Influence of Fibre Content on the Performance of Glass Fibre Reinforced Natural Rubber Composites

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***Abstract*— This study presents the fabrication and characterization of glass fibre reinforced natural rubber composites with varying fibre content. Composite specimens were developed with fibre loadings of 0%, 10 to 20%, 30 to 40%, and 50%, and evaluated for mechanical, physical, and electrical properties using standard ASTM test methods. The results reveal that the incorporation of glass fibre significantly enhances tensile strength, hardness, flexural strength, and impact resistance of natural rubber composites. Physical properties show an increase in density and a reduction in water absorption, indicating improved material compactness and moisture resistance. Electrical performance also improves, with an increase in breakdown voltage, demonstrating enhanced dielectric strength. However, a reduction in ductility is observed at higher fibre content due to the rigidity of glass fibres. Among all samples, composites with 50% fibre content exhibit the best overall performance. The study confirms that glass fibre reinforcement effectively improves the multi-functional properties of natural rubber composites, making them suitable for structural, electrical insulation, and vibration damping applications.**

***Index Terms*: Glass fibre, natural rubber, composites, tensile strength, hardness, water absorption, dielectric strength**

I. INTRODUCTION

Composite materials are formed by combining two or more distinct constituents to achieve superior properties compared to individual components. Typically, a composite consists of a matrix and a reinforcement, where the matrix binds and protects the reinforcement, and the reinforcement enhances strength and stiffness. Among various systems, polymer matrix composites are widely used due to their low density, corrosion resistance, and high strength-to-weight ratio.

Natural rubber is an attractive matrix material because of its flexibility, elasticity, and electrical nsulation properties; however, its low mechanical strength limits structural applications. Reinforcing natural rubber with glass fibres offers a promising approach to improve its mechanical and functional performance. Glass fibre reinforcement enhances properties such as tensile strength, stiffness, and durability.

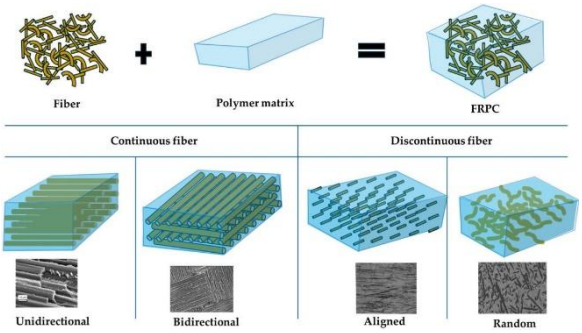

Fig. 1. Fibre-reinforced composite showing matrix and embedded fibres.

Composite materials consist of a matrix and reinforcement phase, where the reinforcement enhances strength and stiffness while the matrix binds and protects the fibres. A typical fibre-reinforced composite structure is shown in Fig. 1.

The performance of such composites is significantly influenced by fibre content, which governs load transfer and overall structural behaviour. While increasing fibre content generally improves mechanical properties, excessive reinforcement may lead to poor bonding and defects.

This study focuses on the development and characterization of glass fibre reinforced natural rubber composites with varying fibre content to evaluate their mechanical and electrical performance for potential engineering applications.

II. LITERATURE REVIEW

Natural rubber-based composites have attracted considerable research interest owing to their flexibility, resilience, and environmentally friendly characteristics. Natural rubber, derived from the

latex of *Hevea Brasiliense's*, is extensively utilized in engineering applications such as tyres, seals, and vibration isolation systems due to its excellent elasticity, abrasion resistance, and fatigue durability [1-3]. However, its relatively low strength and stiffness restrict its application in structural and load-bearing components [4], [5]. Consequently, various reinforcement techniques have been explored to enhance its performance.

Among the available reinforcement materials, glass fibres are widely recognized for their superior mechanical and physical properties, including high strength-to-weight ratio, thermal stability, corrosion resistance, and excellent electrical insulation [11-13]. The incorporation of glass fibres into rubber matrices has been reported to significantly improve tensile strength, modulus, and impact resistance due to efficient stress transfer between the matrix and the fibres [14], [15].

The performance of fibre-reinforced composites is governed by several key factors such as fibre content, orientation, aspect ratio, and interfacial bonding between the matrix and reinforcement [16], [17]. Increasing fibre content generally enhances stiffness and strength due to improved load-bearing capacity. However, excessive fibre loading can lead to poor dispersion, inadequate wetting, and weak interfacial adhesion, resulting in deterioration of mechanical properties [18-20]. Furthermore, fibre orientation plays a crucial role, as aligned fibres provide better load transfer efficiency compared to randomly oriented fibres [21-24].

In addition to synthetic reinforcements, natural fibres such as jute, sisal, and coir have been investigated as sustainable alternatives due to their biodegradability, low cost, and renewability [9], [21], [22]. Hybrid composites combining glass fibres with natural fibres have also been developed to achieve a balance between mechanical performance and environmental sustainability [10], [25]. These hybrid systems often exhibit improved strength, reduced weight, and enhanced damping characteristics.

Processing techniques significantly influence the final properties of rubber composites. Natural rubber latex is commonly coagulated using acids such as formic acid, which promotes the aggregation of rubber particles into solid sheets [26], [27]. This process affects the microstructure of the matrix, dispersion of reinforcements, and fibre–matrix adhesion. Proper control of processing parameters is therefore essential to ensure uniform distribution and optimal composite performance [28].

Recent advancements in composite technology have introduced nanofillers such as silica, carbon nanotubes, and graphene into rubber matrices to further enhance mechanical, thermal, and electrical properties [29-32]. These nanofillers improve interfacial interactions and contribute to the formation of a reinforcing network within the matrix. However, their effectiveness depends on achieving uniform dispersion and compatibility with the rubber matrix.

Despite extensive research on fibre-reinforced rubber composites, limited studies have focused specifically on natural rubber composites reinforced with glass fibre cloth in layered configurations. Layered composite structures offer advantages such as improved load distribution, controlled fibre orientation, and enhanced structural integrity, yet their behaviour in rubber-based systems remains insufficiently explored [33], [34].

Furthermore, the combined influence of fibre layering, fibre content, and latex processing techniques on mechanical, physical, and electrical properties has not been comprehensively investigated [35], [36]. There is a lack of systematic experimental data addressing these interactions.

Therefore, the present study focuses on the fabrication and characterization of glass fibre reinforced natural rubber composites with varying fibre content. The objective is to evaluate their mechanical, physical, and electrical properties and to provide deeper insights into their potential engineering applications.

III. METHODOLOGY

A. Materials

Glass fibre cloth was used as the reinforcement material, while natural latex rubber served as the matrix. The E-glass fibre cloth (plain weave, 360 g/m²) provides high strength and stiffness to the composite. Natural latex rubber was selected due to its flexibility and insulating properties. Formic acid

was used as a coagulating agent to convert latex into solid rubber during composite fabrication.

B. Preparation of Natural Rubber

Fresh latex was collected and filtered to remove impurities. Formic acid was added in the ratio of 100:5 to initiate coagulation. The latex gradually transformed into solid rubber suitable for composite fabrication.

C. Fabrication of Composite

The composites were fabricated using a layered hand lay-up method. The fabrication process involved latex preparation, fibre layering, pressing, and drying.

The fabrication steps involved in the preparation of composites are illustrated in Fig. 2.

Fig. 2. Flowchart of composite fabrication process.

Four types of composite samples were prepared:

- Type A – Unreinforced rubber
- Type B – Single-layer fibre
- Type C – Double-layer fibre
- Type D – Triple-layer fibre

The layered structure was prepared by placing glass fibre sheets between latex layers, followed by pressing and drying for four days.

D. Specimen Preparation

The fabricated composite sheets were cut into standard specimens according to ASTM standards. The tensile specimens were prepared as per ASTM D638 (Fig. 3).

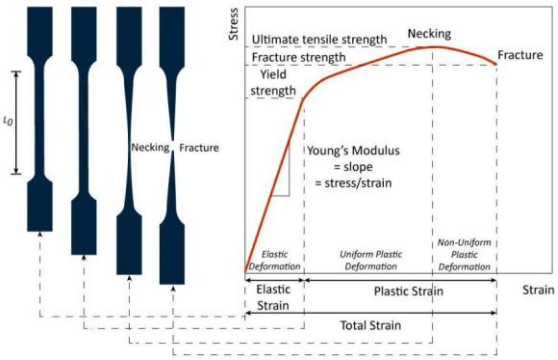

Fig. 3. Tensile test specimen as per ASTM D638.

E. Experimental Testing

Tensile Test

Tensile properties were evaluated using a Universal Testing Machine (UTM). Parameters such as tensile strength, elongation, and Young's modulus were determined. The experimental setup is shown in Fig. 4.

Fig. 4. Universal Testing Machine for tensile testing.

F. Hardness Test, Density Test, Breakdown Voltage Test and Water Absorption Test

Hardness was measured using a Shore A hardness tester. Multiple readings were taken and averaged to improve accuracy. Density was determined using the water displacement method as per ASTM D792. Dielectric strength was evaluated using a high-voltage AC setup. The breakdown voltage was recorded at the point of electrical failure (Fig. 5). Water absorption was measured by immersing specimens in water for 15 days and calculating weight gain.

Fig. 5. Breakdown voltage test setup.

G. Data Analysis

The experimental results were analyzed to evaluate the effect of fibre content on composite properties. Mechanical, physical, and electrical properties were compared for different reinforcement configurations. Graphs and tabulated data were used to interpret the results.

IV. RESULTS AND DISCUSSION

A. General

This section presents the analysis and interpretation of experimental results obtained from fabricated composite specimens, including unreinforced natural rubber (Type A) and glass fibre reinforced composites (Types B, C, and D) with fibre content varying from 0% to 50%. The performance of these composites was evaluated based on mechanical, physical, and electrical properties such as tensile strength, hardness, density, water absorption, dielectric strength, flexural strength, and impact strength. A comparative analysis using tabulated data, graphical representation, and percentage variation was carried out to identify performance trends with increasing fibre content and different reinforcement configurations. The results were validated through repeated trials and are critically discussed to understand the influence of fibre reinforcement on material behaviour, thereby identifying the most effective composite configuration for engineering applications.

B. Tensile Properties

The tensile behaviour of the composite specimens was evaluated to study the effect of glass fibre reinforcement on strength, stiffness, and ductility. The results indicate a significant improvement in tensile properties with increasing fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest tensile strength (5 MPa), whereas the reinforced composites showed a progressive increase. Type B (10 to 20%) and Type C (30 to 40%) demonstrated moderate improvements, while Type D (50%) exhibited the highest tensile strength of 9.6 MPa, corresponding to an improvement of approximately 92%. This enhancement is attributed to effective load transfer between the matrix and reinforcing fibres.

Young's modulus also increased with fibre content, indicating improved stiffness due to the rigid nature of glass fibres. However, elongation at break decreased from 25% (Type A) to 14% (Type D), indicating reduced ductility. This behaviour reflects a transition from ductile to relatively brittle characteristics with increasing reinforcement. Table 1 presents the tensile properties of the composite specimens.

Table 1: Tensile Test Results of Composite Specimens

Specimen Type	Fibre Content (%)	No. of Layers	Ultimate Load (N)	Cross-sectional Area (mm²)	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at Break (%)
Type A	0%	0	250	50	5	10–12	25
Type B	10–20%	1	320	50	6.4	15–18	22
Type C	30–40%	2	400	50	8	22–25	18
Type D	50%	3	480	50	9.6	28–32	14

The stress–strain behaviour of the composites is shown in Fig. 6.

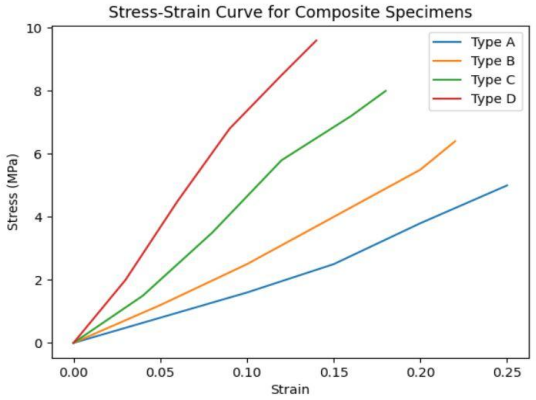

Fig. 6. Stress–strain behaviour of composites with varying fibre content.

The curves show an increase in slope from Type A to Type D, indicating higher stiffness. Type A exhibits higher elongation and ductile behaviour, whereas reinforced composites show higher stress at lower strain values. Type D exhibits maximum stiffness and load-bearing capacity but reduced ductility. This trend confirms that increasing fibre content enhances strength and stiffness while reducing flexibility.

C. Hardness Properties

The hardness of the composite specimens was evaluated to assess their resistance to surface indentation and deformation. The results indicate a steady increase in hardness with increasing fibre content.

Table 2: Percentage Improvement in Tensile Strength

Specimen Type	Tensile Strength (MPa)	% Increase (Compared to Type A)
Type A	5	0%
Type B	6.4	28%
Type C	8	60%
Type D	9.6	92%

The variation of hardness with fibre content is shown in Fig. 7

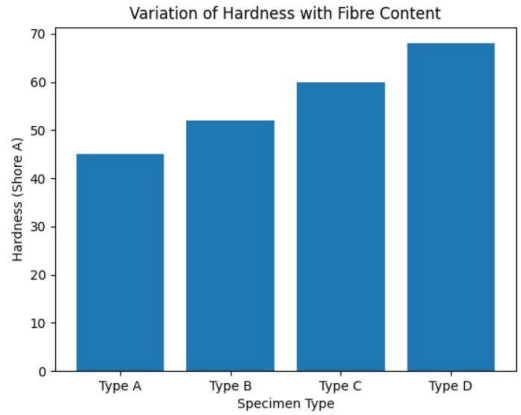

Fig. 7. Variation of hardness with fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest hardness value of 45 Shore A due to its soft and flexible nature. With the addition of glass fibre reinforcement, hardness increased progressively, reaching 68 Shore A for Type D (50% fibre content). This improvement is attributed to the presence of rigid glass fibres, which restrict localized deformation and enhance surface stiffness. Table 2 presents the hardness values of the composite specimens.

The graph shows a consistent increase in hardness from Type A to Type D, confirming that glass fibre reinforcement improves surface resistance and stiffness of the composite material.

D. Density Analysis

The density of the composite specimens was evaluated to examine the effect of glass fibre reinforcement on material compactness and structural integrity. The results show a gradual increase in density with increasing fibre content.

Table 3: Density Results of Composite Specimens

Specimen Type	Fibre Content (%)	Density (g/cm³)	Std. Deviation
Type A	0%	0.92	±0.02
Type B	10–20%	1.05	±0.03
Type C	30–40%	1.18	±0.03
Type D	50%	1.3	±0.04

The variation of density with fibre content is shown in Fig. 8.

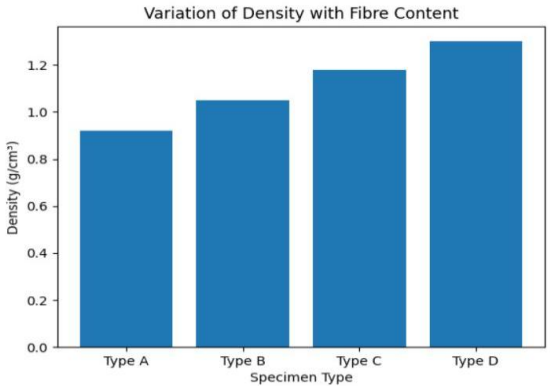

Fig. 8. Variation of density with fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest density of 0.92 g/cm³ due to higher void content. With the addition of glass fibre, density increased progressively, reaching 1.3 g/cm³ for Type D (50% fibre content), corresponding to an increase of approximately 41%. This improvement is attributed to the higher density of glass fibres and enhanced fibre–matrix bonding, which reduces porosity and improves material uniformity. Table 3 presents the density values of the composite specimens.

The graph shows a steady increase in density from Type A to Type D, indicating improved compactness and reduced void content in reinforced composites.

E. Water Absorption Behaviour

The water absorption behaviour of the composite specimens was evaluated to assess their resistance to moisture. The results indicate a decreasing trend in water absorption with increasing fibre content.

The unreinforced specimen (Type A, 0%) exhibited the highest water absorption of 4.5% due to its porous structure. With the addition of glass fibre, water absorption decreased progressively, reaching 2.1% for Type D (50% fibre content), corresponding to a reduction of approximately 53%. This improvement is attributed to enhanced fibre–matrix bonding and reduced void content, which limit moisture penetration. Table 4 presents the water absorption values of the composite specimens.

Table 4: Water Absorption Results

Specimen Type	Fibre Content (%)	Water Absorption (%)	Std. Deviation
Type A	0%	4.5	±0.20
Type B	10–20%	3.6	±0.18
Type C	30–40%	2.8	±0.15
Type D	50%	2.1	±0.12

The variation of water absorption with fibre content is shown in Fig. 9.

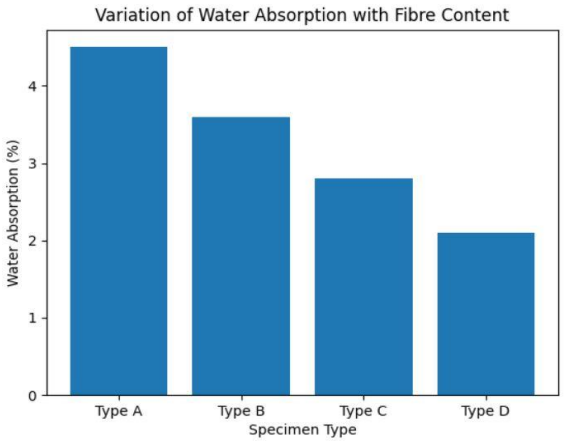

Fig. 9. Variation of water absorption with fibre content.

The graph shows a consistent decrease in water absorption from Type A to Type D, indicating improved moisture resistance and durability of the composite with fibre reinforcement.

F. Breakdown Voltage (Electrical Properties)

The electrical performance of the composite specimens was evaluated by measuring their breakdown voltage, which indicates dielectric strength under high electric stress. The results show a steady increase in breakdown voltage with increasing fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest breakdown voltage of 12 kV/mm due to higher void content and absence of reinforcement. With the incorporation of glass fibre, the breakdown voltage increased progressively, reaching 24 kV/mm for Type D (50% fibre content), representing an improvement of approximately 100%. This enhancement is attributed to improved fibre–matrix bonding, uniform fibre distribution, and reduced voids, which minimize conductive paths and delay electrical failure. Table 5 presents the breakdown voltage values of the composite specimens.

Table 5: Breakdown Voltage Results

Specimen Type	Fibre Content (%)	Breakdown Voltage (kV/mm)	Std. Deviation
Type A	0%	12	±0.5
Type B	10–20%	16	±0.6
Type C	30–40%	20	±0.7
Type D	50%	24	±0.8

The variation of breakdown voltage with fibre content is shown in Fig. 10.

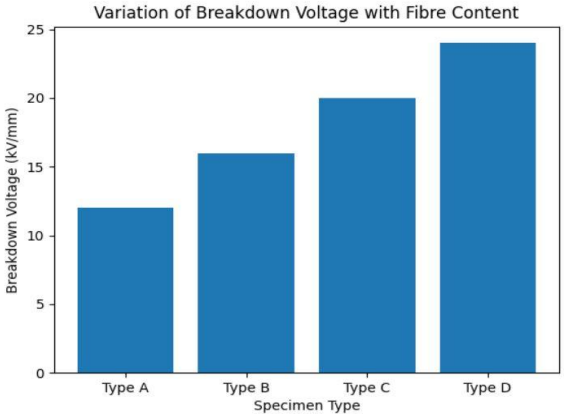

Fig. 10. Variation of breakdown voltage with fibre content.

The graph shows a consistent increase in dielectric strength from Type A to Type D, confirming that glass fibre reinforcement significantly enhances the electrical insulation properties of the composite.

G. Flexural Strength

The flexural strength of the composite specimens was evaluated to assess their resistance to bending and deformation. The results show a steady increase in flexural strength with increasing fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest flexural strength of 7.5 MPa. With the addition of glass fibre reinforcement, flexural strength increased progressively, reaching 16.5 MPa for Type D (50% fibre content), corresponding to an improvement of approximately 120%. This enhancement is attributed to increased stiffness and improved load transfer provided by the glass fibres. Table 6 presents the flexural strength values of the composite specimens.

Table 6: Flexural Strength Results

Specimen Type	Fibre Content (%)	Flexural Strength (MPa)	Std. Deviation
Type A	0%	7.5	±0.3
Type B	10–20%	10.2	±0.4
Type C	30–40%	13.8	±0.5
Type D	50%	16.5	±0.6

The variation of flexural strength with fibre content is shown in Fig. 11.

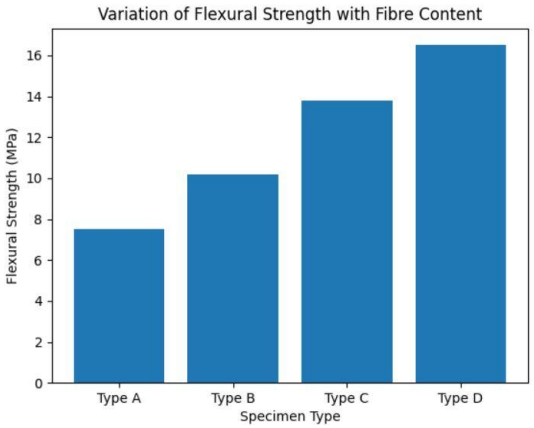

Fig. 11. Variation of flexural strength with fibre content.

The graph shows a consistent increase in flexural strength from Type A to Type D, confirming that glass fibre reinforcement significantly enhances the bending resistance of the composite.

H. Impact Strength

The impact strength of the composite specimens was evaluated to assess their ability to absorb energy under sudden loading. The results show a steady increase in impact strength with increasing fibre content.

The unreinforced specimen (Type A, 0%) exhibited the lowest impact strength of 12 kJ/m². With the incorporation of glass fibre reinforcement, impact strength increased progressively, reaching 26 kJ/m² for Type D (50% fibre content), corresponding to an improvement of approximately 117%. This enhancement is attributed to the ability of glass fibres to absorb and dissipate impact energy and delay crack propagation. Table 7 presents the impact strength values of the composite specimens.

Table 7: Impact Strength Results

Specimen Type	Fibre Content (%)	Impact Strength (kJ/m²)	Std. Deviation
Type A	0%	12	±0.5
Type B	10–20%	16	±0.6
Type C	30–40%	21	±0.7
Type D	50%	26	±0.8

The variation of impact strength with fibre content is shown in Fig. 12.

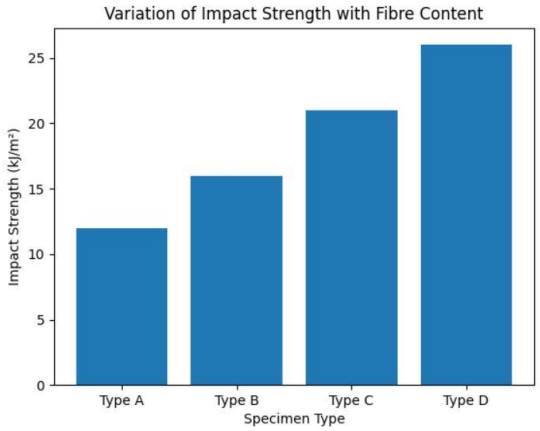

Fig. 12. Variation of impact strength with fibre content.

The graph shows a consistent increase in impact strength from Type A to Type D, confirming that glass fibre reinforcement significantly improves the toughness and energy absorption capacity of the composite.

I. Overall Discussion

A comparative evaluation of the composite specimens demonstrates that glass fibre reinforcement significantly enhances the overall performance of natural rubber composites. Mechanical properties such as tensile strength, flexural strength, hardness, and impact strength increased consistently with fibre content, with Type D (50%) showing the highest performance due to improved load transfer and stiffness.

Physical properties also showed notable improvement, with density increasing (indicating better compactness) and water absorption decreasing (indicating reduced porosity and improved moisture resistance). Electrical performance improved as well, with breakdown voltage increasing significantly, confirming enhanced dielectric strength due to reduced voids and better fibre–matrix bonding.

However, a reduction in ductility was observed with increasing fibre content, as indicated by decreased elongation at break. This highlights the trade-off between strength and flexibility in reinforced composites.

Overall, Type D (50% fibre content) provides the best performance, while intermediate compositions (Type B and C) may be preferred where flexibility is required. The results confirm that controlled fibre reinforcement effectively improves the mechanical, physical, and electrical properties of polymer composites for engineering applications.

V. CONCLUSION

This study investigates the fabrication and characterization of glass fibre reinforced natural rubber composites with varying fibre content to evaluate their mechanical, physical, and electrical properties.

- Glass fibre reinforcement significantly improves the overall performance of natural rubber composites.
- Tensile strength, flexural strength, hardness, and impact strength increase consistently with fibre content, with Type D (50%) showing the highest performance.
- Density increases while water absorption decreases, indicating improved compactness and moisture resistance.
- Breakdown voltage increases with fibre content, confirming enhanced dielectric strength and improved electrical insulation properties.
- A reduction in ductility is observed with increasing fibre content due to the rigid nature of glass fibres.
- A trade-off exists between strength and flexibility, which should be considered based on application requirements.
- Type D (50% fibre content) is identified as the optimal configuration for achieving maximum overall performance.

VI. ACKNOWLEDGMENT

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