Matrix Modification of Carbon Fiber Reinforced Composites with Hybrid Resin System

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Abstract. The most important property required for any structural composite material is high strength to weight ratio and corrosion resistance. To improve the interfacial addition between carbon fiber and epoxy resin, the epoxy matrix has been modified with hybrid resin. The unidirectional carbon/epoxy composites were prepared with different weight proportions of two resins (hybrid resin) with parts by weight(PBW). In this paper unidirectional carbon fiber T700 used as reinforcement and hybrid resin used as matrix for preparing the Uni-Directional(UD) laminate and Naval Ordnance laboratories(NOL) ring specimens. These specimens are prepared with filament winding technique, specimens were tested as per ASTM standards and test was conducted on Instron 4505 with 100KN capacity. From the test results it has been observed that the tensile strength measured by NOL ring specimens are more trustable than the results obtained with unidirectional(UD) test specimens. NOL ring test data is useful for making composite pressure vessels for aerospace applications.

1. Introduction
In recent years, composite materials derived from carbon fiber and epoxy resin are extensively employed in aircraft and space applications because of their high strength, high modulus and light weight [1,2]. Carbon fibers is a polymer having five times stronger than steel and twice as stiffness. It is made of thin strong crystalline filaments of carbon that is used to strengthen the material. The use of epoxy resins as a matrix having good engineering properties like high stiffness, strength, chemical resistance and good adhesion with fibers [4,5]. The major drawback of epoxy resin is their brittleness and having poor pot life with less resistance to crack initiation. This drawback can be eliminated by hybridizing the epoxy resin (modifying the matrix by PBW of two resins). The main objective is matrix modified in to moderate viscosity with higher elongation during the test [6,7]. This will help to design a composite pressure vessel which undergo progressive failure during testing [9]. Carbon fiber reinforced polymer (CFRP) composites have aroused considerable industrial attention because of their attractive mechanical properties. Carbon fibers are principal constituents in a fiber reinforced composite materials. Fibers occupy major volume fraction in a composite laminate and distribute the major portion of the load acting on the structure. Selection of suitable type of fiber, fiber volume fraction, fiber length and fiber orientations are important. The commercially available carbon fiber diameter is around 5-7 µm. Advanced composite materials are made with unidirectional carbon fiber T700 with epoxy resin for high strength structural applications[11]. Mechanical properties of CFRP composites depends not only on the properties of fiber and matrix, but also depends fiber matrix interfacial adhesion.
Composite material properties depend upon properties of individual constituents, distribution, orientation of fibers, fiber volume fraction, physical and chemical properties[12]. The main aim of the present work is to examine the effect of the hybrid resin on mechanical and morphological properties of carbon fiber composites. In this study two epoxy resins of equal proportions are mixed and used as hybrid resin with hardener, tests were carried out according to ASTM standards on Flat laminates and NOL ring specimens in order to compare the mechanical performance of different sample specimens[13,14].

2. Materials and Methods
The reinforcing material of carbon fiber T-700, 12K and two resins(hybrid) of diglycidal either of bisphenol-A(DGEBA) of LY 556 and LY 5052 with hardener HT 972 of solid aromatic amine of diaminodiphenyl methane(DDM) used as matrix for this investigation. The specifications of carbon fiber T700,12K as shown in table 1.and specification of Hybrid Resin LY556 and LY5052 are shown in table2.

| Sl.No. | Parameter       | Value                      |
|--------|-----------------|----------------------------|
| 1      | Grade           | T700                       |
| 2      | Tow size        | 12 K                       |
| 3      | Carbon content  | 95%                        |
| 4      | % Elongation    | 2%                         |
| 5      | Specific gravity| 1.7 – 1.8                  |
| 6      | Tex             | 800g/km(min)               |
| 7      | Tensile strength| 4.0 Gpa(min)               |
| 8      | Tensile modulus | 200 Gpa(min)               |
| 9      | Fiber diameter  | 5-7 microns                |
| 10     | Sizing          | Epoxy compatible           |

Table 1. Carbon fiber T700,12K specifications

| Sl.N o. | Parameter       | Value                      |
|---------|-----------------|----------------------------|
| 1       | Type            | Hybrid                     |
| 2       | Grade           | LY556,LY5052               |
| 3       | Viscosity 25° at CPS | 8000-12000               |
| 4       | Specific gravity at RT | 1.10 - 1.12            |
| 5       | Colour          | Pale Yellow/Clear liquid   |
| 6       | Volatile content by weight | 0.75% Max                |

Table 2. Hybrid Resin LY556& LY5052 specifications

When composite specimen is tested under loading condition both fiber and resin can be able to deform in the same loading direction, but in practical it is not possible. Good adhesion between fiber and resin is required when composite is loaded under tension. This property will ensure the load transfers effectively and prevent from the fiber cracking and fiber/resin debonding.
3. Composite Specimen Preparation

Before making any structural composite product, the test samples of composite product of fiber and resin are used to prepare the laminates for preliminary characterization. In this study, the matrix has been changed to hybrid resin system consisting of two resin systems of LY556 and LY 5052 mixed in proportions of 50:50 ratio and hot curing hardener HT972. The proportions of hybrid resin to the hardener is in ratio of 100:27 by weight was mixed. The hybrid resin is preheated to a temperature in the range of 40-50°C with the help of heaters to maintain the resin viscosity during winding. Two types of samples made with filament winding technique. The flat laminate specimens are made with flat mandrel and NOL ring specimens are made with cylindrical mandrel.

The carbon fiber bands are unwind from a creel and passed through hybrid resin bath. These resin impregnated bands are passed on to a rotating (Flat and cylindrical) metal mandrel. The carbon strands are wound around the cylindrical mandrel to ensure that all fiber strands dip in the resin bath with uniform wetting of all fibers. Fiber tension is critical in filament winding because compaction of resin with fiber is achieved through the fiber tension. The fiber tension must be optimal level because high fiber tension may break the fiber completely or fiber fracture at the surface. Filament winding as shown in fig.1. Mandrel for NOL ring as shown in fig.2. Carbon roving for UD laminate preparation shown in fig.3 and Winding on NOL mandrel as shown in fig.4.

A rectangular flat and cylindrical steel mandrels are used for specimen preparations. The surface of the flat mandrel and cylindrical mandrel is like a mirror finish. The mandrel surface is cleaned with acetone to make it free from oil, grease and dust. The surface of the mandrel is applied with Waxpol for easy removal of the samples from the mandrel. The resin impregnated fiber strands are wound around the flat/cylindrical mandrels with five hoop layers with a band width of 1.9mm and thickness of 0.4mm. The mandrel is rotated with moderate speed, after completion of winding the mandrels is rotated for few minutes for uniform setting of the resin. Curing of specimen along with the mandrel was carried out in hot air oven with a given cure cycle.
4. Specimen Curing

Following cure cycle was maintained for NOL ring mandrel as shown in fig.5
- Oven temperature is increased from room temperature to 100°C in 30 min. and keep the temperature for 2 hours.
- After completion of 2 hours increase the temperature 100°C to 120°C in 20 min. and keep the temperature for 2 hours.
- Again raise the temperature from 120°C to 140°C in 20 min. and keep the temperature for 6 hours.
- After completion of 6 hours cure time switch of the oven and permit the component to cool to room temperature within 4-5 hours.
- Finally remove the cured mandrel from the oven.

The cured mandrel with filament wound cylindrical composite shell is placed on a lathe machine for separating shell in to NOL ring specimens cut with parting tool each specimen width of 6.3 mm maintained. After completion of parting the round circular specimens (NOL rings) separated from the mandrel.

5. Results and Discussions

One of the important property of Carbon fiber reinforced composite is Tensile strength. In the present study tensile strength of unidirectional (UD) flat laminates and NOL ring specimens are tested. In tensile test the UD specimen is subjected to elongate in the fiber direction by uni-axial tensile force. The standard UD flat test specimen dimensions are made according to ASTM standard is shown in fig. 6 the test is carried on electro mechanical testing machine with cross head speed of 2mm/min. is shown in fig.7 and tensile tested specimens are shown in fig 8. The output tensile test data is tabulated in table 3.
Fig. 6 Dimensions of Flat specimen as per ASTM 3039

Fig. 7 Tensile testing test setup

Fig. 8 Failure modes in UD specimens

| S. No | Dimensions in MM | Max. Displacement in MM | Max. Load in KN | Tensile Strength in MPa | Tensile Modulus in MPa | Remarks       |
|-------|-----------------|-------------------------|-----------------|-------------------------|------------------------|---------------|
| 1     | 14.97 x 1.94    | 16.72                   | 48.87           | 1682                    | 140                    | Explosion     |
| 2     | 14.95 x 1.90    | 16.42                   | 44.83           | 1578                    | 140                    | Explosion     |
| 3     | 14.98 x 1.90    | 15.80                   | 38.71           | 1360                    | 126                    | Splitting     |
| 4     | 14.97 x 1.93    | 16.44                   | 47.14           | 1632                    | 135                    | Explosion     |
| 5     | 14.95 x 1.93    | 16.30                   | 44.80           | 1553                    | 124                    | Explosion     |
| 6     | 15.02 x 1.87    | 15.01                   | 37.97           | 1352                    | 126                    | Explosion     |

Table 3: UD laminate tensile test data with Hybrid resin 50:50 with Hardener.

National Ordnance laboratories (NOL) ring test was carried on universal testing machine (UTM) with split disc test fixture attachment as shown in fig 11. In NOL ring test four split ring is used to test the NOL ring specimens.
The internal pressure can be applied to the ring shaped specimens similarly to the burst tests of actual pressure vessels. This test gives the fracture behavior inside of the CFRP layered laminate could be observed directly whereas in actual composite pressure vessel it is highly impossible to observe the fracture behavior under the surface of pressure vessels. A NOL ring fabrication and testing techniques are used for determination of ring tensile strength has been standardized. The standard NOL ring specimen dimension is shown in fig. 9. The test specimen after testing is shown in fig 10 and 12. The tensile hoop stress values are tabulated in table 4.

![NOL ring specimen as per ASTM D2290](image1)

![NOL Ring after testing (Splitting)](image2)

![NOL ring Split disc test fixture](image3)

![Hybrid resin 50:50 with Hardener](image4)
| S. No | Dimensions in MM | Max. Displacement in MM | Max. Load in KN | NOL Tensile strength in MPa | Remarks |
|-------|------------------|-------------------------|-----------------|-----------------------------|---------|
| 1     | 6.30 x 1.74      | 7.423                   | 45.112          | 2058                        | Explosion |
| 2     | 6.22 x 1.70      | 6.925                   | 43.610          | 2030                        | Splitting |
| 3     | 6.32 x 1.70      | 5.834                   | 37.175          | 1730                        | Splitting |
| 4     | 6.23 x 1.70      | 7.870                   | 45.522          | 2149                        | Splitting |
| 5     | 6.39 x 1.70      | 6.805                   | 38.785          | 1785                        | Splitting |
| 6     | 6.30 x 1.74      | 6.911                   | 39.725          | 1812                        | Splitting |

Table 4: NOL ring test data with Hybrid resin 50:50 with Hardener.

Conclusion
The equal proportions of hybrid resin 50:50 is used to make the UD and NOL ring specimens. Based on the experimental result it has been found that failure stresses are more accurately measured by NOL ring test with data acquisition system compared to UD tensile test. The Unidirectional tensile test samples failure modes were observed as explosive fracture and the average ultimate tensile strength measured was 1526 MPa along fiber direction, whereas the NOL ring test data shows failure modes are in splitting and average tensile strength of NOL ring was 1927 MPa. It can be concluded that, the material could withstand with stresses of 1500MPa without any deformation and failures in UD laminates and 1900 MPa for NOL ring specimens.

References
[1] Jinshui Yang, Jiayu Xiao, Jingcheng Zeng, Liping Bian, Chaoyi Peng, and Fubiao Yang "Matrix Modification with Silane Coupling Agent for Carbon Fiber Reinforced Epoxy Composites", Fibers and Polymers, 2013, Vol.14, No.5, 759-766
[2] C. Venkateshwar Reddy, P. Ramesh Babu, R. Ramnarayan, Dilkeshwar Das "Mechanical properties of Unidirectional carbon and glass/epoxy reinforced composites for high strength applications", Materials Today Proceedings, volume 4, issue 2, part A, 2017, pages 3166-3172
[3] Umar Farooq and Peter Myler "Preparation of Aerospace grade Carbon fibrous laminated composite panels with improved performance and reduced Fabrication Process defects and flaws", ARPN Journal of Engineering and Applied Sciences, vol.12, No.4, February 2017
[4] K. Friedrich, "Polymer composites for tribological applications", advanced Industrial and Engineering Polymer Research, 1,(1) 2018, P 3-39
[5] W.M. Chen, Y.H. Yu, P. Li and X.P. Yang "Effect of new epoxy matrix for T800 carbon fiber/epoxy filament wound composites", Compos. Sci. Technol., 2007, 67, 2261-2270
[6] J. Braz. Chem. Soc. "Composite materials based on modified epoxy resin and carbon fiber", Journal of the Brazilian Chemical Society, vol.17, no.6 Sao Paulo Sept./Oct. 2006
[7] M. Nayeem Ahmed, P. Vijaya Kumar, H.K. Shivanand, Syed BasithMuzammil "A Study on flexural strength of hybrid polymer composite materials(E glass fiber-carbon, carbon fiber-graphite) on different matrix material by varying its thickness", International Journal of Mechanical Engineering and technology (IJMET), Volume 4, Issue 4, July - August (2013), pp. 274 - 286
[8] M.A. Kinna, NOL-ring Test Methods, United States naval ordnance laboratory, with oak, Maryland, NOLTR: 1964, p 64-156
[9] C. Venkateshwar Reddy, Ch. Joseph Sraju, P. Rameshbabu, R. Ramnarayan "Study of void effect on tensile strength of carbon fiber reinforced composites for structural applications", International Journal for Research in Applied Science & Engineering Technology (IJRASET), volume 5, Issue viii, August 2017
[10] Sobrinho, L., V. Calado & F. Bastian (2012) Effects of rubber addition to an epoxy resin and its fiber glass reinforced composites. Polymer Composites
[11] S. Erden, K. Sever, Y. Seki & M. Sarikanat "Enhancement of the mechanical properties of glass/polyester composites via matrix modification glass/polyester composite siloxane matrix modification", Fibers and polymers, volume 11, pages 732-737 (2010)

[12] Johnsen B., Mohammed R, Taylor A, Sprenger S., "Toughening Mechanisms of particles Modified Epoxy Polymers", Journal of Polymer, Vol. 48, 530-41, 2007

[13] ASTM, Standard test method for tensile properties of polymer matrix composite materials, ASTM D3039, Annual book of ASTM standards, American Society for Testing and Materials, PA, 15(3) 2003

[14] Fang Liu, Shiqiang Deng, and Jianing Zhang "Mechanical Properties of Epoxy and Its Carbon Fiber Composites Modified by Nanoparticles", Journal of Nanomaterials, volume 2017, Article ID 8146248

[15] Fu, S.-Y. and Lauke, B. (1998) Characterisation of Tensile Behaviour of Hybrid short Glass fiber/Calcite particle/ABS composites. Composites Part A, 29A, 575-583