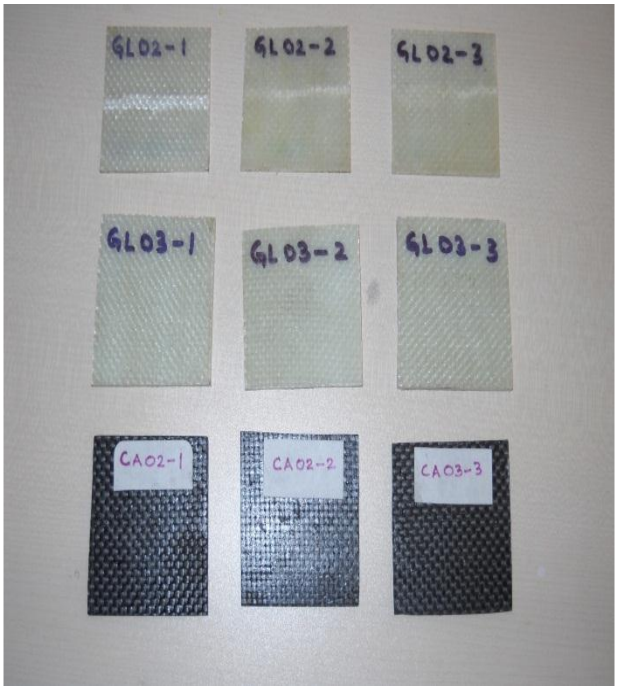

Fig 2: Damaged Specimens after Compression Test

Table I:
Compression Test Specimen Dimensions

Type of Composite	Thickness In mm	Dimension in mm	Fiber & Matrix Volume %	No. of Layers
E-Glass / Epoxy	2	50X50	65:35	8
E-Glass / Epoxy	3	50X50	65:35	12
Carbon / Epoxy	2	50X50	65:35	8
Carbon / Epoxy	3	50X50	65:35	12

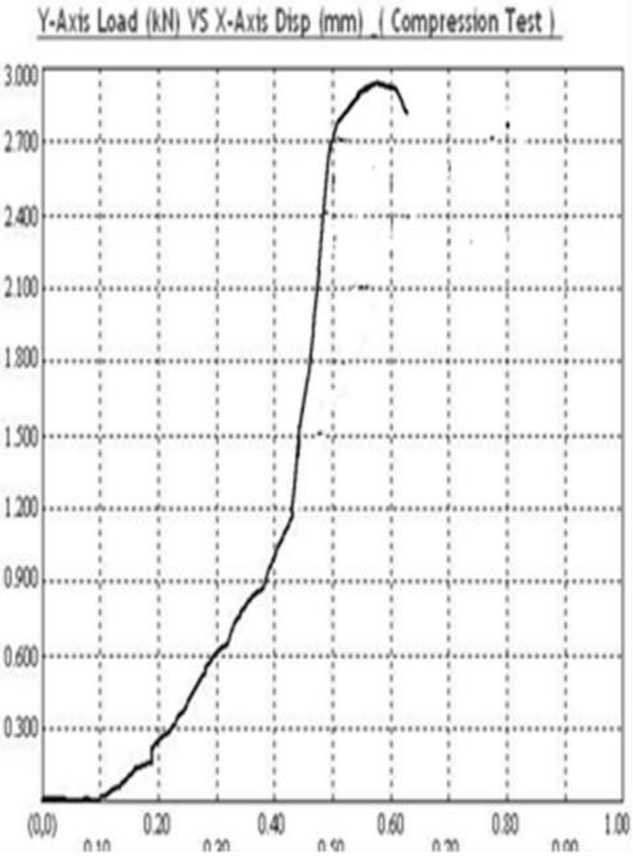

Fig 3: Compression load vs Contraction of E-Glass/Epoxy Laminate (GL 03/45^0)

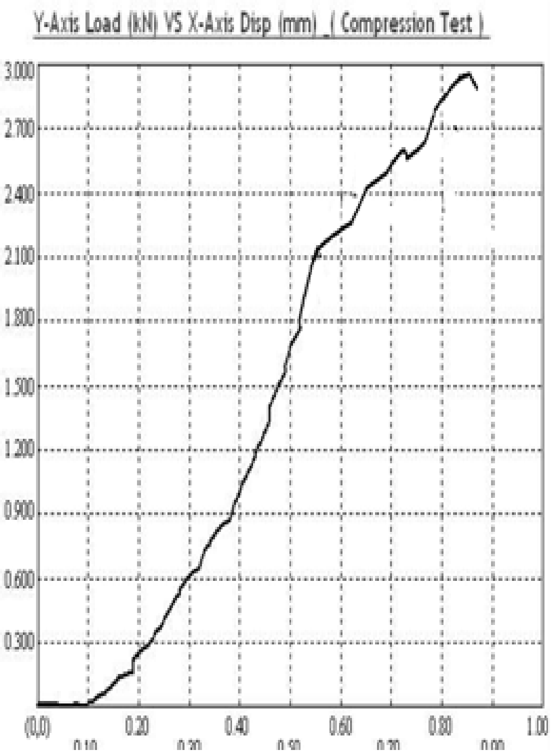

Fig 4: Compression Load vs Contraction of Carbon /Epoxy Laminate (CL 03/45^0)

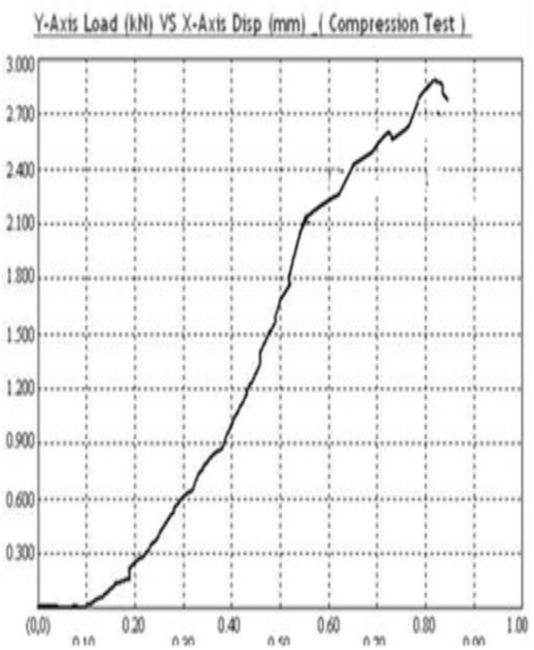

Fig 5: Compression load vs Contraction of E-Glass/Epoxy Laminate GL 03 stack with stacking sequence [0^0/30^0/45^0/60^0].

IV. SIMULATED ANALYSIS OF COMPOSITE LAMINATES (LS-DYNA)

LS-DYNA Version 4.0 is all-purpose advanced finite element analysis software program, having the ability of simulating real problems of composite materials through linear, nonlinear, static and dynamic models. Each of those use appropriate material models incorporating material characteristics, constraints, finite elements, nodal loads and control parameters. It uses explicit time integration method in solving problems of non-linear dynamic response. It encompasses a host of finite elements and many material models as a complete library to simulate and analyse the non-linear behaviour of materials. Its potential applications are plentiful and can be custom-made suiting many fields. LS-DYNA is entirely command driven and comprises of a single executable file. It requires an executable command shell, an input file and adequate disk space to perform the calculation. All input files are in simple ASCII format and can be prepared using any text editor or a graphical pre-processor.

The virtual simulation and analysis is carried out in LS-DYNA using LS-PREPOST as the prime processor in progressive damage mode. It is comprehensively used in aerospace, automobile, construction, military, manufacturing and bioengineering industries.

The effective stress and resultant displacement under compression loading for 3 mm E-Glass and Carbon fibered composite laminates of 45^0 ply orientations and 3 mm E-glass fibered composite laminates of stacking sequence of [0^0/30^0/45^0/60^0]$_{2S}$ is depicted below.

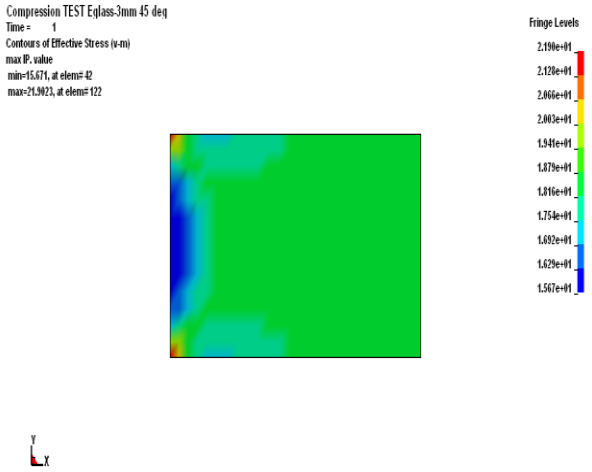

Fig 6: E-Glass 3 mm / 45^0 Effective Stress (C)

Fig 7: E-Glass 3 mm / 45^0 Resultant Displacement (C)

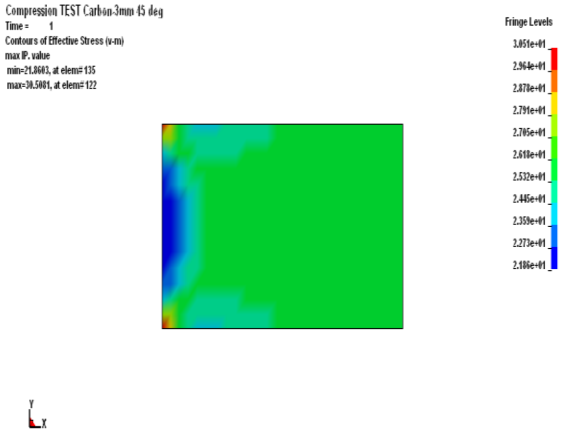

Fig 8: Carbon 3 mm / 45^0 Effective Stress (C)

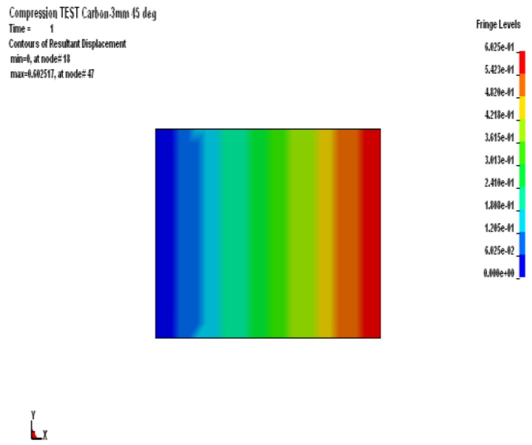

Fig 9: Carbon 3 mm / 45^0 Resultant Displacement (C)

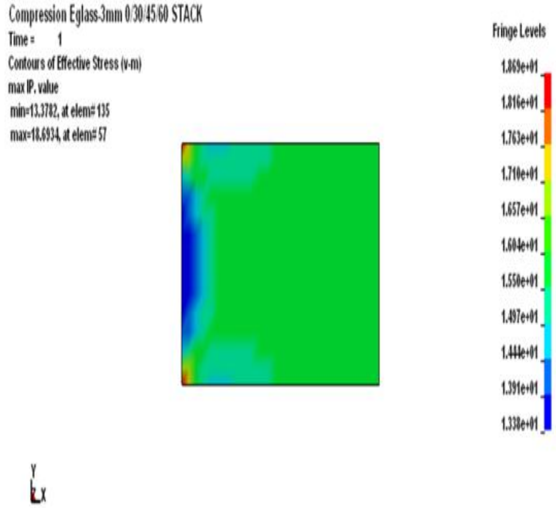

Fig 10: E-Glass 3 mm stack $0^0/30^0/45^0/60^0$ Effective Stress (C)

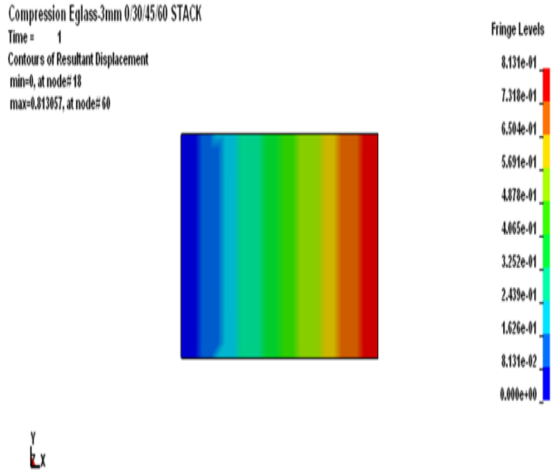

Fig 11: E-Glass 3 mm stack $0^0/30^0/45^0/60^0$ Resultant Displacement (C)

V. COMPARATIVE ANALYSIS OF EXPERIMENTAL AND SIMULATED RESULTS

The following tables and figures depict the comparative results of Experimental & FEM under compression loading.

Table II.
Comparison of Experimental and FEM Results of Compression Test of E-Glass Fibers Reinforced in Epoxy Matrix of 2 mm and 3 mm Thick Bi-Woven Polymer Composite Laminates for 0^0,30^0,45^0,60^0 Ply Orientations and Stacking Sequence of $[0^0/30^0/45^0/60^0]_{2S}$

Specimen Designation	Ply orientations / stacking sequence	Compression strength (σ) MPa		% variance	Contraction at Maximum Load (mm)		% Variance
		Experiment	Ls-dyna		Experiment	Ls-dyna	
GL02	0^0	16.75	15.26	9.76	0.810	0.632	21.97
GL02	30^0	15.36	16.19	5.40	0.596	0.610	2.34
GL02	45^0	17.84	17.79	0.28	0.654	0.671	2.59
GL02	60^0	15.63	15.86	1.47	0.586	0.603	2.90
GL03	0^0	18.92	19.67	3.96	0.816	0.864	5.88
GL03	30^0	15.48	16.83	6.13	0.801	0.818	2.12
GL03	45^0	21.64	21.90	1.20	0.843	0.853	1.18
GL03	60^0	17.70	17.87	0.96	0.790	0.803	1.65
GL02 stack	$[0^0/30^0/45^0/60^0]_{2S}$	17.40	17.75	2.01	0.780	0.770	1.28
GL03 stack	$[0^0/30^0/45^0/60^0]_{2S}$	19.46	18.69	3.95	0.820	0.810	1.21

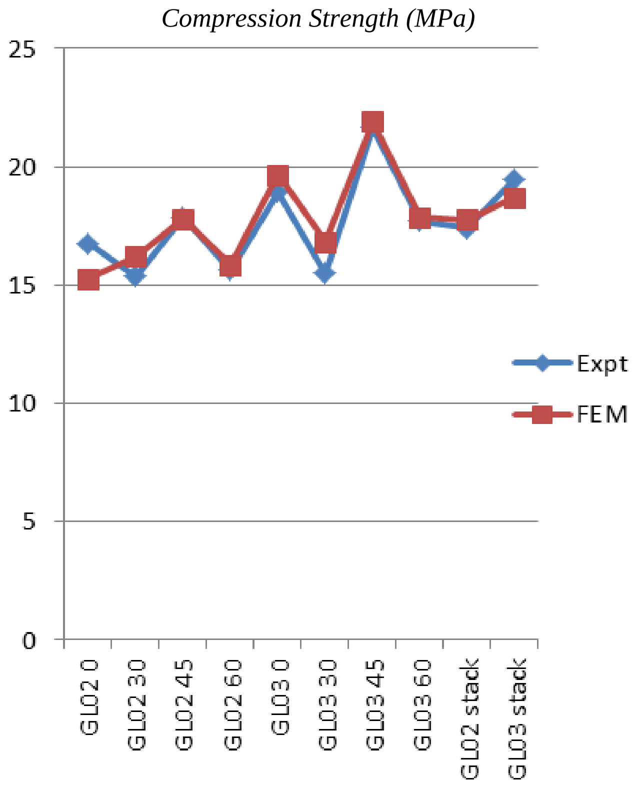

Fig 12: Experimental and FEM results depicting compression strength of E-glass/Epoxy of 2 mm and 3 mm thickness for different ply orientations and stacking sequence

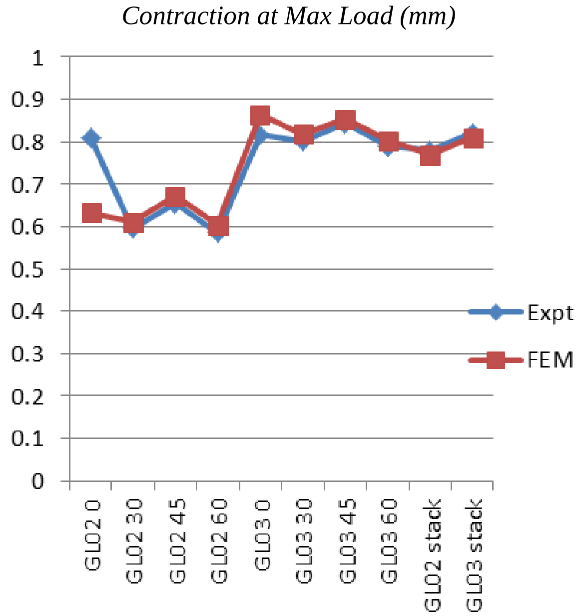

Fig 13: Experimental and FEM results depicting contraction of E-glass/Epoxy of 2 mm and 3 mm thickness for different ply orientations and stacking sequence

Table III.
Comparison of Experimental and FEM Results of Compression Test of Carbon Fibers Reinforced in Epoxy Matrix of 2 mm and 3 mm Thick Bi-Woven Polymer Composite Laminates for 0^0,30^0,45^0,60^0 Ply Orientations and Stacking Sequence of $[0^0/30^0/45^0/60^0]_{2S}$

Specimen Designation	Ply orientations / stacking sequence	Compression strength (σ) MPa		% variance	Contraction at Maximum Load (mm)		% Variance
		Experiment	Ls-dyna		Experiment	Ls-dyna	
CL02	0^0	24.98	27.02	8.16	0.592	0.622	5.06
CL02	30^0	23.12	24.92	7.78	0.465	0.493	6.02
CL02	45^0	25.03	26.06	4.11	0.632	0.674	6.64
CL02	60^0	23.48	25.34	7.92	0.456	0.526	15.35
CL03	0^0	28.91	29.15	0.83	0.567	0.604	6.52
CL03	30^0	28.00	29.65	5.89	0.498	0.513	3.01
CL03	45^0	29.64	30.50	2.90	0.587	0.602	2.55
CL03	60^0	28.30	28.84	1.90	0.543	0.544	0.18
CL02 stack	$[0^0/30^0/45^0/60^0]_{2S}$	24.92	24.37	2.20	0.620	0.610	1.61
CL03 stack	$[0^0/30^0/45^0/60^0]_{2S}$	29.20	28.23	3.32	0.640	0.630	1.56

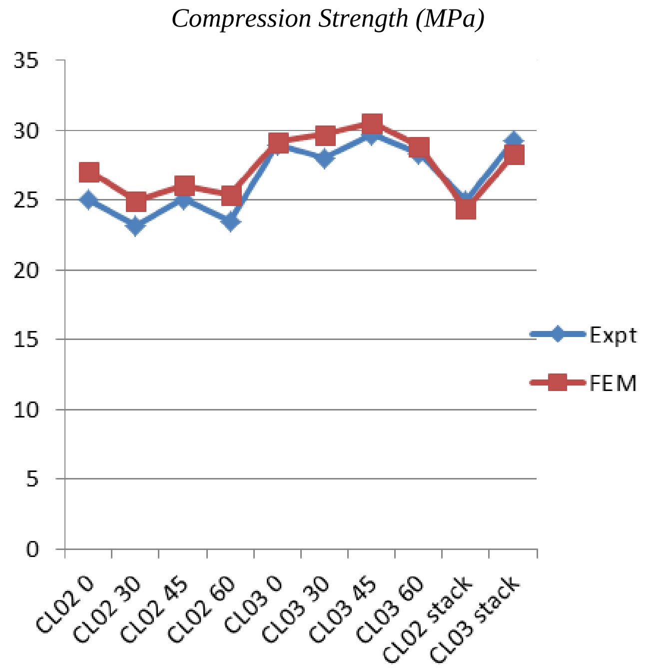

Fig 14: Experimental and FEM results depicting compression strength of Carbon/ Epoxy of 2 mm and 3 mm thickness for different ply orientations and stacking sequence

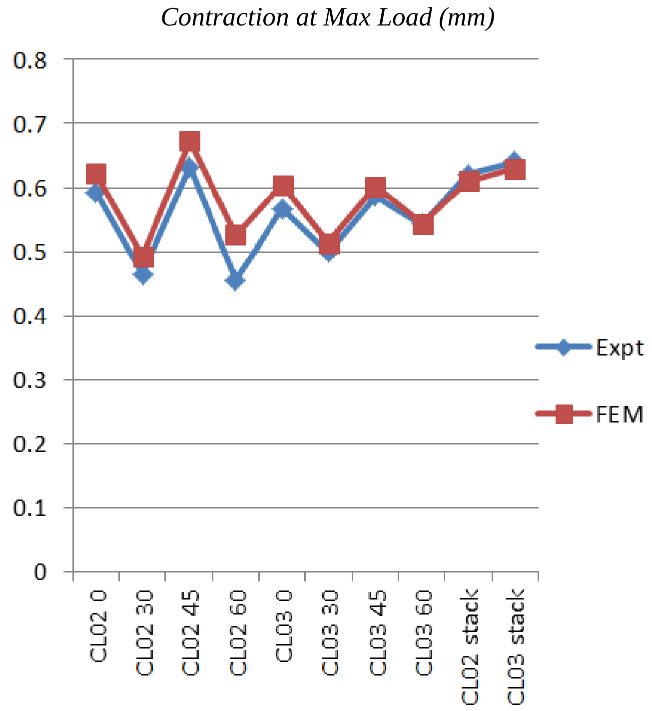

Fig 15: Experimental and FEM results depicting contraction of Carbon/Epoxy of 2 mm and 3 mm thickness for different ply orientations and stacking sequence

Comparative Analysis of Compression Tests

Compression failure is mainly due to buckling followed by breakage, initiating compression stress at the inner layer of the laminate and tensile stress at the outer layer of the laminate, transmitting stresses through the interface, inducing fibers getting delaminated one by one. Finite element modeling analysis by LS-DYNA for compression tests was conducted using LS-PREPOST as the prime processor. It uses “MAT_054-055” – MAT ENHANCED SHELL COMPOSITE DAMAGE model which is based on progressive failure using Chang failure criterion/Tsay-Wu criterion for composite failures. Elemental studies were performed simulating E-Glass/Carbon fiber and epoxy material system under compression loading by inputting all relevant property values of fibers and resin system.

The specimen is created in CATIA as per the dimensions based on ASTM D 1621 standards (50 x 50 mm) for 2 and 3 mm thickness and imported in LS-PREPOST. The FEM results for compressive strength and the corresponding contraction for the laminates comprising of E-Glass/Carbon fibers embedded into Epoxy resin at $0^0/90^0$, 30^0, 45^0 and 60^0 ply orientations and stacking sequence of $[0^0/30^0/45^0/60^0]_{2S}$ of thickness 2 and 3 mm are compared with the experimental observations and is found to be in close agreement with one another. The figures 3 to 5 depict load vs contraction curve under compression loading of Epoxy based E-Glass and Carbon fibered composite laminates of 3 mm thickness experimentally. The figures 6 to 11 depict the effective stress and resultant displacement (contraction) of FEM results of E-Glass and Carbon fibered laminate of 3 mm thickness under compression loading.

Test results show that the Carbon specimens with 3mm thickness and at 45^0 ply orientation have the best compression properties amongst other specimens. Carbon unveils about **20 %** higher strength as compared to E-Glass. Therefore, it is best suited for various applications of Fiber Reinforced Composites.

The results of both experimental and FEM values are compared and the percentage variation between the experimental and FEM results of E-Glass and Carbon fibered test laminate specimens of 2 and 3 mm thickness was found to be well within prescribed limits as per the results tabulated in Table II and III respectively and the figures 12 to 15 depict the values of experimental and FEM results to very close agreement between them.

VI. CONCLUSION

- Compressive failure is due to material crushing, fiber kinking or micro-buckling.
- Edgewise compressive tests for Fiberglass/Carbon reinforced Epoxy Laminate Composites with 2mm and 3 mm thickness were conducted as per (ASTM D 1621) standards.
- Test results apparently show that the Compressive Strength of Carbon/Epoxy Composite Laminate is higher than that of Glass/Epoxy Composite Laminate with 2mm and 3mm thickness for the same loading and boundary condition.
- The laminates have high compression strength with moderate strain at 45^0 ply orientation and suitable for applications involving compression loads.
- Carbon unveils **20%** higher compression strength as compared to E-Glass. It was inferred that Carbon/Epoxy laminate of 3mm thickness have high value of compressive strength and no failure of specimen was observed during the test. This shows that the Carbon reinforced materials sustain buckling stress better than fiberglass.
- The experimental results were validated with FEM results and are found to be in good agreement with each other.

REFERENCES

[1] David Roylance, “Introduction to Composite Materials”, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, March 24, 2000.

[2] Sanjay K. Mazumdar, Ph.D, “Composites Manufacturing Materials, Product, and Process Engineering” CRC Press, Boca Raton London New York Washington, D.C.

[3] Kevin Potter, “An Introduction to composites”, first edition, 1997.

[4] William D. Callister, “Fundamentals of Materials Science and Engineering”, Jr. Department of Metallurgical Engineering, the University of Utah.

[5] Powell, P.C, Engineering with Polymers, Chapman and Hall, London, 1983

[6] Harris, B., Engineering Composite Materials, The Institute of Metals, London, 1986.

[7] Hiroyuki Kawada, Norihiko Taniguchi, Kun-Nan Tsay M., ”Evaluating the Mechanical Properties of Glass fiber/Epoxy interfacing using slice compression test”, Adv. App. Mech, pp 1-8.

[8] Kabiri Ataabadi, S. Ziaei-Rad, H. Hosseini-Toudeshky, “Compression failure and fiber-kinking modeling of laminated composites”, Steel and Composite Structures, Vol. 12, No. 1, 2011, pp 53-72.

[9] Buixansky, N. A. Fleck, “Compressive failure of Fiber composites”, J. Mech. Phys. Solids, Vol.41, 1993, pp. 183-211.