Cost Effectiveness of Fabric Reinforced Epoxy Composites for Structural Applications

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***Abstract*— The objective of this paper is to gain a better understanding of mechanical properties of epoxy resin composites reinforced with unidirectional basalt and compare with unidirectional carbon and bidirectional glass fiber sheet. Cost effectiveness of different fabric was studied. In this investigation, specimens were prepared for three fabric composite families having longitudinal unidirectional carbon and basalt fabric and cross bidirectional glass fabric using epoxy based polymer reinforced according to ASTM D3039 to evaluate tensile strength of the composites. The failure of composites was examined and average tensile strength, tensile modulus and elongation were found.**

***Keywords*— Cost, Basalt Fibre, Carbon Fibre, Glass Fibre, Tensile strength, Epoxy component**

I. INTRODUCTION

In modern era, FRP composites are widely used in structural elements as strong and light material always fascinate mankind for typical applications. Due to this, FRP composites are the matter of extraordinary attention of researchers and building producers in the technical world. 'Composite Material' is an advanced engineering material incorporating a variety of materials that act together on a macroscopic scale. Composite material consists of filament (e.g., E-glass, carbon, and aramid) and matrix (e.g., epoxy, polyester, and vinylester resins). Composites were broadly use in the aerospace industry during the 1960s and 1970s due to their remarkable properties such as lightweight, noncorrosive, nonmagnetic, and nonconductive [1]. FRP materials were widely accepted in infrastructure construction industry during the late 1980s and throughout the 1990s [1]. Composites have the applications range from non-structural gratings and claddings to full structural systems for industrial supports, buildings, long span roof structures, tanks, bridge components and complete bridge systems [2].

Composites consumption in India posted an impressive growth in the last few years. "The Indian composites market is expected to reach an estimated $2.0 billion by 2021" [3]. There is enormous scope of use of FRP in construction due to seismically deficient buildings, long coast line and long monsoon season needs the non-corrosive FRP. After Gujarat earthquake occurred in 2001, FRP application for retrofitting is gaining attention in India [4]. In India, FRP is used mostly in retrofitting and strengthening of deteriorated concrete structures, however no work has been done on the development of new FRP-Concrete hybrid structure elements. The major issue is high initial cost of FRP which limits the use of FRP in structural elements but it has low maintenance cost thereby reducing the overall cost of structure. Cost can be reduced by using Basalt Fibre Reinforced Polymers (BFRP) instead of GFRP as unidirectional basalt fibres, show comparable mechanical properties to glass fibres [5].Very little research attention has been made in case of BFRP, which is the new material in civil engineering compared to carbon, glass and aramid and has shown to be a promising material for the development of new FRP-Concrete hybrid structure elements used in the important infrastructure may include multi-storey buildings, bridges etc. Basalt fibres show comparable mechanical properties to glass fibres at lower cost and exhibit good resistance to chemical and high temperature exposure. Basalt fibres are alternative to carbon high-temperature resistant and are utilized as fire protection [6].

II. MATERIALS AND METHODS

A. *Composites Preparation*

Composites were manufactured using unidirectional carbon and basalt fabric provided by Arrow Technical Textiles Pvt. Ltd., Mumbai, India and bidirectional glass fabric provided by Ludhiana Proof Insulation Co. Ludhiana, India. Table 1 shows the mechanical and physical properties of used fabric provided by manufacturers. Epoxy resin was prepared from base Epoxy-LY556 (Density 1.15-1.2 g/cm³ and viscosity 10000-120000 mPa s) and hardener HY-951 (Specific gravity at 25 °C-0.98 g/cm³ and viscosity 10-20 mPa s) using mixed ratio 100:10 (Base: Hardener).

TABLE I. MECHANICALAND PHYSICAL PROPERTIES OFMATERIALS

Fabric	Thickness (mm)	Tensile Strength (MPa)	Area Weight (g/mm^2)
Carbon	0.111	≥ 3500	200
Basalt	0.115	2100	300
Glass	0.18 (7 mil)	-	204

Three fabric composites families having longitudinal unidirectional carbon and basalt fabric and cross bidirectional glass fabric using epoxy based polymer reinforced (UCE, UBE and BGE) were prepared in flat plywood mould through hand layup process. The specimens were prepared according to ASTM D 3039[7]. A curing process was maintained for 48 hours minimum.

B. Tensile Test

The tensile test was performed on 5 specimens (250 mm of length x 15 or 25 mm of width x 1-2 mm of thickness) for each composite family. Tabs are provided of length 50 mm at the grip. The tensile tests were conducted in universal testing machine with hydraulic grip at constant speed of approximately 2 mm/min at normal temperature. Volume fraction of fabric V_f and matrix $V_m$is determined by using following equation 1 and equation 2.

$$V_f = n\,A_w/\rho\,T \qquad (1)$$

$$V_f + V_m = 1 \qquad (2)$$

$V_f = \frac{nA_w}{\rho T}$In equation 1, n is the number of layers of fabric, A_w is the areal weight of fabric, ρ is the density of fabric and T is the thickness of laminate. Tensile strength was calculated by using following equation[8],

$$\sigma = P_{max}/A \qquad (3)$$

In equation 2, σ is tensile strength (MPa), P_{max} is maximum load at failure (N) and A is Average cross-section area (mm^2).

After test results, specimens were analyzed for failure modes according to ASTM D 3039 [7].

C. Cost Effectiveness

Cost is the most important parameter to be considered in construction sector. Cost effectiveness is the amount to which something is effective in relation to the cost. Cost effectiveness parameter (CEP) is ratio of tensile strength to cost per cross sectional area. In order to determine CEP, cost of different FRP fabric and matrix (epoxy resin and hardener) is considered. The cost of different materials at the time this research was conducted is given in Table 2.

TABLE II. COSTOF DIFFERENT MATERIALS

Material	Cost
Unidirectional CFRP fabric (INR/m²)	2000
Unidirectional BFPP (INR/m²)	200
Bidirectional GFRP fabric (INR/m²)	100
Matrix (Epoxy resin and Hardener) (INR/kg)	900

III. RESULTS AND DISCUSSION

Fabricated materials were tested on universal testing machine to determine the tensile strength, tensile modulus, ultimate load and elongation. Table 3 showed the average tensile strength, modulus values of five specimens for each fabric composite family. The results showed that UCE had the highest tensile strength value (1166.75 MPa) and tensile modulus (150.354 GPa). Also BGE composite had least tensile strength due to undulations of roving in the fabric woven arrangements. In Table 4, fabric properties are discussed based on net fibre area and gross laminated area. Gross laminated area of system includes both fibres and resin in calculating total cross sectional area whereas net fibre system only consider fibres excluding resin. Gross laminated area system showed low tensile strength as compared to net fibre system due to relative higher thickness. But tensile strength of net fibre area is less than bare fibre as indicated in Table 1 as tested values of fabric composite families were not just the material properties of individual fibres [7].

TABLE III. RESULTS OF TENSILE TESTS

Fabric Composite Family	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at break (%)
UCE	1166.75	150.35	0.776
UBE	452.5	26.00	1.74
BGE	112	8.88	1.26

TABLE IV. TENSILE STRENGTH BASED ON AREA

Parameters	Families	Net –fiber Area property	Gross-laminate area property
Area (mm^2)	UCE	9.99	15
	UBE	10.35	15
	BGE	27	50
Tensile Strength (MPa)	UCE	1751.87	1167.75
	UBE	655.79	425.5
	BGE	207.41	112

The carbon fabric composite is the stiffest with least strain value (0.00776) and 61.21 percent stronger than basalt fabric composite. Considering for an instance, the tensile modulus of UBE showed an increase of 65.82 percent with respect to BGE.

After the completion of tests, specimens were examined and evaluated for failure criteria as shown in Figure 1. In BGE no matrix cracking and interface debonding was observed and there was laterally fractured near the tab. But in UCE, failure occurred in the form of long splitting in the gage length (SGM failure as classified by ASTM D3039[7]) and one of the specimen of UCE showed delaminating due to adhesive failure. In a particular specimen of UBE, failure occurred at bottom longitudinal splitting near the grip due to stresses at the grip.

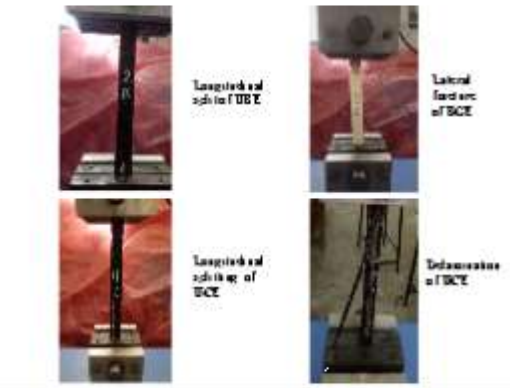

Fig. 1 Failure criteria

The analysis of results for different FRP fabric in terms of CEP is summarized in Table 5. Table 5 depicts that UBE is the most economical among three fabric families.

TABLE V. COST ANALYSIS

Fabric Composite Family	Tensile Strength (MPa)	Total cost per cross sectional area (INR/ mm²)	CEP
UCE	1166.75	0.02553	45687.714
UBE	452.5	0.007301	61975.68
BGE	112	0.02857	3919.51

IV. CONCLUSIONS

In the present work, unidirectional carbon fabric, bi-directional glass fabric as well recently developed unidirectional basalt fabric is considered in account. Static tensile test was performed on three fabric composites families having longitudinal unidirectional carbon and basalt fabric and cross bidirectional glass fabric using epoxy based polymer reinforced (UCE, UBE and BGE). All failures were examined and classified as ASTM D3039.

UCE evidenced the highest tensile strength value (1166.75 MPa) and tensile modulus (150.354 GPa) with respect to UBE and BGE. BGE showed least tensile strength due to weaving pattern of the fabric. BGE failed laterally and UCE and UBE showed longitudinal split failure. Also BGE showed no debonding and delamination failure unlike UCE and UBE.

Cost effectiveness study was conducted on different FRP fabric by evaluating Cost effectiveness parameter (CEP). Based on current study, cost effectiveness investigation showed that UBE is most economical among different composite fabric families.

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