

Optimizing Weight Fractions and Chemical Treatments to Increase the Shore Hardness of Woven E-Glass, Woven Jute, and Kenaf Hybrid Composite Laminates

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Abstract

The usefulness and promise of composite materials in various industrial contexts have received extensive attention in recent years. Chemical treatment and weight fraction modifications are the subject of this investigation into the shore hardness qualities in woven E-Glass, Woven Jute, and Kenaf Hybrid composite laminates. The key objectives are to analyze how the NaOH chemical treatment affects the laminate's hardness and how the fiber weight fraction affects stiffness. Our process entails making composite laminates in a range of circumstances, from raw to treated (NaOH), and from 20% to 25% by weight. Testing the Shore hardness of the laminates is a crucial tool for determining their stiffness. According to the findings, NaOH chemical treatment improves the shore hardness, which is useful for its enhanced rigidity. The importance of optimizing the weight fraction of the composite design is further emphasized by the fact that raising the weight fraction of fibers typically leads to improved hardness. This study elucidates the value of shore hardness testing for characterizing composites and evaluating the effects of treatment and weight fraction modification. Considering the importance of stiffness and durability in numerous fields, research has far-reaching consequences. The research also adds to the field of material engineering by advocating for environmentally friendly options by using natural fibers such as jute and kenaf. In sum, the findings of this study deepen our knowledge of composite materials and pave the way for novel, eco-friendly materials and processes.

Keywords

Natural Fiber, Kenaf Fiber, Jute Fiber, Glass Fiber, Sodium Hydroxide.

1. Introduction

Composites are widely used in today's industries because they can be molded into any shape and last far longer than their more conventional counterparts. They are indispensable across a wide range of industries. Thanks to their exceptional strength, longevity, and adaptability. Due in large part to their increased quality, durability, fatigue and corrosion resistance, and damage tolerance, composite materials are now the preferred choice over traditional metals for some aircraft machine parts (Nor et al. 2018).

Composite materials made from natural fibers have gained popularity in current ages due to their durability and environmental friendliness. Natural fibers have cheaper production costs than their synthetic and carbon fiber counterparts; their densities are lower; their particular tensile properties are equivalent; they do not abrade equipment or skin; they use less energy; they pose less health hazards; and they can be renewed, recycled, and decomposed (Malkapuram et al. 2009). In addition, Recent studies have shown that natural fiber has the potential to be employed as reinforcing material in composites, ushering in an entirely novel phase of bio-composites that outperforms orientated Glass fiber reinforcement composites (GFRC) (Sanjay et al. 2015).

The main goal of this study was to enhance the consequence resistance of composite laminates. The selection of kenaf, a type of natural fiber, as a suitable material for reinforcement was based on their renewable nature and environmentally benign attributes. To comprehensively examine the range of potential outcomes, this study

utilized both chemically treated and non-treated kenaf fibers. Woven Jute fiber, as explored in this research study, is a natural and eco-friendly material that plays a major part in the development of hybrid composite laminates. Jute, obtained from the Corchorus plant, is renowned for its sustainability and versatility, making it a promising alternative to synthetic fibers commonly used in composite materials. In this investigation, Woven Jute fibers have been strategically integrated into composite laminates alongside the Kenaf and E-Glass fibers, with the aim of enhancing their mechanical properties and promoting environmentally conscious composite solutions. The strategic placement of fibers within the laminates constitutes a crucial part of this research. The Glass fiber, as a key component in hybrid composite laminates, plays a pivotal role in enhancing the mechanical properties and impact resistance of these materials. This research study explores the use of glass fibers, specifically E-Glass, in combination with natural fibers like Kenaf and Woven Jute, to create sustainable and eco-friendly alternatives to conventional composites. The composition was carefully designed as E-Glass-woven Jute-kenaf-woven Jute-E-Glass (GJKJG), with the intention of utilizing the combined advantages of these distinct materials. To assess their appropriateness for utilization in various sectors like automotive, aerospace, furniture, construction, marine, and sports equipment, a complete examination of Shore hardness was undertaken.

Understanding the behavior of composites under different situations and determining whether or not they are suitable for a certain application necessitates characterizing the materials. The Shore hardness test, which evaluates a materials resistance to an indentation, plays a significant role in this characterization. It's important because for companies where precision and uniformity are of the utmost importance, tests for Shore hardness are an indispensable quality control tool. These evaluations contribute in the design and optimization of a composite by providing insight into how it will perform under a variety of loads and environmental situations. Engineers can improve product efficiency and reliability by choosing the most appropriate materials for specific tasks by comparing their shore hardness ratings. By measuring the composites Shore hardness, one can gain insight into the materials resistance against wear, impact, or other forms of harm that occurs over time. This assessment replicates the effect of external forces on the laminates, resembling real-world situations, and offers vital insights into their ability to withstand damage and their potential as environmentally friendly options. In summary, the research provided in this study demonstrates potential for both enhancing our comprehension of composite materials and facilitating the development of environmentally friendly alternatives in vital sectors. The integration of equally natural as well as synthetic fibres, together with the strategic arrangement of their components, presents a promising pathway for advancements in materials engineering. Using Shore hardness testing as a framework, we cordially invite you to go on a scholarly expedition that delves into the realms of research, innovation, and the pursuit of sustainable progress.

1.1 Objectives

Mechanical characteristics and shore hardness are our main objectives in characterizing composite materials made of both synthetic and natural fibres. By intelligently blending natural and synthetic fibers, we attempt to find the best composition for material qualities. Through our research, we aim to develop sustainable, eco-friendly composite materials for numerous sectors. In conclusion, this study examines the manufacture and performance of precise-layered composite laminates. Shore hardness testing will assess these laminates impact resistance. This study helps utilise composite materials' potential and progress industrial industries sustainably.

2. Literature Review

In recent years, composite materials have gotten a lot of attention because they have great mechanical properties that make them useful for many engineering uses. Natural fibers like kenaf and woven jute have been looked at as possible replacements for manufactured fibers to make composites more sustainable and friendly to the environment. A hybrid composite refers to a specific category of composite material wherein many reinforcement threads are included into a singular matrix material. These reinforcement fibers can be made of natural fibers like woven jute or kenaf, manufactured fibers like fiber-E-Glass, or even metal fibers. Most of the time, the matrix material is a polymer resin like epoxy or polyester, or in the case of metal matrix composites, it is aluminum. The matrix material is what keeps the reinforcement fibers together. Most composite materials were made out of E-Glass fiber-reinforced polymer (GFRP) composites (Sathishkumar et al. 2014). The mechanical behavior of a fiber-reinforced composite depends on the mechanical properties of its constituent fibers, the strength of its matrix, the chemical stability of its matrix, and the strength of its interface bonds, which facilitate stress transfer (Erden et al. 2010). The characteristics of the component components, the fibers, and the resin utilized determine the composite materials (Mitra 2014). The increasing concerns of the environment regarding the escalation of fuel

costs, the exhaustion of fossil fuel resources, and the phenomenon of global warming have prompted a surge in the utilization of woven Jute fibers as a means of reinforcement in the advancement of composite materials. The aforementioned concerns have prompted researchers to direct their attention towards green composites (Singh et al. 2018). The most often utilized natural fiber is woven jute. Because of its great lignin content (up to 12–16%), woven jute has a low extension to break and can grow up to 3.5 meters in height. It is also extremely fragile. The fibers of woven jute are less resistant to UV radiation, acid, and moisture (Singh et al. 2018). Woven fibers perform better than non-woven fibers in the mechanical behavior during hardness tests.

A naturally occurring fiber, kenaf is derived from the *Hibiscus cannabinus* plant. It is becoming more and more well-liked as a reinforcing material for hybrid composites, which are composites created by mixing two or more distinct kinds of reinforcements or fibers. To create a material with improved performance and features, hybrid composites use kenaf to blend the advantages both natural and synthetic fibers. It has favorable characteristics under tension stress circumstances in addition to other outstanding qualities including high specific strength and modulus, non-abrasiveness, low density, and affordability (Ribot et al. 2011 and Oksman et al. 2003).

In composite materials, the E-Glass fiber is frequently utilized as a reinforcing element. By modifying the fiber stacking order, the kind of polymer matrix, and the overall composite architecture, the properties of the E-Glass fibre composite can be altered. This adaptability enables producers to develop composite materials with particular properties that are ideal for the purposes for which they are intended.

A material's ability to resist distortion, in particular its ability to tolerate persistent deformation, can be determined by hardness testing. To do this, an indenter is pressed into the surface of the material and the depth or dimension of the resulting indentation is measured (ASTM D785 2015). The toughness value of a composite material can be affected by the composition and qualities of the material used for reinforcement and matrix (Bhatnagar 2022). Most of the time, the hardness of composites dropped a little when they were exposed to UV light or cold temperatures, but in some cases, the drop was small (Garbacz and Dulebova 2017). Testing the Shore hardness of woven composites including glass fiber composites, kenaf, and jute is crucial for determining their mechanical properties. In the context of determining surface hardness, Shore hardness conventionally involves assessing whether a test surface is susceptible to scratching by one of the prescribed mineral requirements (Akbay and Ekincioglu 2021). Shore hardness measurements are frequently used in the plastics sector to evaluate surface strength; nevertheless, test findings show that different materials have different sliding qualities and wear resistance despite having comparable Shore hardness (Pieniak et al. 2023). The Shore hardness range consists of two distinct categories, namely Shore A for materials with lower hardness levels and Shore D for materials with higher hardness levels (Wang et al. 2023).

The Shore D test can often give important information about the hardness of materials that are 3D printed and be used to describe the characteristics of their performance and quality (Palacios et al. 2023). The determination of hardness involves measuring the depth of an indentation caused by a rigid ball subjected to either a spring force or a dead load. This indentation is then quantified and transformed into hardness degrees, which are represented on a scale ranging from 0 to 100. On the hardness scale, a value of 0 indicates rubber with an elastic modulus of zero, while a value of 100 indicates rubber with an elastic modulus of infinity (Balcioğlu 2019). The transverse fiber strand stiffness of textiles is measured using Shore hardness in the context of textile-reinforced concrete. Higher Shore hardness values indicate stronger bond strength. A fabric's ability to adhere to concrete is proportional to its Shore hardness (Beßling et al. 2022). In comparison to untreated fiber composites, composites with chemically treated fibers often had better hardness (John et al. 2008).

3. Methodology

Both treated and untreated kenaf fibres and woven jute fibre were used in the laminate preparation process. For a continuous eight hours, kenaf fibres were submerged in 6% NaOH solution as part of the chemical treatment (Figure 1). As the concentration of the NaOH solution increases, fracture strain exhibits an increase from $1.55 \pm 0.21\%$ to $1.91 \pm 0.18\%$, while the mechanical properties of the composite laminates demonstrate an initial increase followed by a subsequent decline. The fibres were first sun-dried (Figure 2), at which point they were placed in a vacuum oven (Figure 3) for 24 hours at 80.2 degrees Celsius to remove moisture and reduce cellulose and lignin. This painstaking procedure successfully produced fibres free of contaminants. The fibres were hand-combed

precisely to remove any short ones, guaranteeing their high quality. The fibres were evaluated and prepared for lamination after some time.



Figure 1. Chemical treatment process on the kenaf fiber



Figure 2. Drying fibers in sunlight



Figure 3. Drying in the vacuum oven

There were two different sizes of molds used: (29 x 18 cm) and (16 x 12 cm). The matrix was secured in the mold with polypropylene paper and double-sided tape. The epoxy resin to hardener ratio was 10:1. The matrix's weight percentage was decided upon as the initial step in its creation (20% or 25%). The following Table 1 shows the amount of matrix used for each mold type, as well as the percentage of mass made up of Woven Jute, Kenaf, and E-Glass fiber.

Table 1. Mass percentages of fibres and matrix

Types of composites	Woven Jute Fibre Percentage	Kenaf Fibre Percentage	Fibre E-Glass Percentage	Epoxy Percentage	Hardener Percentage
20% Raw Fibre	7	7	86	90	10
20% NaOH treated Fibre	7	7	86	90	10
25% Raw Fibre	7	7	86	91	9
25% NaOH treated Fibre	7	7	86	91	9

The laminates were fabricated according to the percentages (Figure 4). With a 10:1 ratio, the exact amount of epoxy and hardener was injected into each layer of fibre. Then, molds were placed on both sides and the blended fibres were gently wrapped in polypropylene paper. Polythene was used to tightly wrap the assembly to prevent any movement of the matrix. After that, samples were kept in a compression molding machine. The hard composites were examined after the molds had been in the compression molding for 24 hours (Figure 5). The composites had a good surface polish and proved to be sufficiently hard. Their thickness was then measured after that.



Figure 4. Fabrication of composites

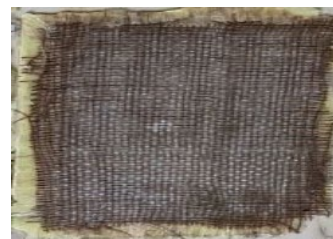


Figure 5. Composites after 24 hours in compression molding

Shore hardness is a measure of how challenging a material is to penetrate with a spring-loaded needle-like indenter. There is a scale for evaluating soft materials, including elastomers. 8 lbs are the loading forces on Shore D. Values for beach hardness fall between 0 and 100 (Figure 6). Maximum penetration varies from 0.097 to 0.1 inch across the various scales. A Shore hardness of 0 corresponds to this value. The maximum hardness value of 100 corresponds to zero penetration. The samples were cut according to the standard of ASTM D2240 with the help of laser cutting (Figure 7).



Figure 6. Conducting Shore D hardness Test



Figure 7. Hardness Specimen Sample

4. Results and Discussion

Shore hardness, or in this case, Shore D hardness is a measure of how hard a material is when a sharp indenter tries to penetrate or make a mark on its surface. It's frequently applied to evaluate the stiffness or hardness of elastomers, polymers, and various other non-metallic materials. On a scale from 0 to 100, Shore D hardness is represented as a numerical value; higher values denote greater stiffness or hardness. In Table 2, Demonstrates the Average Hardness (Shore D) for 20% and 25% weight fractions for raw and treated composites.

Table 2. Categorized values of shore D hardness result of different types of composite materials

Specimen designation	Hardness values of composites Samples	Hardness (Shore D)	Average Hardness (Shore D)
20% weight fraction Raw fiber composite	S1	94.5	94.83
	S2	95.16	
25% weight fraction Raw fiber composite	S1	94.5	95.58
	S2	96.6	
20% Treated (NaOH) fiber composite	S1	96.4	96.17
	S2	95.95	
25% Treated (NaOH) fiber composite	S1	96.16	96.66
	S2	97.16	

These results showed that the composites made of raw fibers with 20% and 25% weight fractions Shore D hardness 94.83 and 95.58. But in the case of composites made of NaOH-treated fibers with 20% and 25% weight fraction, The Shore D hardness values were 96.17 and 96.66. It was observed that for treated cases, 20% and 25% weight fraction exhibit better results. The highest Shore D hardness value for 25% treated fiber weight fraction hybrid composite was found 96.66. It demonstrates that hybridizing of chemically treated natural fibers with synthetic

E-glass fibers improves the hardness properties to multiple orders with respect to the same configuration of hybrid composites having same natural fibers but chemically untreated. So, increase of fiber weight fraction, the Shore D hardness increased significantly since more fiber content made the composite stiffer which quite rigid and durable. Figure 8 shows the hardness we get from 20% and 25% weight fraction of both treated and untreated fibre composites.

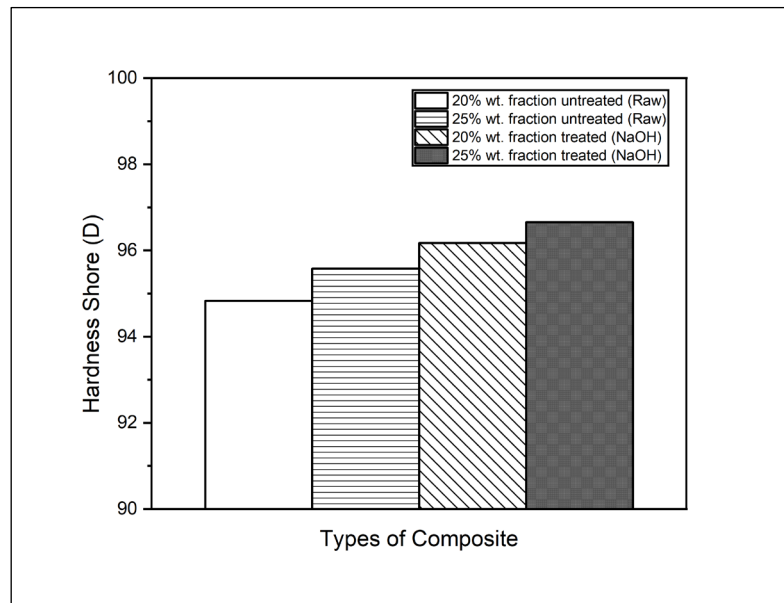


Figure 8. Hardness Shore D results of treated and untreated fibre composites

The fibers used to make the composite laminates can either be raw or treated (NaOH) before being bonded together. The percentages 20% and 25% denote the fiber weight fractions of the composite materials. Here's a discussion of the results is provided:

- Raw vs. Treated (NaOH): For each 20% and 25% weight fractions, treated (NaOH) has better shore hardness than raw. This suggests that NaOH treatment increases composite laminate hardness.
- Weight Fraction Effect: Comparison of raw or treated (NaOH) conditions at different weight fractions shows that 25% has somewhat higher shore hardness than 20%. This suggests that composites with more fiber are harder.
- Implications: Shore hardness indicates the composite laminate stiffness. Stiffness-sensitive applications like structural components prefer higher shore hardness ratings. NaOH treatment increases composite hardness, which may make them better for specific applications. The influence of the weight fraction upon shore hardness implies that fiber content can control composite mechanical characteristics.
- Further Analysis: Tensile testing can link shore hardness to various mechanical parameters as tensile strength as well as modulus of elasticity.

Shore hardness measures material stiffness, and our results show that both chemical treatment as well as weight fraction affect the composite laminate hardness. To obtain more definitive conclusions, compare shore hardness ratings for different fibre types and perform further mechanical testing to assess these composites performance.

5. Conclusion

In conclusion, the shore hardness study conducted on woven E-Glass, Woven Jute, and Kenaf Hybrid Composite Laminates has yielded significant findings. Notably, the treatment with NaOH was observed to enhance the composite laminate shore hardness consistently, surpassing the raw condition across weight fractions. Moreover, a general trend indicated that 25% weight fractions exhibited slightly greater shore hardness compared to 20%, highlighting the influence of fiber weight percentage on composite laminate hardness and stiffness. Although not explicitly stated in the data, variations in shore hardness among glass, jute, and kenaf fibers were likely observed, offering valuable insights for material selection in specific applications. This research underscores the utility of

shore hardness testing for evaluating composite laminates, enabling assessments of material stiffness and hardness, comparisons between treated and untreated fibers, and the optimization of fiber weight fractions for tailored mechanical properties. The implications of this study are far-reaching, spanning industries such as sports, automotive, construction, marine, aerospace equipment, and sustainability efforts, fostering innovation and eco-conscious material choices while advancing the field of material engineering.

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Biographies

Amartya Biswas is an aspiring undergraduate student pursuing a B.Sc. in Mechanical Engineering at Ahsanullah University of Science and Technology. His passion for innovation and curiosity led him to delve into the world of research, focusing on three dynamic areas: Composite Materials, Advanced Manufacturing, and Supply Chain. Amartya's dedication to these fields showcases his commitment to shaping the future of engineering and technology.

Mahbubur Rahman is a final-year undergraduate student at Ahsanullah University of Science and Technology, pursuing a B.Sc. in Mechanical Engineering. His academic journey has been defined by a profound interest in the intricacies of Mechanical Properties, Mechanics of Materials, Mechanical Behavior of Materials, and Mechanical Engineering Design. With a passion for understanding and improving the fundamental aspects of materials and mechanical systems, Mahbubur is poised to make significant contributions to the field of mechanical engineering through his research endeavors.

Ibrahim Uddin Bhuiyan earned his bachelors degree in Mechanical Engineering from Ahsanullah University of Science and Technology (AUST) in 2022. He is currently pursuing a masters degree in Nuclear Power Engineering at Bangladesh University of Engineering and Technology (BUET). He is working as a Graduate Engineer Trainee (GET) at Tex Fastener. His research interests span composite materials, computational fluid dynamics (CFD), electronics circuits, internet of things (IoT), Arduino projects, and nuclear waste management.

Md. Mashuk obtained his undergraduate degree in Mechanical Engineering from Ahsanullah University of Science and Technology (AUST) in the year 2022. His academic pursuits reflect a keen interest in a wide spectrum of disciplines, including composite materials, automotive engineering, materials science, 3D modeling design, simulation and machine learning. He wants to carry out a lot of research in areas like sustainable product design, electric vehicles, additive manufacturing and so on.

Mushfiqul Moula graduated on Mechanical Engineering from the Ahsanullah University of Science and Technology in 2022. His broad range of scientific interests includes design engineering, fluid mechanics, composite materials, automotive engineering, and mechatronics. Using a multidisciplinary approach, he can produce significant advances in a variety of sectors, including fluid systems, automotive technologies, mechatronics, design processes, and the development of novel materials.