RESEARCH PAPER

Development and testing of composite glass fibre specimen's mechanical properties in three different orientation & different percentage of nylon infill using taguchi approach

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Abstract**—** In the present study, the tribological performance of E glass fibre was studied. The experimental design was developed using the Taguchi approach with an L27 orthogonal array, and the composites are planned to be fabricated through the hand lay-up technique. To identify the influence of parameter, Taguchi technique was used, which are the best tools for statistical analysis. MINITAB™ version 17 software was used for the analysis of experimental data with considering "smaller is better" as excellent quality. Taguchi technique was used on specimen to check various Mechanical Properties such as hardness test, impact test methods, WEAR TEST Abrasion testing, Tensile Test and Flexure test.

Keywords**—** E glass Fibre, Taguchi, Minitab, wear, impact, tensile, hardness

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I. Introduction

The specimen prepared of composite glass fibre will be tested under Mechanical Hardness (e.g., Rockwell, Vickers, Shore, Barcol), Impact test, Tensile Test and Flexural Test. Specimen preparation involves cutting samples to specific sizes with flat surfaces, ensuring proper surface finish and maintaining a consistent indentation axis.

II. Testing of plain hardness specimen

Test procedures involve applying a controlled force with an indenter, measuring the resulting indentation, and calculating the hardness value according to the chosen standard.

A. Shore hardness

ASTM is the standard for Shore hardness testing, particularly for plastics and polymers. Shore hardness testing of composite specimens, according to indentation of a material using a durometer. The test involves applying a specific indenter under a defined force and measuring the depth of indentation. The resulting value, expressed on the Shore scale (A or D), indicates the material hardness. The test procedure requires a flat, rigid surface, and the indenter must be pressed firmly and steadily against the sample, avoiding any sudden impact.

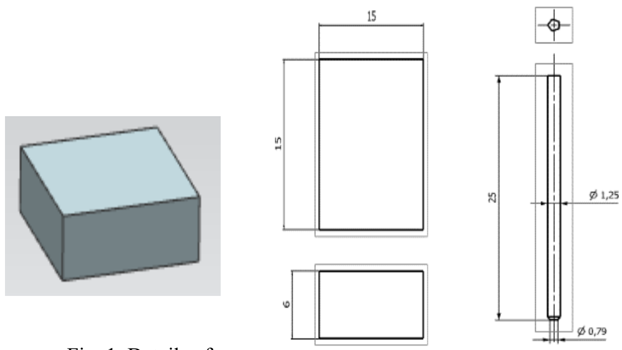


Fig. 1 Details of Specimen and indenter

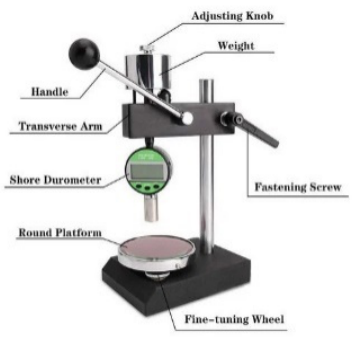


Fig. 2 Testing Machine

E-glass fiber was selected as a suitable reinforcement material for this study because mechanical properties such as hardness, Young's modulus, and chemical stability can be directly evaluated from the fiber itself. In contrast, parameters including dielectric constant, dissipation factor, dielectric strength, surface and volume resistivities, and thermal expansion are determined using glass that has been fabricated into bulk samples and annealed to remove residual forming stresses.

The density of glass fibers is determined and reported either in their as-formed state or after bulk annealing. According to ASTM C 693 standards, this test method is commonly employed for measuring density. As shown in Table 3, fiber density is approximately 0.04 g/cc lower than that of bulk annealed samples at room temperature. The densities of glass fibers used in composite applications vary from about 2.11 g/cc for D-glass to 2.72 g/cc for ECRGLAS reinforcements.

The hardness strength of glass fibers is typically reported for pristine single filaments or multifilament strands tested in air at ambient conditions. Due to surface imperfections introduced during strand formation, strand strength values are generally 20–30% lower than those of individual filaments listed in Table 2. The presence of moisture substantially reduces the pristine strength of glass fibers. This effect can be minimized by testing single filaments at liquid nitrogen temperatures, where moisture interference is negligible. Under these conditions, fiber strength tends to increase by 50–100% compared to results obtained at room temperature in an environment with 50% relative humidity.

For instance, S-2 glass fibers exhibit a maximum tensile strength of 11.6 GPa at liquid nitrogen temperature for fibers measuring 10 µm in diameter and 12.7 mm in gauge length. The reduction in fiber strength due to moisture exposure under sustained load is referred to as static fatigue. Moreover, as the exposure temperature rises, the pristine strength of glass fibers progressively declines.

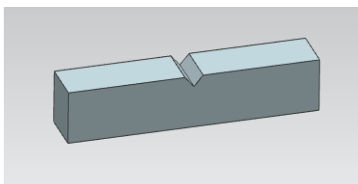
III. Development & Testing of Plain Impact Specimen

Impact testing serves as an important assessment method used to determine how well a material or component can withstand sudden loads or impacts. It evaluates properties such as toughness, strength, and durability under shock conditions. This type of testing is widely applied across multiple industries to verify the safety, reliability, and performance of materials and products. By replicating real-life impact situations, the process helps detect potential points of failure and contributes to optimizing material compositions and product designs.

A. *Izod Impact Test*

The Izod test uses a pendulum to strike a notched specimen, but the specimen is clamped in a cantilever configuration. It's another common method for assessing impact resistance. The Izod impact test is primarily applied to evaluate plastics and other comparatively soft materials. In this method, the test specimen with a notch is mounted vertically rather than horizontally. During testing, the pendulum strikes the sample precisely above the notch, whereas in the Charpy test, the impact occurs on the opposite side of the notch.

The Izod technique is widely used to determine the impact strength of polymers and plastics employed in various applications such as consumer goods, automotive parts, and packaging. Standard testing procedures for the Izod impact test are defined by ASTM D256, ASTM D4508, and ASTM D4812.



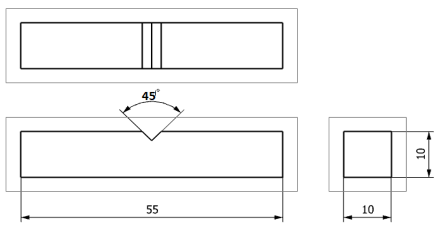


Fig. 3 Details of Specimen

B. *Optimization of E glass specimen(DOE)*

The Design of Experiments (DOE) methodology, particularly the use of Orthogonal Arrays (OAs), is an essential part of Taguchi's method for systematically analyzing and testing the effects of control factors at various levels. Commonly applied orthogonal arrays include L4, L9, L12, L16, L18, and L27. In these arrays, each column represents a specific factor and its levels, while each row corresponds to an experimental trial carried out under those conditions.In industrial applications, designed experiments are utilized to methodically explore the influence of process and product parameters on overall product quality. Once the critical process conditions and variables affecting quality are identified, improvement strategies can be effectively implemented to enhance manufacturability, reliability, performance, and consistency of the final product.The notations used in above table for different parameters and levels are as per Table II and design is as follows of Orthogonal Array of Taguchi L9 mentioned in Table III.

IV. Development & Testing of Plain Wear Specimen

Abrasion testing is conducted to evaluate the wear resistance of solid materials, including composites. The main objective of this method is to generate comparative data that ranks materials based on their ability to withstand sliding abrasion under controlled conditions, thereby aiding in the estimation of material lifespan. The wear tests on composite samples were performed following the ASTM G65 standard procedure. The wear tests were conducted on a pin-on-drum abrasive wear tester, designed for standard wear tests described in ASTM standards. In this method, the test specimen translates over the surface of an abrasive paper, which is mounted on a revolving drum, with the resulting wear of the material expressed as volume loss. The test setup is schematically illustrated in figure below

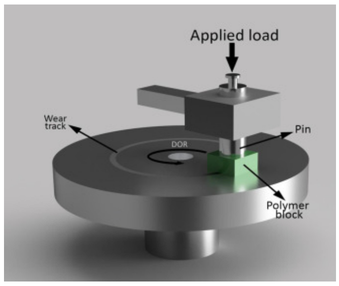


Fig. 4 Pin on Disc wear Apparatus

A. *Optimization of E-Glass Wear Specimen (DOE)*

Minitab 17 software was utilized for conducting the design of experiments. Minitab is a statistical analysis tool that simplifies the process of data evaluation and interpretation. Originally developed to support the teaching of basic statistics, it serves as a user-friendly platform for performing various statistical analyses. Considering its simplicity and reliability, Minitab 17 was selected for this study.

Minitab functions as an interactive program, meaning that users can input data directly or specify its source, after which the software instantly executes the given commands and produces results. It primarily uses two types of files: worksheets and projects. Worksheets contain raw data, while projects store commands, graphs, and related analytical outputs. All other data are managed within these two primary file structures.

V. Development & Testing of Plain Tensile Specimen

Tensile testing is conducted for multiple purposes. The outcomes of these tests assist in selecting suitable materials for various engineering applications. Tensile properties are commonly included in material specifications to maintain consistent quality. During the development of new materials or manufacturing processes, tensile tests are performed to enable comparisons between different materials and processing methods. Additionally, data obtained from tensile testing help predict material behavior under different types of loading beyond uniaxial tension.The strength of a material is often the main parameter of interest, determined either by the stress required to induce significant plastic deformation or by the maximum stress the material can endure before failure. These strength values are applied in engineering design with adequate safety factors to ensure structural reliability. Another key aspect is ductility, which indicates the extent to which a material can deform before fracturing. Although ductility is rarely used directly in design calculations, it serves as an important quality indicator of toughness and fracture resistance. Materials exhibiting low ductility in tensile tests usually show poor performance under other loading conditions. Elastic properties may also be evaluated during tensile testing, though specialized methods are required for precise measurement. More accurate assessments of these properties are often obtained through ultrasonic testing techniques.

A. Tensile Specimen

A standard tensile test specimen, as illustrated in Fig. 1, consists of enlarged ends or shoulders that facilitate proper gripping during testing. The central portion, known as the gauge section, is the most critical region of the specimen. This section has a smaller cross-sectional area compared to the rest of the specimen, ensuring that deformation and eventual failure occur within this region. The gauge length, positioned at the center of the reduced section, defines the area where elongation measurements are taken.The spacing between the gauge section and the shoulders must be sufficient to prevent the larger ends from restricting deformation within the gauge length. Additionally, the gauge length should be significantly larger than its diameter to maintain a uniform stress distribution. If these proportions are not maintained, the stress pattern may become complex rather than representing pure uniaxial tension.

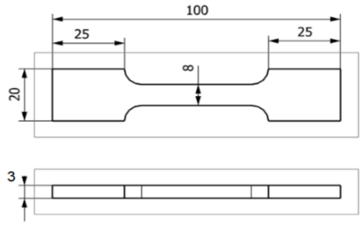


Fig.5 Tensile Specimen

Different methods can be used to grip the specimen, as shown in Fig. 6. In some setups, the grip section is secured between wedge-type grips. The primary consideration when choosing a gripping method is to ensure that the specimen remains firmly held during testing, even under maximum load, without any slipping or breakage in the grip area. Additionally, any bending of the specimen should be kept to a minimum.

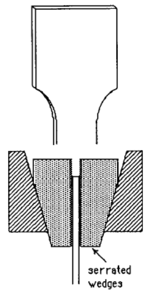


Fig.6 Serrated wedge gripping arrangements

B. Tensile Machine

Universal testing machines are the most widely used equipment for evaluating materials under tension, compression, or bending loads. Their main purpose is to generate the stress–strain curve of the tested specimen.

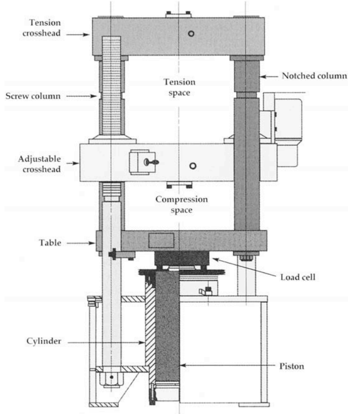


Fig.6. Electromechanical Universal testing machine

C. Procedure Specimen Preparation

1. The specimens were cut into the required shapes using a 3D-printed template.
2. A unidirectional glass fiber sheet was secured with adhesive tape on one side.
3. A coating of epoxy resin and hardener, mixed in an 80:20 ratio, was applied to the specimen sheet.
4. The coated sheet was left to cure for about 35 to 40 minutes before the next layer was applied.
5. A second layer was placed, and steps 2 and 3 were repeated until the desired sheet thickness for the specimen was achieved.
6. The assembled specimens were then placed under a press load and left to cure for 24 hours.
7. Finally, the cured specimens were machined and ground to obtain the required shape.

Fig.6. Plain E glass Fibre Specimen

VI. DEVELOPMENT & TESTING OF PLAIN FLEXURAL SPECIMEN

Since the properties of many materials, particularly thermoplastics, can change with variations in ambient temperature, it is often necessary to conduct testing under conditions that mimic the actual service environment. The flexural test determines the force required to bend a specimen using a three-point loading setup and is suitable for evaluating both rigid and semi-rigid materials, including resins and laminated fiber-reinforced composites.The results of flexural testing are used to select materials that can bear loads without significant deflection. Flexural testing of polymers, composite materials, and fiber-reinforced laminates is commonly performed using three-point and four-point bending methods as per standards such as ISO 14125, ISO 178, ASTM D790, and ASTM D6272. These standardized tests ensure that materials perform reliably under different loading and environmental conditions. Various specimen dimensions can be used depending on the testing standard. Typically, ASTM D790 specifies specimen sizes such as 3.2 mm × 12.7 mm × 125 mm or rectangular samples with dimensions of 160 mm × 20 mm × 8 mm × 10 mm × 1 mm, while ISO standards often employ specimens measuring 10 mm × 4 mm × 80 mm.

A. Flexural Test

Flexural testing also provides a semi-quantitative understanding of the interfacial strength between fibers and the matrix in a composite material. This type of test generates both raw and processed data, including values of flexural stress and strain at yield, stress and strain at break, as well as flexural stress corresponding to specific deflection levels—3.5% for ISO standards and 5.0% for ASTM standards. Additionally, flexural modulus and stress–strain curves are obtained from the test. The flexural modulus serves as an indicator of a material's stiffness when subjected to bending loads.

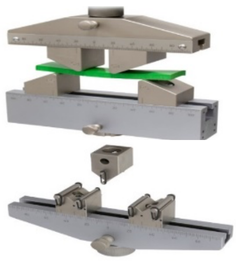


Fig.7. Flexural testing equipment

The three-point flexural test is a staple in material testing, particularly for structures like beams that are primarily subjected to bending rather than tension. During this test, the material is distorted (strained) and experiences resistance (stress) as a load is applied at a single point while the specimen is supported at two other points. This setup creates a bending moment that helps in determining the point flexure and flexural properties of the material.

Standardized methods are crucial for ensuring consistent and reliable results in flexural testing. Standards like ASTM D790, ISO 178, and DIN 53121 outline specific procedures for preparing specimens and conducting a test method. These standards help in maintaining uniformity across different tests and materials, providing a benchmark for material characterization and quality control.

A. Flexural Specimen

Composite materials, particularly fiber-reinforced ones, are commonly evaluated for their resistance to bending stresses through flexural testing. The three-point bending method is especially suitable for non-homogeneous materials like composites, as it ensures a more even distribution of stress across the specimen during testing..

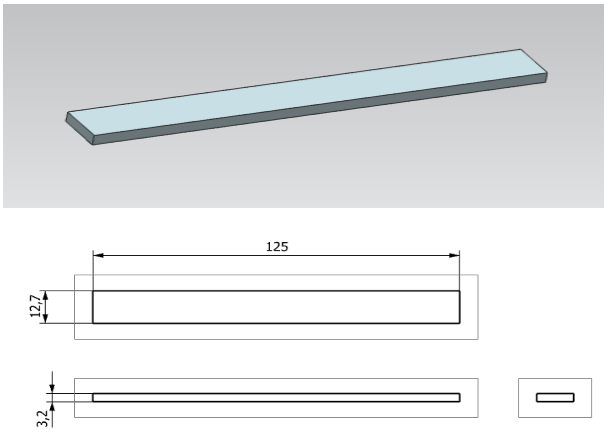


Fig.8. Flexural Specimen

VII. DOE BY TAGUCHI MINITAB 16

The symbols and abbreviations representing various parameters and their corresponding levels used in the above table are presented below.

TABLE1 II

Notations for different parameters and levels

Parameters	**Levels**		
	1	**2**	**3**
Direction of Lay (Degree)	0	45	90
% Nylon 6	0	15	30

The data presented in the above table were arranged into an orthogonal array developed using the Taguchi design approach. This array, which includes the actual values of the input parameters, served as the basis for conducting the experiments. In the present study, two input parameters were considered, each having three levels. Accordingly, from the available Taguchi designs in Minitab, the L9 orthogonal array was selected. The experimental design based on this array is shown below.

TABLE1 III

Orthogonal Array of Taguchi L9

Angle of Lay	**Nylon 6 (%)**
0	0
0	15
0	30
45	0
45	15
45	30
90	0
90	15
90	30

VIII. CONCLUSIONS

1. The development and testing of composite glass fiber specimens, particularly those reinforced with E-glass fibers and varying nylon 6 infill percentages, demonstrate critical insights into their mechanical properties across multiple dimensions including flexural, tensile, impact, wear, and hardness characteristics. Flexural testing, conducted according to ASTM and ISO standards using three-point and four-point bending methods, provides essential data on the material's ability to resist bending forces, with parameters such as flexural stress, strain, and

modulus informing design and quality control decisions.

2. Tensile testing further complements these findings by evaluating material strength, ductility, and elastic properties, which are crucial for selecting materials for engineering applications and predicting performance under different load conditions. Impact testing assesses the toughness and durability of composites under sudden forces, highlighting the importance of understanding material resilience for safety and reliability in real-world applications.

3. Wear testing, following ASTM standards, measures abrasive resistance, crucial for predicting material lifetime in service environments, while hardness testing across various scales (Rockwell, Shore, Vickers, etc.) ensures proper surface durability and resilience of composites.

4. Throughout these investigations, design of experiments (DoE) techniques, particularly Taguchi methods using orthogonal arrays, enable systematic evaluation of variables such as fiber orientation, nylon infill percentage, layer thickness, and processing conditions. This approach identifies significant factors affecting performance metrics and facilitates optimization for robust and high-quality composite manufacturing.

5. Overall, these comprehensive mechanical characterizations underscore the viability of glass fiber composites, especially those using E-glass fibers and epoxy resin matrices, as cost-effective, lightweight alternatives to traditional materials in automotive and structural applications. The experimental data provide a solid foundation for improving composite design, ensuring durability, and tailoring properties to meet specific engineering requirements and operational environments.

6. This integrated testing and analysis framework is key to advancing composite material technology and supporting its widespread industrial adoption.

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