Development and comparison of tensile and compressive strength and percentage shrinkage of glass-jute hybrid fibre reinforced polymer composites

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Abstract: Glass-jute hybrid fibre reinforced polymer composites were developed by using pultrusion process. In order to carry out these experiments, an experimental setup for pultrusion process was developed. Reinforcement of natural jute fibre and glass fibre was done in the developed composites. Unsaturated polyester resin as matrix and coconut coir ash, carbon black and egg shell ash as filler were used. The variation in tensile strength of pultruded Hybrid FRP composites were observed due to variation in weight percentage of coconut coir ash, carbon black and eggshell ash as filler. Filler’s weight percentage was variable while weight percentage of unsaturated polyester resin as matrix and glass and jute as fibre reinforcement were fixed. Single filler with variable percentage was used in the development of composite specimens with fixed weight percentage of matrix and fibres. Total fifteen hybrid composite specimens (samples) were developed, out of which carbon black, coconut coir ash and egg shell ash fillers have five samples of each with their variable weight percentage. Maximum tensile strength was observed 76 MPa in hybrid composite specimen namely hybrid composite specimen with 9% carbon black filler and maximum compressive strength was observed 99.44 MPa in hybrid composite specimen with 15% Eggshell ash as filler.

Keywords: Hybrid fibre, Pultrusion process, Compressive strength, Tensile strength, Eggshell, Coconut coir.

1. Introduction:
Composite materials with reinforcement of natural fibres are not only having low cost, high strength to weight ratio with broad area of application but also good for environment point of view. A number of natural fibres like coconut coir, jute, palm etc are being used as reinforcement. Eggshell like waste material can also be used as filler material. Composite materials are being developed by the researchers since a long time period but now a day’s development of hybrid composites with hybrid filler composition is point of main focus. Katz et al. [1] elaborated in their handbook about the large scale use of unsaturated polyester resin in polymer composites development. Characteristics of molding and curing are easy to process and their low cost makes the unsaturated polyester resin most suitable material. Researchers can easily mix the fillers with unsaturated polyester resin to enhance the properties of composites being developed. Biodegradable natural fibres like jute fibre, sisal fibre, palm fibre etc are most
suitable fibres to use in hybrid composites as these fibres are having properties like more tensile strength, good toughness and low weight and cost. Automobile and railway coach industry, building and construction industry, packaging industry etc are the few names which are largely using composites of jute. The composites developed by appropriate selection of filler material with suitable matrix material will be with improved properties than the metallic materials. Sometimes cost is minor and physical properties are major point of concern while doing selection of filler particles. Fillers will play a crucial role in changing the physical properties of composites when added with polymer resin. Use of fillers like carbon black with glass fibre, jute fibre in to the matrix of polymer not only lowers down the cost of composites but also changes the physical properties like modulus of elasticity, stiffness and tensile strength etc. [2-5]. Fillers were hybridized with fibres to find out the change in properties of jute and bagasse fibre composites when the loading of bagasse in composites was changed [6]. Epoxy resin and carbon black shows better adhesion with each other and hence we get improved flexural properties than pure epoxy resin when both are used combinedly for composite development [7].

Pull and Extrusion are the two words which combinedly makes the name of best and newly emerged method of composite development as Pultrusion. Gupta et al. [8] explained the pultrusion process as a manufacturing process to develop composites at very low cost and with improved properties like light in weight, improved tensile strength and good toughness etc. Optimization of tensile strength was explained in glass fibre reinforced polymer by controlling the parameters like heating die temperature, speed of pullers and filler’s weight percentage. Swolfs et al. [10] reviewed about hybridization of fibres in polymer composites. They provided some key points about various hybrid configurations, low elongation and high elongation fibres. Failure of low elongation fibres and hybrid composite’s final failure was also explained. Effect of stacking sequence on tensile, shear and flexural properties for woven jute/glass interlayer hybrids was also observed and provided a conclusion that in order to obtain the best flexural properties, glass fibre must be positioned at the outer layers because as compare to jute fibres, glass fibres have better mechanical properties. Natural glass fibre reinforced polymer hybrid composites were tested for mechanical properties by Sanjay et al. [11] and concluded that jute fiber’s tensile strength is directly proportional to the fiber’s cross section area. Hybrid composites will have improved thermal and water resistant properties if sisal fibre will be added with glass fibre during hybrid composite development. Gupta et al. [14] found that reinforcement of small particles of CaCO3 and carbon black can increase the tensile strength of test specimens of composites and observed maximum tensile strength as 291.5MPa when fillers carbon black and CaCO3 were used in combination with bagasse fibre at optimum level. [15] Natural fibres have very poor moisture resistance .When we compare their strength with glass like synthetic fibres, it was observed that natural fibres have low strength. [16] Natural Fibres are hydrophilic in nature. Dimensional stability was greatly affected when loading of natural fibre like sugar palm fibre was done as absorption of water was more by presence of hydrophilic sites. Increase in fibre content was leading to increase in swelling values of thickness. Saba et al. [17] revealed during morphological analysis by SEM that minimization of empty spaces between fibre and matrix, fibre pullout reduction, decrease in protruding of fibre etc. can be achieved by addition of 3% nano oil palm filler in the development of Kenaf/Epoxy composites. [18] Tensile strength was found good when addition of Silica was 5% and was decreasing with increase in weight percentage of silica. [19] Flexural and compression properties obtained were at highest level with the use of smaller fibre tex no i.e. tex 1400 yarn and with its maximum loading i.e. 70%(V/V). [20] The static flexural modulus was found decreasing linearly with the increase in fibre mixing ratio (β) during hybridization in hybrid composites and static flexural modulus was considerably changed due to glass yarns bilateral configuration in composite’s shell region. When β was changed from 0 to 0.09, the observed change in dynamic modulus was 47.11GPa to 43.95GPa.
2. Method and Set-Up for Experiments

Experimental work was completed using a well designed set up of pultrusion which was developed as per the need. Set up for pultrusion is as shown in figure 1.

Iron section of shape ‘H’ was used to assemble complete set up as shown in figure 1 and it consists of following parts:

(1) **Hot Die**: In order to do the pultrusion process of Hybrid FRP composites, a die of stainless steel material was used, which is clearly shown in figure 1. Die heating was done with the help of an electric heater. To get the desired temperature inside the die, a temperature controller was used. A thermocouple was used at the die’s parting line to control and measure the temperature.

(2) **Pre-former**: The function of the pre-former is to provide initial shape to the glass-jute fibre which is already assimilated with resin. This cold die also draws out the resin which is in excess from glass-jute fibre; the function of the pre-former is as shown in figure 1.

(3) **Assembly of Puller**: Pulling function is done with the help of these assembled parts. These are main parts of this assembly of puller:

- (a) 3 φ motor of AC with 1 HP capacity.
- (b) Speed controlling arrangement of pultrusion process:
  - (i) Frequency drives for AC motor of 1 HP capacity.
  - (ii) Gear box of 1:60 ratio of speed.
- (c) Three sets of pulling rollers

![Figure 1. Set up of Pultrusion. 1. Resin Bath 2. Pre-Former 3. Die for heating 4. Pulling steel strip 5. Device for Temperature control 6. Speed controlling frequency drive 7. Rollers for pulling operation 8. Gear box to reduce the speed ratio 9. Assembly for pulling mechanism 10. Jute and glass fibre](image)

2.1 Material for Experiments:

Matrix material: Polyester resin of unsaturated type.
Reinforcement material: Two materials were combined and used as reinforcement material namely glass fibre and jute fibre. Tex unit of jute yarn was 2200 g/km⁻¹.

Material as filler:
- (a) Coconut coir ash in powder form of 150 micron grain size.
- (b) Powder of carbon black of 150 micron grain size.
- (c) Powder of eggshell ash of 150 micron grain size.

Accelerator: 6% concentration of cobalt naphthelate.
Catalyst- Methyl ethyl ketone peroxide. (In a fixed amount in each experiment).
Cross sectional view images of various filler materials were taken at Scanning Electron microscope (JEOL JSM 8390-LV Model), which are as shown below in figure 2, Figure 3 and figure 4. All powder material specimens were coated with conducting material before observing the surfaces through SEM. Various fixed and variable parameters were selected before proceeding to experimental work.

Weight content of filler and resin was decided. Single filler was used in a single experiment and also weight fraction of filler was different in different experiments. In order to find out the filler’s effect on tensile strength of hybrid glass-jute fibre reinforced polymer composites (Hybrid GJFRP), the percentage weight (weight fraction) of fillers coconut coir ash powder, carbon black powder and eggshell ash was kept as parameter of variance, while some parameters were fixed during whole experimental work. The fixed parameters are: temperature of die 180°C, glass-jute fibre to resin ratio by weight and pulling speed as 60 mm min⁻¹. Fillers namely Coconut coir ash, Carbon black and Eggshell ash used were in experiments separately as 3%, 6%, 9%, 12% and 15% weight percentage of resin weight which becomes 21.45gm, 42.9gm, 64.35gm, 85.8gm and 107.25 gm respectively. Each experiment was carried out by using single filler in different weight percentage.

**Table 1.** Constant parameters for experiments

| Constant Parameters: | Value                |
|----------------------|----------------------|
| Temperature of Die   | 180° C               |
| Speed of Pultrusion  | 60 mm min⁻¹          |
| Jute Fibre + Glass Fibre | 300 gm (225 gm Jute fibre + 75 gm Glass fibre) |
| Resin weight         | Weight of (Jute Fibre + Glass Fibre) x 2.5 = 750 gm |
| Methyl ethyl ketone per oxide as catalyst | 0.5 % of resin weight = 3.75gm |
| Cobalt naphthelate   | 1% of resin weight = 7.5 gm |

**2.2 Compound Formation**

The fillers namely carbon black, coconut coir ash and eggshell ash were used in the experiments individually in varying proportionate. Total fifteen experiments were carried out using different weight percentage of these above said fillers. Five experiments were carried out using carbon black as filler, next five experiments were carried out using filler coconut coir ash and last five were carried out
using eggshell ash filler in varying weight percentage. Weight of the resin and weight of glass and jute fibre was kept constant during each and every experiment. Glass fibre and Jute fibre bundles were dipped in the blend of resin and individual filler. These wetted bundles of glass and jute fibre were then finally used for the process of pultrusion. Length of fibre of glass and jute was kept 1100 mm. A bath of filler resin compound was given to the bundles of glass and jute yarn which were pulled against the hot die. Hence cylindrical shape composites of size 1100mm were developed.

**Figure 5.** SEM image of Hybrid Composite specimen with 12% carbon black filler

**Figure 6.** SEM image of Hybrid Composite specimen with 12% Eggshell ash filler

**Figure 7.** SEM image of Hybrid Composite specimen with 12% coconut coir filler

SEM images of developed Hybrid GJFRP specimens show the breakage of fibres and pores in internal structure. Presence of internal cracks was also observed. Internal structure and interfacial properties were also studied with the help of SEM images. Uneven and incomplete distribution of fibre and matrix was observed in the composite material.

### 3. Specimen Testing and Results Discussions

Developed fifteen cylindrical shape hybrid composite specimens were tested for compressive strength, tensile strength and percentage diametral shrinkage.

#### 3.1 Tensile Strength
Test Samples for tensile strength testing were prepared as shown in figure 8 and ASTM D638 was followed to prepare the test specimens [9]. Computerized universal testing machine manufactured by Fine Manufacturing Industry Miraj (Maharashtra), India was used to conduct the tensile tests. Tensile strength result shows that hybrid composite specimen with filler carbon black having weight percentage as 9% is having maximum tensile strength as 76 MPa while hybrid composite specimen with Eggshell ash filler having weight percentage as 6% have second highest tensile strength as 71 MPa. Hybrid composite specimen with coconut coir ash filler having 15% weight has least tensile strength as 43MPa. It was observed that as we increase the carbon black content as filler, tensile strength of composites goes on decreasing as cluster of carbon black particles produce concentration of stress and lack of continuity in constructed matrix and also damages the filament of fibres [21]. Carbon black particles as filler firstly increase the tensile strength but after a limit of its addition, tensile strength goes on decreasing [24]. As we increase the amount of Eggshell ash powder, tensile strength of developed composite was going on increasing but this phenomenon was up to a limit as increase in bond area due to addition of eggshell ash particles creates a better bond between matrix polymer of hydrophobic nature and eggshell ash particles of hydrophilic nature [22-23]. Tensile strength of composites with coconut coir ash filler was going on increasing with small weight percentage addition but after a limit, variation was very less. During tensile strength testing of specimens’ brittle fracture was observed and mechanism of fracture was observed in images like as shown in fig 10. Tensile test graphs of developed Hybrid composites are completely different from same graphs of metals and alloys as there is sudden breakage i.e. brittle fracture in composites.

3.2 Compressive Strength

Similarly all the fifteen specimens of hybrid composite were tested for compressive strength on Universal testing machine by INSTRON (USA). Compressive strength results in figure 12 shows that hybrid composite specimen with filler eggshell ash having weight percentage as 15% have maximum compressive strength as 99.44 MPa while hybrid composite specimen with filler carbon black having weight percentage as 9% have least compressive strength as 15.66 MPa. Scanning electron microscope (SEM) images showed that bonding between unsaturated resin matrix and jute-glass fibres was much better in composite specimen with eggshell ash filler and also compressive strength was going on increasing with increasing weight percentage of eggshell ash filler [22]. Carbon black mixed unsaturated resin was not in proper bonding with glass-jute fibres and increased amount of carbon black filler did not provide any significant improvement in compressive strength. It was also observed that hybrid composite specimen with least addition of filler i.e. 3 weight percent coconut coir ash filler addition was having highest compressive strength as 61.05 MPa. Hence G. Kretsis [25] concluded that compressive strength is approximately 80% of the tensile strength but due to findings of some exceptional cases, no general opinion can be created in hybrid composites. Compressive strength is not clearly defined in research work data for hybrid composites and it is calculated from the ultimate load.
Figure 10. Broken Tensile Specimen after Tensile Strength Testing

Figure 11. Tensile Strength Vs weight % of filler materials

3.3 Diametral Shrinkage

Shrinkage in diameter took place in developed cylindrical shape Hybrid composites specimens when they cooled and solidified. Shrinkage was also varying with varying percentage of fillers as shown in figure 13. Highest percentage shrinkage as 11.58% took place in the composite specimens containing 6% weight percentage of eggshell filler while minimum shrinkage 3.7% took place equally in two hybrid composite specimens containing 9% weight percentage of carbon black filler and 12% weight percentage of coconut coir ash filler. Percentage shrinkage was not uniformly increasing or decreasing with increase in filler weight percentage.
4. Conclusions
Glass-jute fibre reinforced composite specimens were tested for tensile strength, compressive strength and percentage shrinkage when carbon black, coconut coir ash and eggshell ash were mixed as filler in varying weight proportionate. The following are the concluding points:
(1) While keeping constant amount of unsaturated resin and glass-jute fibres, the maximum tensile strength obtained was 76 MPa with 9% addition of carbon black and minimum tensile strength obtained was 48 MPa with 15% addition of coconut coir ash particles as filler. Hence, tensile strength was increasing with the increase of filler percentage up to a limit, after a limit it was decreasing.
(2) The maximum compressive strength obtained was 99.44 MPa with 15% addition of Eggshell ash and minimum compressive strength obtained was 15.66 MPa with addition of 12% carbon black. These results are providing no general trend for compressive strength and it can be calculated from ultimate load only especially in case of hybrid composites.
(3) It was also observed that percentage diametral shrinkage in composite specimens was not uniformly increasing or decreasing when the specimens were cooled and solidified.
(4) Highest percentage shrinkage in diameter as 11.58% took place in the composite specimens containing 6% percentage of eggshell filler while minimum shrinkage 3.7% took place equally in two composite specimens containing 9% weight percentage of carbon black filler and 12% weight percentage of coconut coir ash filler.

References
[1] Milewski, J. V., & Katz, H. S. (Eds.). (1978). Handbook of fillers and reinforcements for plastics. Van Nostrand Reinhold Company.
[2] Alamri, H., & Low, I. M. (2012). Mechanical properties and water absorption behaviour of recycled cellulose fibre reinforced epoxy composites. Polymer testing, 31(5), 620-628.
[3] Zhou, S., Wu, L., Sun, J., & Shen, W. (2002). The change of the properties of acrylic-based polyurethane via addition of nano-silica. Progress in Organic Coatings, 45(1), 33-42.
[4] Baral, D., De, P. P., & Nando, G. B. (1999). Thermal characterization of mica-filled thermoplastic polyurethane composites. Polymer Degradation and Stability, 65(1), 47-51.
[5] Sare, I. R., Mardel, J. I., & Hill, A. J. (2001). Wear-resistant metallic and elastomeric materials in the mining and mineral processing industries—an overview. Wear, 250(1-12), 1-10.
[6] Saw, S. K., & Datta, C. (2009). Thermo mechanical properties of jute/bagasse hybrid fibre reinforced epoxy thermoset composites. BioResources, 4(4), 1455-1475.
[7] Khalil, H. A., Firoozian, P., Bakare, I. O., Akil, H. M., & Noor, A. M. (2010). Exploring biomass based carbon black as filler in epoxy composites: Flexural and thermal properties. Materials &
Gupta, A., Singh, H., & Walia, R. S. (2016). Hybrid filler composition optimization for tensile strength of jute fibre-reinforced polymer composite. *Bulletin of Materials Science, 39*(5), 1223-1231.

Standard, A. S. T. M. (2010). Standard test method for tensile properties of plastics, ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/D0638-10.

Swolfs, Y., Gorbatikh, L., & Verpoest, I. (2014). Fibre hybridisation in polymer composites: a review. *Composites Part A: Applied Science and Manufacturing*, 67, 181-200.

Sanjay, M. R., Arpitha, G. R., & Yogesha, B. (2015). Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: A review. *Materials today: proceedings*, 2(4-5), 2959-2967.

Standard, A. S. T. M. (2011). Standard test methods for constituent content of composite materials.

Walia, R. S., Shan, H. S., & Kumar, P. (2006). Multi-response optimization of CFAAFM process through Taguchi method and utility concept. *Materials and Manufacturing Processes, 21*(8), 907-914.

Gupta, A., Singh, H., & Walia, R. S. (2015). Effect of fillers on tensile strength of pultruded glass fiber reinforced polymer composite.

Akil, H. M., Cheng, L. W., Ishak, Z. M., Bakar, A. A., & Rahman, M. A. (2009). Water absorption study on pultruded jute fibre unsaturated polyester composites. *Composites Science and Technology, 69*(11-12), 1942-1948.

Atiqah, A., Jawaid, M., Ishak, M. R., & Sapuan, S. M. (2017). Moisture absorption and thickness swelling behaviour of sugar palm fibre reinforced thermoplastic polyurethane. *Procedia engineering, 184*, 581-586.

Saba, N., Paridah, M. T., Abdan, K., & Ibrahim, N. A. (2016). Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites. *Construction and building materials, 123*, 15-26.

Ashik, K. P., Sharma, R. S., & Raghavendra, N. (2017). Evaluation of Tensile, Modul and Fracture Properties of Jute/Epoxy Natural Composites with addition of Silicon Di Oxide as Filler Material. *Materials Today: Proceedings, 4*(9), 9586-9591.

Zamri, M. H., Akil, H. M., & MohdIshak, Z. A. (2016). Pultruded Kenaf Fibre Reinforced Composites: Effect of Different Kenaf Fibre Yarn Tex. *Procedia Chemistry, 19*, 577-585.

Hashemi, F., Brancheriau, L., & Tahir, P. (2018). Hybridization and yarns configuration effects on flexural dynamic and static properties of pultruded hybrid kenaf/glass fiber composites. *Composites Part A: Applied Science and Manufacturing*.

Gupta, A., Singh, H., & Walia, R. S. (2016). Hybrid filler composition optimization for tensile strength of jute fibre-reinforced polymer composite. *Bulletin of Materials Science, 39*(5), 1223-1231.

Patrick, S. N., Aigbodion, V. S., & Hassan, S. B. (2012). Development of polyester/eggshell particulate composites. *Tribology in industry, 34*(4), 217-225.

White, N. M., & Ansell, M. P. (1983). Straw-reinforced polyester composites. *Journal of Materials Science, 18*(5), 1549-1556.

Huang, J. C. (2002). Carbon black filled conducting polymers and polymer blends. *Advances in Polymer Technology: Journal of the Polymer Processing Institute, 21*(4), 299-313.

Kretsis, G. (1987). A review of the tensile, compressive, flexural and shear properties of hybrid fibre-reinforced plastics. *Composites, 18*(1), 13-23.

Cox, H. L. (1952). The elasticity and strength of paper and other fibrous materials. *British journal of applied physics, 3*(3), 72.

Singh, S., & Angra, S. (2018). Experimental evaluation of hygrothermal degradation of stainless steel fibre metal laminate. *Engineering science and technology, an international journal, 21*(1), 170-179.

Singh, S., & Angra, S. (2018). Flexural and Impact Properties of Stainless Steel based Glass Fibre Reinforced Fibre Metal Laminate under Hygrothermal Conditioning. *International Journal of Engineering, 31*(1), 164-172.