Effect of Transverse Low Velocity Impact Damage on Torsional and Bending Strength and Effect of chemical reactivity of Hybrid Aluminium/Composite Tubes

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I. ABSTRACT:

The major reasons for switching toward composite materials are due to their properties of higher specific stiffness, strength and performance that are comparable with conventional materials. Nowadays, the use of composite materials in our lives has become very common and these are found application as drive shaft, building and infrastructural system, landing gears for helicopters, furniture, transportation, rocket structures, tube structures for sports equipment, , truss structures, robot arms.

In this experimental study a hybrid composite shaft was fabricated by wrapping 320 GSM carbon and 435 GSM E-glass woven fabric fibre with Araldite material, completely around aluminium tube with manufacturing method in which hand layup method aided with high pressure compressed air is productively used for the purpose that woven fabric could conform to curved surfaces. A pendulum type drop weight test set-up was construct which is able to produce low-velocity transverse impact damage on composite specimens. A total of sixteen specimens were manufactured in which four specimens from each type of composite material and four bare aluminum tubes are impacted at energy level of 10.5 J on two consecutive points whish are 50 mm apart along the longitudinal axis of specimen, twenty-four specimens in total, were tested under torsion, three point bending test. For a low velocity impact, it is notice that invisible cracks develops in carbon/glass fibre along with small conical impression occur in aluminum tube in hybrid aluminum composite tubes. Load-deflection & torque-angle of twist relation data were documented for with and without impact damage specimens and compare these data. And by the use of NaCl solution study about chemical reactivity of twill woven fabric of Carbon and Glass based aluminum composite tube. Fabric of carbon/glass wound around the aluminum tube by the use Araldite Epoxy and Hardener.

KEYWORDS: Twill Woven fabric of Carbon/Glass composite, low velocity impact, Torsion and bending strength, Chemical Reactivity, NaCl solution, three point bending.

II. INTRODUCTION

In the 19th Century the composites industry began to develop, better plastic resins and improved reinforcing fibers were developed. The composites industry is gradually evolving, with much of the growth now focused on field of engineering. Composite materials can be classified based on the form of their constituents, number of layers, orientation of fibers, length of fibers etc. Depending on the size of the reinforcement we can classify the composites as fibrous composites, powdered composites, particulate composites and Nano composites. When continuous fibers are used as reinforcements, the composites can be uni-directional, bi-directional or tri-directional.

Fibers are put into three groups based on their strength-wise performance, they are high (Boron, Carbon, Kevlar), medium (Glass), and low performance (Natural) fibers. A fiber metal laminates (FMLs) is one of a class of composite materials consists by sandwiching of several thin metals and layers of fibers embedded in matrix material. This allows the material to behave much as a conventional metal structure, but with considerable higher specific stiffness, strength and advantages regarding properties such as metal fatigue, impact, weight savings, corrosion resistance, fire resistance and strength properties. The metals recently being used are aluminum, magnesium or titanium, and the fiber-reinforced layer are glass, carbon or Kevlar. Man-made hybrid materials of aluminum manifest better strength, hardness, toughness, rigidness etc. The role of the matrix in composite materials are to keep the fibers in place, to provide a barrier against an adverse environment such as chemicals and moisture, to transfer stresses between the fibers, to protect the surface of the fibers from mechanical deterioration, to provide lateral support against the possibility if fiber buckling under compressive loading. The application of composite materials can be broadly classified into Aerospace applications, Road and Rail transport applications, Offshore accord water vehicles, Building and other civil structures, Chemical Industries, Electrical, Electronics and communication applications, Mechanical systems and machine elements, sports applications and Biomedical applications. Composites research is receive appreciation and grants from governments, manufacturers and universities to find new fibers and resins to develop even more applications for composites. In recent years, many researchers have done intensive work on the problem of low velocity impact on fiber metal laminates (FMLs) in different ways because impact damage is an event that occurs repeatedly on composite structures. The sources of impact such as scrap or tools collision during manufacturing, maintenance, assembly or component operation, etc. These low intensity impact damages significantly reduce the mechanical properties, stiffness and then remnant strength of composite structure. These impacts can cause internal damage like matrix failure, fiber breakage, plastic deformations and delamination of layer of thin metal and fibers. Composite material possess superior properties than the metallic structure because it has advantages of light weight, stronger, tougher, better aesthetics, rust-free, higher damping properties etc.

III. PROBLEM STATEMENT

Low velocity impact damage is an accidental occurrence that happens frequently on any structures and the sources of such impact is flying fragment, scraps or tools hit the components during operation, maintenance, or assembly work, these impact damages significantly affects the mechanical strength of composite structure. Low velocity Impact damage during the service life of structures made up of composite materials is a major importance since its mechanical strength can be tremendously reduced as a result of such damage. Recently the interest of researchers has been directed towards on low velocity impact damage and the prediction of residual strengths of damaged fiber-reinforced composite materials, using them as potential substitutes for metals. These statistics indicate that this is a very dynamic area of research, and the main focus of present article seeks to provide comprehensive review of previous and recent research work published on torsion strength and bending strength of hybrid composite structures after low velocity impact damage and chemical reactivity. In the study composite tube first damaged by low velocity impact and then tested and for chemical reactivity specimens submerged in NaCl solution for 7days after that weight of specimens is compare before and after submerging in a NaCl solution.

IV. GEOMETRY AND FABRICATION OF SPECIMEN

The aluminum (Al) tube (AA6063-T4) used for this experimental study was of outer diameter (do) = 19.2 mm, inner diameter (di) = 16.8 mm and length l= 180 mm. The mechanical properties of aluminum tube used in this work are mention in Table 1 [3]. Two layers of carbon and glass woven fabric were wrapped around aluminum tube with a manufacturing method in which combination of hand layup method and high pressure compressed air were utilized. Carbon and glass woven fabrics with the surface density of 320 GSM (gram per square meter) and 435 GSM respectively, are used with Araldite resin material to manually fabricate total sixteen composite tubes. 2-D plain weave woven fabrics [0/90] lay-up used in the project are shows Fig. 1. Fabric parameters of the fibers are listed in Table 1 and in this table, cw & cf are the strand breath, and ew & ef are the gap between two consecutive strands. f and w superscript designate the fill and warp direction of the plain weave woven fabric, respectively. Araldite resin matrix material and Araldite hardener were used in this work in proportion of 2:1 by volume respectively. The arrangement of compressor unit and pressure cylinder is shown in Fig. 2. Specimens fabricated by above mention technique are shown in Fig. 3.

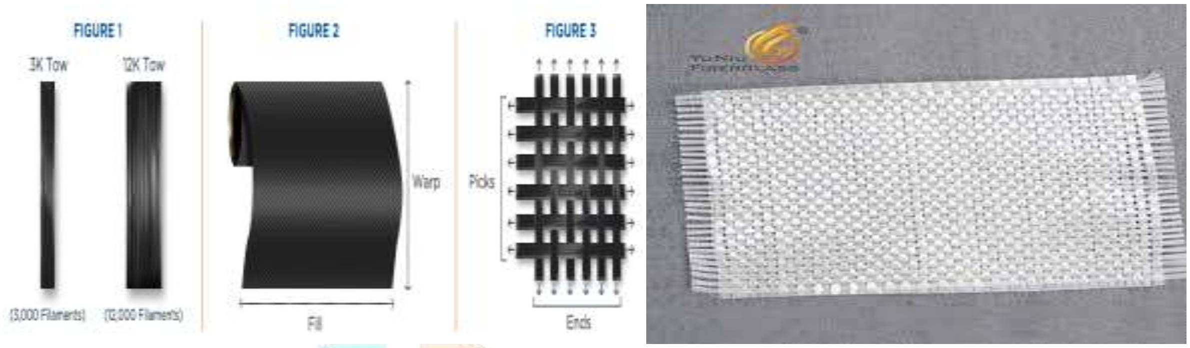


Fig.1 : woven weave fabric

Fig.2: arrangement of compressor unit and pressure cylinder

Fig.3: Specimens Fabricated by above Technique

The thicknesses of the woven fabrics were measured to be:
Carbon woven fabric thickness = 0.32 mm
Glass woven fabric thickness = 0.35 mm
The cylindrical specimens have the following characteristics:
Specimens are made of aluminum/E-glass fibre:
Specimen length: 180 mm
Average inner diameter: 16.74 mm
Average outer diameter: 19.96 mm and
Specimens are made of aluminum/carbon fibre:
Specimen length: 180 mm
Average inner diameter: 16.74 mm
Average outer diameter: 19.86 mm

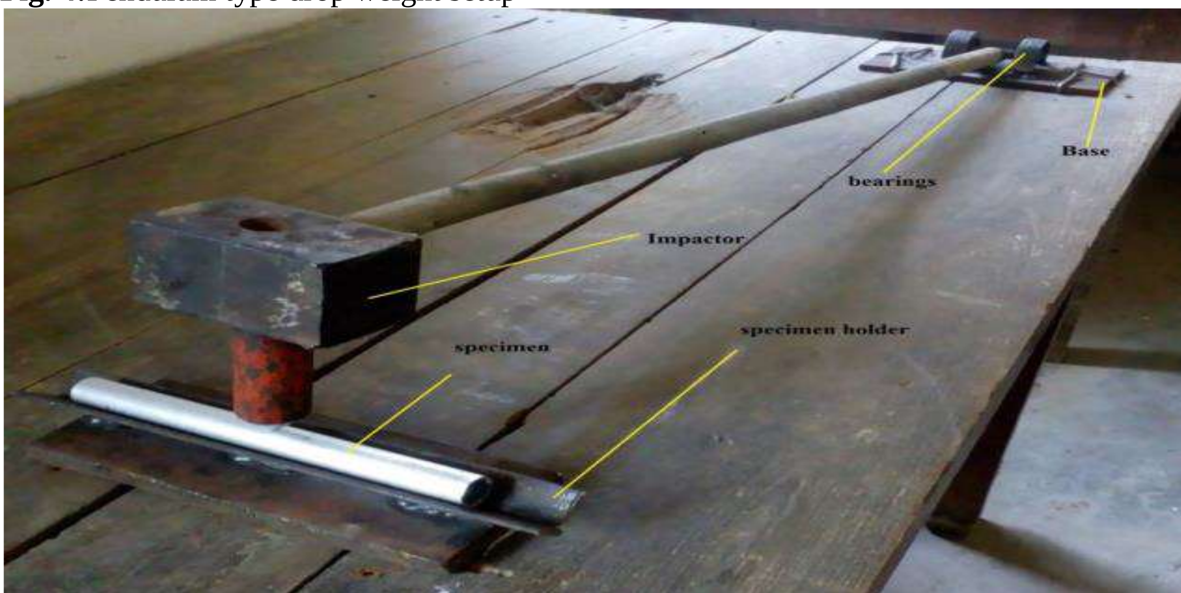
Table 1: Dimension of 2-D Plain Weave Woven Fabric Structure

Material	c_w	e_w	c_f	e_f
Glass fiber	1.2	.70	1.2	.70
Carbon fiber	2.78	.42	2.78	.42

- **DROP WEIGHT TEST SET-UP AND IMPACT TEST DETAILS**

A Pendulum type drop weight impact set-up was designed and constructed to perform the low velocity transverse impact for this study see Fig. 4. The test set-up mainly consists of an impactor, base plate; V shaped specimen holder, two bearing, thin hollow connecting rod and table for mounting base plate and specimen holder. The base plate and specimen holder was mounted on table to restrict it from sliding during impact. The impactor tip has conical shape geometry and total mass of 1.7 kg, made using hardened steel has enough hardness to avoiding any deformation of the impactor tip during the test. A timer device was used to measure time taken by the impactor to travel a curved distance subtending approximately 32-33° angle. This was used to calculate the rotational kinetic energy. The total impacted energy is the sum of potential energy and rotational kinetic energy. The effective height of dropping impactor was 478 mm. The specimen tube was held firmly in place on holder in its full length from both sides, so uniform distribution of the load on the contact area occurs. The impactor drops by gravity fall and the damage was occurring by hitting specimen in transverse direction. Three specimens from each of E-glass, carbon and bare aluminium tube are impacted at energy levels 10.5 J on two consecutive points of 60 mm apart along the longitudinal axis. The two damage points are 30 mm away from center point of specimen. For a low velocity impact, it is notice that invisible cracks develops in carbon/glass fibre along with small point impression occur in aluminium tube in hybrid aluminium composite tubes and deep conical shaped impression occurs in bare aluminium tubes.

Fig. 4: Pendulum type drop weight setup



These impacted damage specimens are shown in Fig. 5.

V. EXPERIMENTAL SETUP

Torsion Test

- The TT type torsion testing machine serves for conducting test in torsion for six specimens and was located at the material testing laboratory of Department of Mechanical Engineering, JEC Jabalpur, India. The machine is equipped with pendulum dynamometer, a recording device for registering torque-twist diagram. The accuracy of the torque indication is ±1% of true torque. Angular velocity of 1.5°/min was used as torsion test speeds. The maximum torsion capacity for this experiment is set at 245 Nm. Three specimens for each type of hybrid aluminum-woven fabric composite tubes and bare aluminum tube with and without impact damage were tested under torsion.

- **Bending Test**

The three-point bending test were conducted on a UTN-10 model universal testing machine and was located at the material testing laboratory of Department of Mechanical Engineering, JEC Jabalpur, India. The length of the samples was 180 mm and the span between the supports was 150 mm for both three and four point bending testing. The loading span for four point bending test is 1/3 of the support span. Three specimens for each type of hybrid aluminum-woven fabric composite tubes and bare aluminum tube, with and without impact damage, were tested under three point bending. The load−displacement curves were obtained and the samples were loaded until the applied load reached maximum value.The deflection at the loading point was recorded on indicating dial.

Fig.6: Specimens after torsion and Bending test Respectly

- ***Chemical reactivity***

As shafts are used widely in marine applications, resistance to corrosion and saline water is crucial. Chemical tests uses relative weight loss technique for determining reactivity. The behavior of fabricated shafts was investigated using brine solution. The solution containing approximately 3.5% salt was prepared and small samples of fabricated shafts were submerged in it. The samples were weighed before submerging and extracted after one week and were weighted again. Weight loss gives the extent of chemical reaction as it directly relates reactivity with a brine solution.

Specimen details made of E-Glass fiber Aluminium composite
Length of specimen 90 mm
Inner diameter 16.13 mm
Outer diameter 18.10 mm
Weight of specimen before test conduct 16.94gm

Specimen details made of Carbon fiber Aluminium composite
Length of specimen 90 mm
Inner diameter 16.13 mm
Outer diameter 18.08 mm

Weight of specimen before test conduct 16.74gm

Figure .7: submerged samples.

VI. RESULTS AND DISCUSSION

In this research, the effect of transverse low velocity impact damage on torsional and bending strength of hybrid aluminum-woven fabric composite tubes was studied. It is assumed that the specimens were perfectly balanced and there were no damage on the specimen except the damage due to impactor impact.

- **Torsion test analysis**

From the torsion test, it was observed that specimens without impact were fractured at gauge length and specimens with impact were fractured from impacted point, as shown by the drop of torque value. It was be noted that first delamination of composite fiber layer occurs from the aluminium tube, then buckling of both aluminum and composite fiber layer seen during failure of hybrid composite specimen under torsion. Torque-twist angle relations were documented for all specimens. Figure a and b shows torque twist angle relationship for specimens without and with impact damage tested under torsion. Torque-twist angle experimental values for specimens without and with impact. The results obtained are given as follows:

- ✓ Bare aluminum tube with and without impact damage endure maximum torsional load of 23.25N m & 35.8 N m respectively and maximum twisting angle of 5.4° & 7° respectively.
- ✓ Hybrid aluminum/E-glass composite tube with and without impact damage endure maximum torque of 61.2 N m & 80.6 N m respectively and maximum twisting angle of 12° & 14.5°respectively.
- ✓ Hybrid aluminum/carbon composite tube with and without impact damage endure maximum torque of 49.6 N m & 69.7 N m respectively and maximum twisting angle of 9.7° & 13.5°respectively.

❖ **Bending test analysis**

One specimen with no impact damage and one specimen with impact damaged bare aluminum tube were tested under three point bending test, similarly done for hybrid glass and carbon tubes. During bending, the damage areas of specimens were kept in upward position. The end supports were considered simply supported and there was no slipping of the specimens over the supports throughout the bending tests. The load vs corresponding deflection of center point could be obtained from the three point bending tests. Load- deflection relations were documented for all specimens. Fig. 10 (a) and Fig. 10 (b) shows Load- deflection relationship for specimens without and with impact damage tested under 3-point bending. In this study, Load- deflection relations were recorded during the test until the applied load reached its maximum value and start decreasing. As load increases visible buckling of top surface and yielding of aluminum commence on the upper half of the specimens at the loading points.

The results for 3-point bending obtained are outline as follows:

- ➢ Bare aluminum tube with and without impact damage endure maximum bending load of 187 N & 248 N respectively and maximum downward deflection of 5.46 mm & 6.1 mm respectively.
- ➢ Hybrid aluminum/E-glass composite tube with and without impact damage endure maximum bending load of 273.40 N & 347 N respectively and maximum downward deflection of 12.4 mm & 13.2 mm respectively.

Hybrid aluminum/carbon composite tube with and without impact damage endure maximum bending load of 251 N & 324 N respectively and maximum downward deflection of 9.1 mm & 11.23 mm respectively.

❖ **Chemical test**

Preparing NaCl solution (4.5% salt prepared)

- Concentration = quantity solute/quantity of preparation

Fig.8: Specimens after NaCl solution

- Weight of specimen after 7days submerged in a NaCl solution
    - ✓ For Carbon fiber Al hybrid tube = 18.71 gm
    - ✓ For E-Glass fiber Al hybrid tube = 18.23 gm

Weight Comparision

- Change In weight(%) = [(Final weight – Initial weight)/(Initial weight)]*100………Eqn.1

From Eq no.1

E-Glass fiber composite tube

- ✓ Change in weight(%) = [(18.23-16.74)/(16.74)]*100
- ✓
- ✓ = 8.90% weight increased
    - Carbon fiber composite tube
- ✓ Change in weight(%) = [(18.71-16.94)/(16.94)]*100

= 10.45% weight increased.

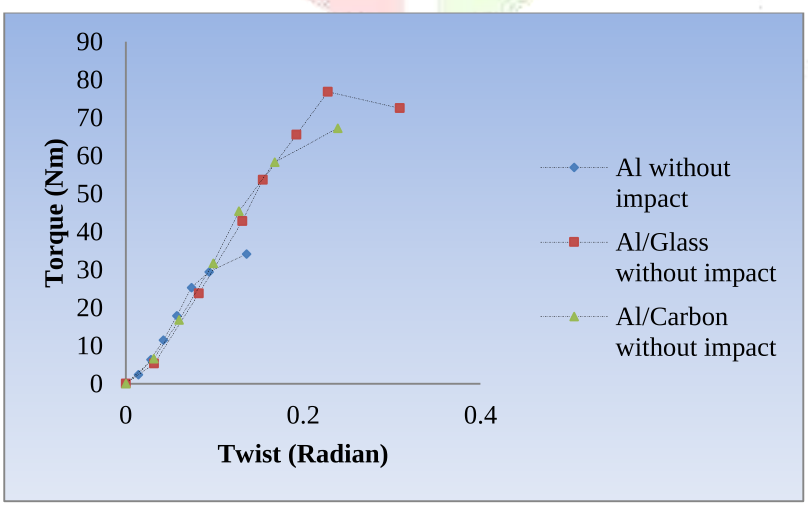


Fig.9: Comparison of torque -twist angle relationship for specimens without impact damage tested under torsion.

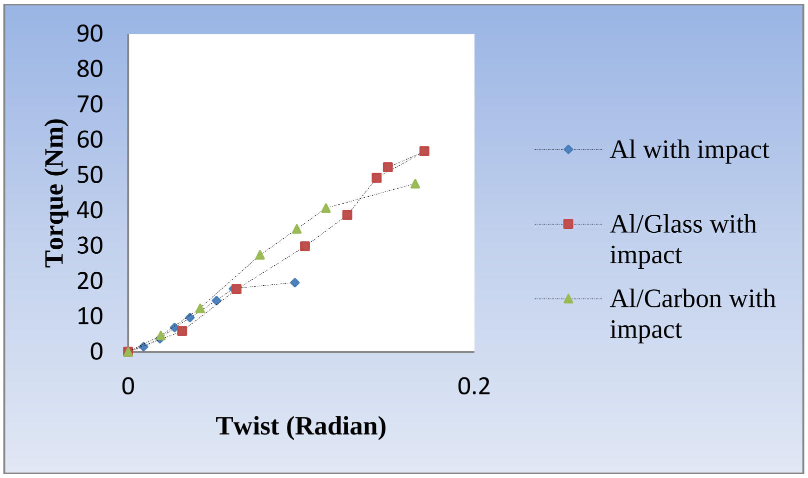


Fig.10: Comparison of torque -twist angle relationship for specimens with impact damage tested under torsion

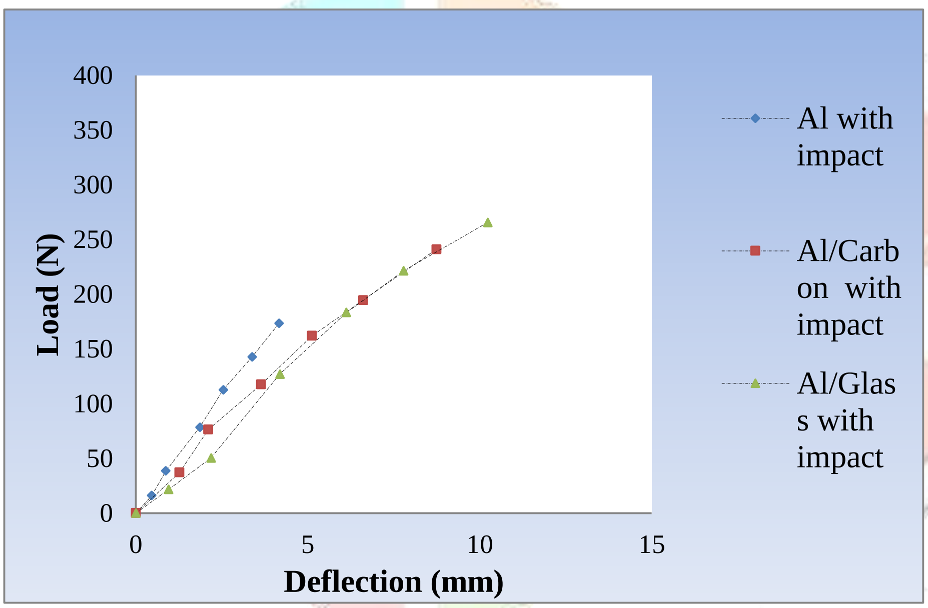


Fig.11 : Comparison of load-deflection relationship for specimens with impact damage tested under 3-point bending

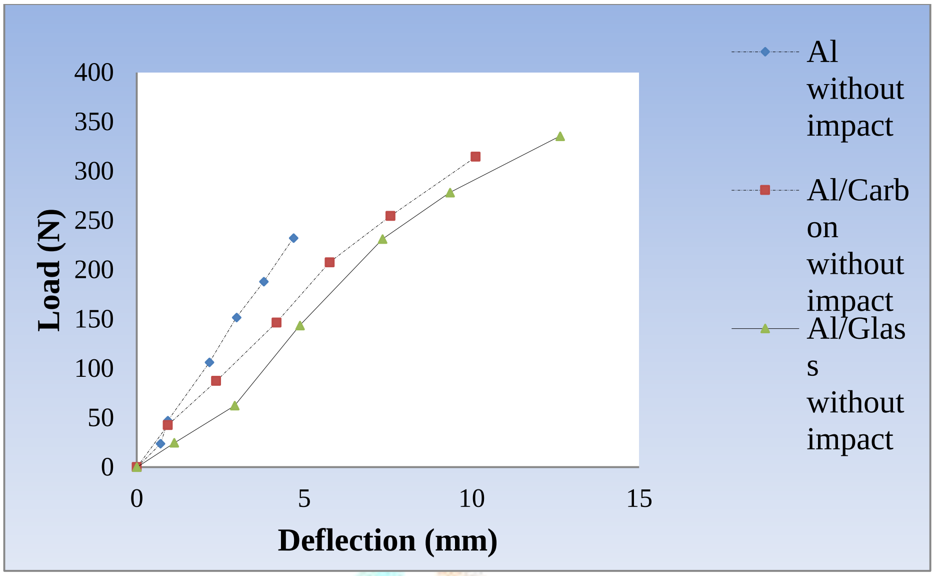


Fig.12: Comparison of load-deflection relationship for specimens without impact damage tested under 3-point bending

CONCLUSIONS

In this experimental study, composite tubes were first damaged by transverse low velocity impact and then tested under torsion and bending tests to understand the effect of damage on torsional and bending strength of hybrid composite tubes. From the above mentioned result the conclusions are summarized as in Table 2

Specimens	% reduction in torsion capacity due to damage	% reduction in twist angle due to damage	% reduction in bending load capacity for 3-point bending due to damage
Bare aluminum tube	35.055	22.85	24.59
Hybrid aluminum/E-glass composite tube	24.069	17.24	21.21
Hybrid aluminum/carbon composite tube	28.83	28.148	22.53

REFERENCES

1. S.A. Mutasher, "Prediction of the torsional strength of the hybrid aluminum/composite drive shaft" Materials and Design 30 (2009) 215–220
2. M.A. Badie, E. Mahdi, A.M.S. Hamouda, "An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft" Materials and Design 32 (2011) 1485–1500
3. Durk Hyun Cho, Dai Gil Lee, Jin Ho Choi, "Manufacture of one-piece automotive drive shafts with aluminium and composite materials" Composite structure Vol. 38, No. l-4, (1997) pp. 309-319, 1997
4. A.R. Abu Talib , Aidy Ali, Mohamed A. Badie, Nur Azida CheLah, A.F. Golestaneh, "Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft" Materials and Design 31 (2010) 514–521
5. Ercan Sevkat, Hikmet Tumer, "Residual torsional properties of composite shafts subjected to impact loadings" Materials and Design 51 (2013) 956–967
6. G. Minak, S. Abrate, D. Ghelli, R. Panciroli, Zucchelli, "Low-velocity impact on carbon/epoxy tubes subjected to torque – Experimental results, analytical models and FEM analysis" Composite Structures 92 (2010) 623–632
7. N.K. Naik, Y. Chandra Sekher, Sailendra Meduri, "Damage in woven-fabric composites subjected to low-velocity impact" Composites Science and Technology 60 (2000) 731-744
8. Yu, G-C., Wu, L-Z., Ma, L., Xiong, J., "Low Velocity Impact of Carbon Fiber Aluminum Laminates", Composite Structures (2014), doi: http://dx.doi.org/10.1016/j.compstruct.2014.09.054
9. Bienias, J., Jakubczak, P., Dadej, K., "Low-Velocity Impact Resistance of Aluminium Glass Laminates - Experimental and Numerical Investigation", Composite Structures (2016), doi: http://dx.doi.org/10.1016/j.compstruct.2016.05.056
10. http://nptel.ac.in/courses/101106038/
11. http://nptel.ac.in/courses/105108124/
12. http://nptel.ac.in/courses/112104161/
13. Ashok G. Ambekar, "Mechanical Vibrations and Noise Engineering" PHI learning private limited, ISBN-978-81-203-2900-3
14. Mateen Tariq, Salman Nisar [4] study Effect of Hybrid Reinforcement on the performance of Filament Wound Hollow shaft
15. Manufacturing Engineering and Technology(IV Edition) B Serope Kalpakjian Steven R. Schmid Composite materials (241, 253) [Advanced-250, ceramic matrix 253, metal matrix 252, processing 516 522, Strength198 249].