Investigation of Impact Performance of Glass/Epoxy Laminates

Aarthy S
P.G Student, Department of Mechanical Engineering
Regional Centre of Anna University, Tirunelveli, Tamilnadu, India

Velmurugan T
Assistant Professor, Department of Mechanical Engineering
Regional Centre of Anna University, Tirunelveli, Tamilnadu, India

Abstract- The main objective of this paper is to investigate the effect of properties of resin and fibre on the performance of Glass/Epoxy laminates, a fibre-reinforced composites. Compression failure of composite structures previously damaged by an impact event is due to the propagation of impact-induced damage mechanisms such as interlaminar bonding, constituent micro cracking, sub laminate buckling, as well as the interactions between these mechanisms. This requires fabrication of woven glass fibre epoxy matrix laminates with 1% graphite fillers. Fabrication is done by vacuum bag method followed by curing for specified time in hot air oven. The impact test was carried out for a specific height with given mass and diameter of hemispherical shape impactor. The compression loading was given to the impacted specimen. The damage size was analyzed. Ultimate Compressive residual strength was then calculated.

Keywords – graphite fillers, damage tolerance, compression-after-impact, laminates, mechanical testing

I. INTRODUCTION

In terms of structure, materials can be divided into four basic categories: metals, polymers, ceramics and composites. A composite structure is a material composed of two or more phases combined in a macroscopic scale, whose properties are superior constituent materials, acting in an independent manner. In other words, a composite is a combination of at least two different materials both chemically and geometrically.

Composites are material of choice for light-weight structures due to their excellent weight/strength and weight/stiffness properties. Composite structures may be subjected to low-velocity impacts. Many parameters are involved in impact problems and this induces very different target responses depending on their specific set of interactions. Under the dynamic loading of the material, these unseen damages can become larger and even cause the loss of the material. Because of this, on a layered composite build, foreseeing the damage caused by the impact is very important on design and usage. [19]

Low velocity impact is considered potentially dangerous mainly because the damage might be left undetected. In many situations, the level of impact at which visible damage is formed is much higher than the level of residual properties occurs. Impact damage is generally not considered to be a threat in metal structures. In contrast composites can fail in a wide variety of modes and contains Barely Visible Impact Damage (BVID), which nevertheless severely reduces the structural integrity of the component [17]. Damage tolerance in laminates is usually studied by determining the effect of different impact energies on their residual strength, the Compression After Impact (CAI) test being the experimental test of components damaged by low energy impact. The global testing process has two steps: in the first, the specimen is subjected to low-energy transverse impact that generates a certain degree of damage inside the laminate; then the damaged specimen is tested in in-plane compression to determine its residual strength. The CAI test must be carried out in a device that avoids global buckling of impacted specimen, so that failure comes as the delamination progresses with the local buckling of the sublaminates produced by impact [22]. The impact event typically causes matrix cracking, fibre breakage and delamination within the structure. Under compressive loads, these failures interact and the impact-induced damage propagates to failure at significantly lower load levels compared to undamaged states [12]. The CAI has become a key experiment to gather damage tolerance performance during the design or certification phase of a new structure or material, involving composites. CAI performance is dependent on the behaviour of the material under impact loading conditions. Impacts on an airframe can occur from various hazards, ranging from the impact of a ballistic projectile to the fall of a screwdriver during a maintenance procedure. The range of impact velocities and energies are wide. A velocity threshold at 20 m/s marks a transition between two different types of damage creation behaviour. In a recent study,

the FAA(Federal Aviation Authority) identified 14 different parameters influencing the impact performance of a composite structure. Some are related to the structure being impacted (material constituents, lay-up sequence, laminate thickness, structure design), others are related to the impacting object (mass and shape of the striker, velocity and energy of the impact). Various investigators have studied many of these parameters such as the stacking sequence and the impact velocities [7]. The effect of resin and fibre properties on composite by CAI performance was studied. Impact responses of laminates were strongly influenced by fracture toughness of the resin. To manufacture the samples, 11 ply quasi-isotropic panels were laid up by hand. The stacking sequence was [45/0/-45/90]. After curing in hot-air oven they were cut into 150×100 mm^2 coupons with 3 mm thickness. Impact tests were performed with a drop weight impact machine. The impactor has a hemispherical tip with a diameter of 10 mm. The specimens were supporting using a jig following the Boeing standard for CAI and compressed at a constant displacement rate of 1 mm/min [15].
The rest of the paper dealt with the Experimental procedure and mechanical tests.

II. EXPERIMENTAL PROCEDURE

2.1 Materials –

The fibre used here for the material is E-glass which is a plain weave and is bidirectional. Resin used here is epoxy LY 556 and is mixed with hardener HY 951 in the ratio of 1:10 along with graphite fillers which is a fine black powder of about 400 mesh.

Figure 1. Resin mixed with graphite powder

2.2 Specimen Preparation –

The required specimen dimension is 300×150×3 mm and the fabric is cut accordingly in order to achieve the stacking angle $[0/\pm45/90]_s$. During hand lay-up, each ply is impregnated with epoxy resin mixed with graphite fillers. After laying up, the sealant is covered on all four sides of the laminate and its upper surface with a perforated sheet. Surface mat was spread above it to absorb the excess resin. Vacuum of about 550 Hg/mm^2 was applied through vacuum valve at one corner of the system which helps in air evacuation. The system was allowed for ambient cure for about 20 hours along with the vacuum pressure. The bagged part was then placed in hot air oven which is shown in fig. 2 at 120^0 C for two hours and later allowed to cool at room temperature. The volume fraction of the laminate is shown in table-1and the final laminate is shown in Figure 2.

Table -1 Volume Fraction

Constituents	Percentage (%)
Fibre	**63.4**
Resin	**32.6**
Hardener	**3**
Fillers	**1**

Figure 2. Glass-Epoxy laminate with graphite filler

III. MECHANICAL TESTS

3.1 Impact Test –

The impact test was carried out to determine the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a drop-weight impact event. In accordance with ASTM D7136, a flat rectangular plate of dimension 100 mm × 150 mm was cut and was subjected to impact damage using a drop tower setup with a hemispherical striker tip and required mass were added. Impactor used here weighs 2 kg with 10 mm diameter. Place the specimen ensuring that it is centered relative to the cut-out. Secure the specimen in place using clamping so that rebounding can be prevented during the impact event.

3.2 Impact Energy –

Impact energy due to the impact event was calculated from the expression as given below,

$E_i = mgh$

where,

E_i = Potential energy of the impactor, J

m = mass of the impactor, kg

g = acceleration due to gravity, 9.81 m/s^2

h = drop-height of impactor, m

therefore,

$E_i = 2×9.81×1$

$= 19.62$ J

3.3 Impact Velocity –

Impact velocity can be found as,

$E_i = (mv_i^2)/2$

where,

m = mass of the impactor

v_i = velocity of the impactor

E_i = impact energy

therefore,

$19.62 = (2× v_i^2)/2$

$v_i = 4.43$ m/s

3.4 Compression After Impact (CAI) Test –

This test method helps to find compression residual strength properties of multidirectional polymer matrix composite laminated plates already been subjected to drop weight impact test as per ASTM D 7136.

Figure 3. Multi-piece support fixture

The damaged piece is installed in a multi-piece support Fixture as in Figure 3 that has been aligned to minimize the loading eccentricities and induced specimen bending. The specimen/fixture assembly is placed between platens and end-loaded under compressive force until failure. Impacted samples were subjected to compression loading based on ASTM D 7137 specification at the rate of 1 mm/min. The speed of testing was set such that the failure is produced within 1 to 10 minutes. Preloading was applied to the specimen/fixture assembly in order to ensure all loading surfaces are in contact and to align the platens. Then the compressive force was reduced and made to re-zero to balance all instrumentation. Loading was done at specified rate until maximum force was reached and it has dropped off about 30% from the maximum.

IV. EXPERIMENTAL RESULTS

After the laminate subjected to impact force, delamination occurs which was then progressively propagated during the application of compressive force. The impacted specimen is shown in Figure 4 and the compression after impact specimen is shown in Figure 5 & Figure 6

Figure 4. Impact induced damage

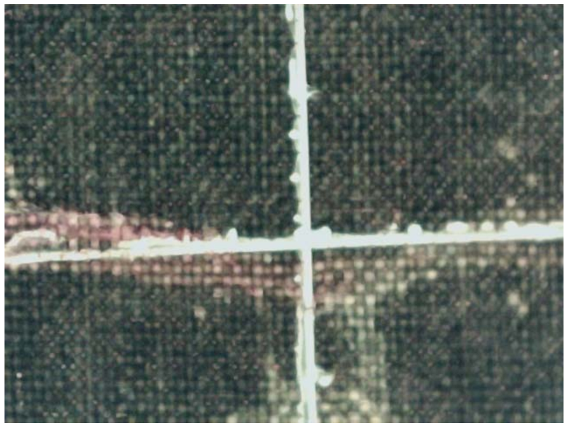

Figure 5. Damage after compression loading viewed from front face

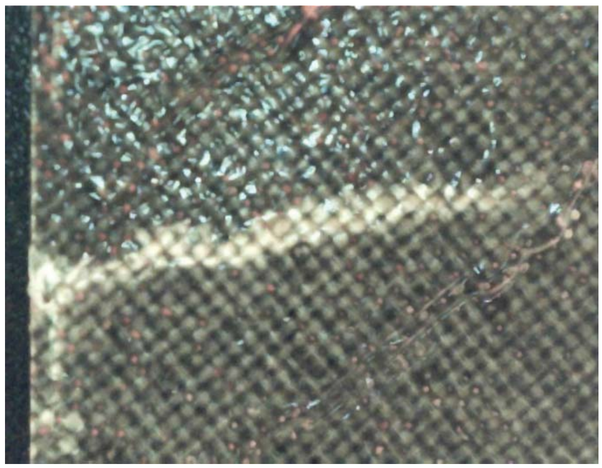

Figure 6. Damage after compression loading viewed from back face

From Figures, it is evident that after impact induced compression, the final failure was controlled by sudden extension of the horizontal crack towards the edges of the specimen. Load-displacement curve of impacted composite laminate in compression is shown in Figure 7.

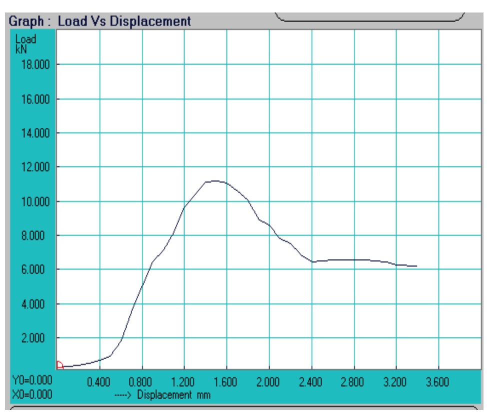

Figure 7. Load-Displacement curve of an impacted composite laminate in compression

From the plot shown in Figure 7, the ultimate compressive residual strength was calculated as below.

$F_{CAI} = P_{max}/A = P_{max}/bd$

where,
P_{max} = maximum force prior to failure, N
B = specimen width, mm
H = specimen thickness, mm
F_{CAI} = ultimate compressive residual strength, MPa
therefore,
$F_{CAI} = 11205/(100\times2.6) = 43$ Mpa
Thus, the ultimate compressive residual strength was found to be 43 MPa.
Delamination occurs in the specimen after CAI test is shown in the Figure 8,

Figure 8. Delamination after CAI test

V.CONCLUSION

This paper provided a detailed investigation of compression after impact test response of woven glass/epoxy laminate with 1% graphite fillers. Resin toughness is more influencing parameter than the fibre strength and stiffness. CAI is seen as a matrix dominant failure process. Ultimate compressive residual strength for resin with graphite fillers is more than that without the inclusion of it [12]. Delamination propagation is the critical mechanism that lowers the sublaminate buckling strength of impacted specimens. Delamination propagation extends throughout the width of the specimen between middle plies, which influences the sublaminate buckling. Delamination propagation is marked by mode transition: the loading-direction shear dominated initial impact-induced delamination extends in low amplitude compression loads, which transitions to the lateral shear dominated delamination at higher amplitudes. The delamination extends laterally toward the sides of the specimen. The crack initiate at the back face of the specimen. The constituent cracks propagate laterally and along the thickness direction in shear mode to cause ultimate failure of the specimen under compressive loading.

REFERENCES

[1] Arturas Kersys, Neringa Kersiene, Antanas Ziliukas, “Experimental Research of the Impact Response of E-Glass/Epoxy and Carbon /Epoxy Composite Systems”, *Materials Science Vol.16. No.4. 2010*

[2] A. Sjogren, A. Krasnikovs, J.Varna, “Experimental determination of elastic properties of impact damage in carbon fibre/epoxy laminates” *Elsevier: Composites Part A 1237-1242, 2001*

[3] A.R.. Brindle, X Zhang, “Predicting the Compression-after-impact performance of carbon fibre composites based on impact response” *Cranfield university, 2007*

[4] *ASTM International,* “Standard test method for Measuring the Damage Resistance of a Fibre-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event” D7136/7136M - 12

[5] ASTM International, “Standard test method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite plates” D7137/D7137M - 12

[6] Debabrata Chakraborty, “Delamination of laminated fibre reinforced plastic composites under multiple cylindrical impact” *Materials and design 28 1142 -1153, 2007*

[7] D.D.R. Cartie, P.E. Irving, “Effect of resin and fibre properties on impact and compression after impact performance of CFRP” *Composites: part A 33 pp.483-493, 2002*

[8] Florence Roudolff, Michael Gadke, “Damage tolerance of composite structures for large transport aircraft” *Aerosp. Sci. Technol. 4 pp. 23-32, 2000*

[9] Giovanni Belingardi, Roberto Vadori, “Low velocity impact tests of laminate glass-fiber-epoxy matrix composite material plates” *International Journal of Impact Engineering 27 pp.213-229, 2002*

[10] G. Belingardi, M.P. Cavatorta, D.S. Paolino, “Single and repeated impact tests on fiber composite laminates: Damage Index vs. residual flexural properties” *Politecnico di Torino 2008*

[11] G.J. Short, F.J. Guild, M.J.Pavier, “Post-impact compressive strength of curved GFRP laminates” *Composites: Part A 33 pp. 1487-1495, 2002*

[12] Hao Yan Oskay, Arun Krishnan, Luoyu Roy Xu, “Compression After Impact Response of Woven Fiber-Reinforced Composites” *Vanderbilt University, 2010*

[13] John P. Dear, Samuel A. Brown, “Impact damage processes in reinforced polymeric materials” *Composites Part A 34 pp. 411 – 420, 2003*

[14] N.K.Naik, R.Ramasimha, H.Arya, S.V. Prabhu, N.ShamaRao, “Impact response and damage tolerance characteristics of glass-carbon/epoxy hybrid composite plates, *Bethel: Society for experimentel mechanics, p.198-201, 2000*

[15] N.K.Naik, Y.Chandra Sekher, Sailendra Meduri, “Damage in woven-fabric composites subjected to low-velocity impact” *Indian Institute of Technology, Powai, Mumbai, 1998*

[16] N.K.Naik, R.Ramasimha, “Estimation of compressive strength of delaminated composites” *IIT Mumbai, 1998*

[17] N.Rajesh, Mathivanan, J.Jerald, “Experimental Investigation of Woven E-Glass Epoxy Composite Laminates Subjected to low-velocity at different levels” *Journal of minerals and materials characterisation & engineering, vol.9, no.7, pp.643-652, 2010*

[18] N .Rajesh, Mathivanan, J.Jerald, “Interlaminar fracture toughness and low-velocity impact resistance of woven glass epoxy composite laminates of EP3 Grade” *Journal of minerals and materials characterisation & engineering, vol.11, no.3, pp.321-333, 2012*

[19] Rajeshpandian R, Muruganandhan R, “ Experimental and finite element analysis of mechanical response on unidirectional glass fibre epoxy laminate” *Anna University Chennai, 2009*

[20] Ramazan Karakuzu, Emre Erbil, Mehmet Aktas, “ Damage prediction in glass/epoxy laminates subjected to impact loading” *Indian Journal of Engineering and material Sciences, vol.17, pp.186-198, 2010*

[21] Robin Olsson, “Analytical prediction of large mass impact damage in composite laminates” *Composites: Part A 32 pp.1207-1215, 2001*

[22] S. Sanchez-Saez, E.Barbero, R. Zaera, C.Navarro, “Compression after impact of thin composite laminates” *University of Madrid, 2004*