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Effect of various nano-particles and surface treatments on the mechanical properties of jute basalt fiber reinforced epoxy-based composites: a review

P. Gulati[1], J. Inder Preet Singh[1*], V. Sharma[2*], J. Shekhawat[1], P. Prabhath Chowdary[1], A. Kumar Sharma[3]

[1]*School of Mechanical Engineering, Lovely Professional University, Phagwara, India*
[2]*Professor (Research), University Center for Research and Development (UCRD), Chandigarh University, Mohali, Punjab, India*
[3]*Department of Mechanical Engineering, Manipal University, Jaipur, India*

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Depletion of fossil fuels, global warming, carbon footprints on the environment are the major issues leading to the requirement for sustainable materials. Researchers are endeavoring to develop the green polymer composites for various structural and non-structural applications. Lots of research studies are going on for the surface improvement of natural fibers with the help of various surface treatments. For further improvement in the mechanical properties, nano particles are also used as reinforcements in the polymer composites made by natural fiber reinforcement. Still a lot of research is further required which replace synthetic composites with green polymer composites due to their biodegradability and sustainability concerns. This review aims to give more insight into the adoption and effect of methods used for surface treatment and the use of nano particles on the mechanical properties of jute/ composites made using epoxy with basalt reinforcement.

Keywords: nanoparticles, natural fibers, polymer composites, mechanical properties, jute fiber, basalt fiber, surface treatment

INTRODUCTION

A composite material has characteristics that are significantly different from those of its constituent materials when it is formed using multiple materials having varied physical as well as chemical characteristics The first uses of composites date back to 1500 B.C. when the Egyptians and Mesopotamians made use of straw and mud in the construction of houses and buildings. These composites have stood the test of time, with continual improvements and advancements to enhance their strength and usability. Over the years, new technologies and techniques have been developed to make these traditional materials more durable and sustainable. Straw and mud composites offer a natural and eco-friendly alternative to modern building materials. They are readily available, inexpensive, and have excellent insulating properties. Additionally, they have a low carbon footprint, making them a popular choice for environmentally conscious construction projects [1]. Over the years, traditional materials like steel, concrete, and timber have been widely used for various construction and development purposes. However, as society has become more aware of the importance of sustainability, there has been a shift towards utilizing composite materials in different applications. Composites offer numerous benefits, such as being lightweight, strong, and corrosion-resistant, making them ideal for a wide range of uses. The introduction of natural fiber-reinforced polymer composite materials has come as a timely solution to the need for more sustainable and environmentally friendly alternatives. With their high mechanical properties, natural fibers show great promise in potentially replacing conventional composites. Developmental efforts are under process to explore the possibilities of obtaining polymer composites by reinforcing with natural fibers that are not only effective but also eco-friendly.

Natural fibers are derived from various sources such as jute, flax, kenaf, banana, many more, each with its unique characteristics. These fibers are of biological origin, emphasizing their biodegradability and renewability, making them a preferred choice in today's environmentally conscious world. Moreover, natural fibers offer high specific strength and modulus, processing flexibility, low self-weight, cost-effectiveness, and significant resistance to corrosion and fatigue. The development and utilization of natural fiber-reinforced polymer composites represent a significant step towards sustainable materials that

* To whom all correspondence should be sent:
E-mail: jaiinder.14740@lpu.co.in

do not compromise on performance. As research in this field progresses, innovative applications of natural fibers are expected in various industries, contributing to a greener and more sustainable future [2]

Strong reinforcing fibers held together with cost-effective, tough, environmentally durable resin systems showed immense potential. Being lightweight made it exceptional reinforcement for already deteriorating conventional structures. Increased durability, controllable thermal properties, tailored performance were among other benefits [3]. High moisture absorption, high anisotropy, poor compatibility with traditional resins, and lower homogeneity than glass and carbon fibers are a few disadvantages [4].

The strength of composites depends highly on the adhesion between fiber and polymer matrix. Fiber surface treatments are performed to shield the fibers from mechanical harm and to increase fiber-matrix adhesion. Different kinds of surface treatment have different effects on the properties of fiber [5]. [6] discussed the issue of poor compatibility of natural fibers hydrophobic polymer matrices and the solution, i.e., greener surface treatments using different alternatives such as plasma treatment, use of enzymes, use of fungi, coating natural fibers with nanocellulose. To improve the interfacial strength and bonding between natural fibers and the matrix material, [7] applied surface treatment techniques such as alkalization and mercerization. According to this study, if a fiber has good matrix compatibility, its mechanical characteristics will improve as needed for various applications. Figure 1 represents the classification of various natural fibers [7].

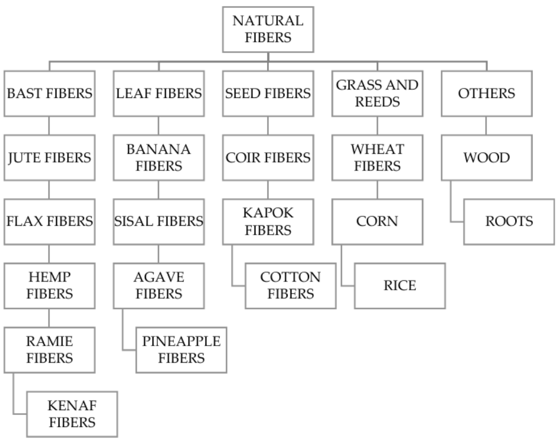

Figure 1. Classification of various natural fibers [7]

Composites made of a polymer matrix with functional nanoparticles added as fillers have been popular for a few years. A variety of nanoparticles such as silicon carbide, silica, calcium carbonate, zinc, alumina, carbon black nanoparticles, etc. are being used for reinforcements in the fabrication of composite materials [8]. Nanoparticles can enhance and even change the properties of composites (including optical, dielectric, electronic, magnetic, and mechanical) [9]. [8] Used basalt nanoparticles on basalt epoxy composites. Compared to traditional basalt fiber epoxy-reinforced composites, these composites demonstrated better mechanical characteristics. This is explained by the fact that there is an enhanced force of friction between the matrix and nanoparticles, which causes a higher mechanical interlock of the composite system. To create nanocomposites that can withstand hard environments and reduce the danger of fire accidents, [10] treated basalt/epoxy composite tubes, neat epoxy, and filament-wound E-glass/epoxy tubes with silica nanoparticles. The addition of silica nanoparticles (less than or comparable to 1.5 wt %) to the neat epoxy and FRP composites resulted in an improvement in the flexural and thermal properties [11]. Treated coir-basalt-innegra fibers reinforced bio-synthetic epoxy composites with coir micro-particles and titanium carbide (TiC) nanofillers. The best results for flexural strength (4.43 times pure bio epoxy composites) were found when synthetic epoxy composites were treated with 5% micro-fiber of coir and 5% nanoparticles of TiC.

In recent times, basalt and jute fibers have emerged as key players in the world of natural fibers. Basalt fiber has become a popular choice due to its ability to create cost-effective hybrid materials with impressive qualities. Its exceptional heat resistance, capable of withstanding temperatures up to 600°C with minimal weight loss, makes it a sought-after material for various applications. Additionally, basalt fiber boasts sophisticated mechanical properties, further enhancing its appeal in industries looking for durable and reliable materials. By harnessing the potential of basalt fiber, manufacturers can develop innovative products that meet the demands of modern technology and construction. As sustainability and efficiency have become increasingly important, the versatility and performance of basalt fiber make it a promising contender in the natural fiber market [12] Jute is a natural fiber with properties similar to basalt fiber, making it a popular choice for various applications. Not only is jute cost-effective and strong, but it is also biodegradable and sustainable, making it an environment-friendly option. Additionally, jute can absorb more energy, making it a material, trustworthy for different purposes. One of the advantages of jute is its abundance in nature, ensuring a steady supply for industries. Furthermore, jute burns cleanly and releases no carbon dioxide, further adding to its eco-friendly profile. Overall, the unique properties of jute make it a versatile and practical choice for a wide range of products and industries, contributing to a more sustainable and greener future [13]. But jute has a major drawback, i.e. low impact strength as compared to other counterparts.

Composites are widely recognized for their versatility and strength, making them vital components in various industries in today's world. The increasing demand for composites underscores the importance of exploring continuous advancements in this field. This comprehensive study delves deep into the intricate fundamentals of composite materials, with a particular emphasis on natural fiber composites like basalt and jute fibers. These natural fibers, with their exceptional properties and eco-friendly characteristics, have generated significant interest from researchers. The current research meticulously scrutinizes the unique properties of basalt and jute fibers individually, while also delving into the enormous potential of combining them to create jute basalt composites. By closely examining the chemical and mechanical properties of these fibers, the researchers aim to gain insights into how these materials can be effectively applied in a wide array of applications. Moreover, the study underscores the critical role of surface modification in increasing the complete performance of composites. Various methodologies for surface modification are thoroughly discussed, including the incorporation of nanoparticles to further elevate the properties of composites to new heights. Through an exploration of diverse nanomaterials and their potential applications, the researchers aspire to push the boundaries of composite technology, unlocking innovative possibilities. Furthermore, the research elaborates on the different methodologies employed in composite development and envisions potential advancements on the horizon. By continuously striving for innovation and staying abreast of emerging trends, researchers are opening doors to new avenues for polymer composites, ensuring their sustained growth and evolution in our rapidly changing world.

Based upon the source, natural fibers can be categorized as animals such as wool from sheep, camel, goat, rabbit, horse, and angora, and plants such as seed fiber cotton, kapok, akon, rice & husk, bast fiber as flax, hemp, jute, ramie & husk, leaf fiber as sisal, plam, manila, carua & abaca, hard fiber as agave, banana & coir, bamboo, wheat, rice, grass & corn and mineral as asbestos, basalt & mineral wool [14-15].

Jute fiber

- *Origin of jute fiber.* When it comes to the industrial and engineering applications of textiles, jute (*Corchorus capsularis* L. and *C. olitorius* L.; *Malvaceae* s. l.) may be the most versatile natural fiber crop [16]. There are 40 to 100 species of Corchorus, which can be found in warm climates on every continent as well as many tropical and subtropical areas [17]. The juvenile fibers can be easily identified between the starch sheath and the wood if a transverse piece of a young internode of Corchorus is cut off. While the fibers in jute are created as a secondary growth from the cambium itself, the flax fibers start as a part of the original stem structure in the cambium, formed straight from the primary tissue. While none of the bast cells created by the cambium thicken in flax, some do in jute, and these result in the jute fibers [18].

Jute fiber, renowned for its illustrious past, reaching back to ancient civilizations, has been predominantly cultivated in the fertile Ganga-Brahmaputra delta of the Indian subcontinent. The transformative establishment of jute mills in the bustling city of Kolkata, a pivotal moment during the mid-1800s, marked a turning point in the jute farming industry, propelling it towards remarkable commercial success. The industry witnessed an unprecedented surge in demand for jute sacks when the Netherlands commissioned substantial quantities for the transportation of coffee beans to the flourishing East Indian Plantations in 1838. The intrinsic essence of jute fibers journey resonates with the essence of innovation, adaptation, and sustainability, underscoring its enduring relevance in a rapidly evolving industrial landscape [19] But as early as 1575, references to jute sacking bags can be found in regional literary works [17].

- *Microstructure of jute fiber.* Jute stands out as a remarkably versatile multicellular fiber, highly revered across numerous industries for its unparalleled strength and utility. This exceptional attribute is intricately woven into the very essence of jute, deriving from the meticulous construction of the cylindrical sheath that envelopes it. The process of imbuing jute with such formidable characteristics involves a remarkable convergence of individual fibers, aptly known as reed within commercial circles. These fibers seamlessly interlock to form a robust three-dimensional network within the jute plant's stem, a process that underscores their pivotal role within the plant's ecosystem. Despite constituting only, a modest fraction—typically ranging between 4-6%—of the entire plant, these fibers hold immense significance, showcasing the plant's remarkable ability to produce these resilient strands. Stretching impressively between 1.5 to 3 m in length when bundled together, the reed fibers eloquently display the plant's inherent capacity to generate such enduring materials. After undergoing the meticulous retting process, these distinct reed segments emerge prominently, offering a stark contrast to the plant's woody components and thereby revealing the unique and unmistakable characteristics of jute fibers. The cross-section and microstructure of jute fiber comprises of the lumen, micro-fibrils, cell wall, primary wall and secondary wall, etc. [20].

- *Extraction of jute fiber.* Extraction of jute can be done using two major methods microbial retting and chemical retting [21].

Jute retting mechanism. The process of fermentation in plants is not only captivating but also incredibly complex, unfolding with a series of intricate steps that showcase nature's ingenuity. Starting with the plant's absorption of water and subsequent swelling, the stage is set as it eventually bursts open, unveiling a treasure trove of sugars, glucosides, and nitrogenous compounds. This pivotal moment heralds the arrival of microorganisms, eager denizens residing in both the plant and the water, ready to partake in a feast of nutrients. These microscopic organisms, with their insatiable appetite, embark on a transformative journey where they meticulously break down the plant's rich organic tapestry. Proteins, hemicelluloses, pectin, and sugars succumb to the enzymatic prowess of these tiny conquerors, unraveling into simpler compounds that fuel the microcosmic ecosystem within. As the symphony of fermentation progresses, the sugars gracefully bow out first, leading the way for the degradation of pectin, hemicelluloses, and nitrogenous substances to follow suit. Ultimately, the grand finale of fermentation in plants unfolds as a harmonious natural process, a vital cog in the machinery of ecosystem balance. A cycle where organic matter finds renewal, microorganisms find sustenance, and the intricate dance of life continues unabated [21].

Microbial retting. The primary obstacle to retting jute with high-quality fiber production is the availability of high-quality retting water. Retting requires a significant amount of fresh water. Taking this into account, numerous innovative retting techniques were created that used much less water than the conventional retting technique. These newly developed enhanced retting techniques work in tandem with microbial formulation [22]

Chemical retting. Chemical retting is a process used to extract fiber from jute ribbons by dissolving the cementing substance with specific chemicals. This method results in stiffer and slightly coarser fibers with a rougher feel compared to microbial retting. The gravimetric fineness values of fibers from both processes are similar, but after drying, the fibers require hand rubbing to reduce stiffness. Additionally, a cationic softener can be used on up to 0.2% of the fiber's weight to further soften the strands. Ammonium oxalate and sodium sulphate have been identified as suitable chemicals for this process. While chemical retting allows for controlled fiber extraction without altering the fiber's characteristics, it is costly and impractical for field use by cultivators. Despite these drawbacks, the fiber's quality remains unaffected by the process [21].

- *Chemical composition of jute fiber.* Jute, a type of bast fiber, is primarily composed of cellulose, lignin, and hemicellulose, all extracted from the bark of the jute plant. Cellulose makes up most of the jute fiber at 58-63%, providing strength and durability. Lignin, comprising 12-15%, adds rigidity and helps bind the cellulose units together. Hemicellulose, at 20-24%, also contributes to the structure and strength of the fiber. Additionally, jute contains small amounts of lipids, pectin, aqueous extract, and other substances. This unique combination of chemical components gives jute its desirable properties, making it a valuable resource for various applications in industries such as textiles, packaging, and construction [23]. Table 1 shows the mechanical properties of jute fibers.

Mechanical properties of jute fiber

Table 1. Mechanical properties of jute fiber [24-25]

Property	Value
Mean elastic modulus	30GPa
Fiber Strength	2455MPa
Interface strength	83MPa
Young's modulus	10-30GPa
Tensile strength	393-800MPa
Elongation	1.5-1.8 %
Density	1.46(g/cm^3)

Basalt fiber

Basalt rock, formed from solidified magma at temperatures between 1500-1700 °C, is the key ingredient used to produce basalt fiber. This fiber, known for its exceptional heat resistance, stability, and vibration properties, is considered an environmentally friendly product. The process involves extracting basalt rock, composed of frozen lava, and finely separating it into fibers known as basalt fibers. These fibers are predominantly made up of plagioclase and pyroxene, which together account for 80% of its composition. The use of basalt fiber in various industries has been on the rise due to its unique properties and environmentally friendly nature [26-27].

- *Extraction of basalt fiber.* Extraction of basalt fiber includes grinding, washing, melting, drawing, winding processes employed with suitable equipment. Figure 2 represents the plant layout of basalt fiber production [28].

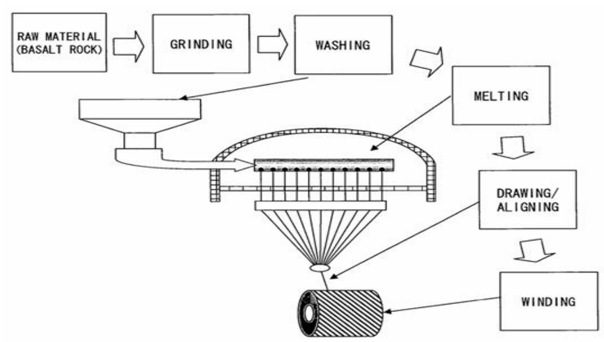

Figure 2. Plant layout of basalt fiber production (open access) [28]

- *Chemical composition and mechanical characteristics of basalt fiber.* Basalt fiber is rich in the oxides of Mg, Ca, Al, Si and having high percentage of SiO_2 and Al_2O_3 33.3% of basalt is a copious mineral. Table 2 below represents the compositions in detail [29]. The mechanical characteristics of basalt fiber are represented in Table 3.

Table 2. Chemical composition of basalt fiber [29]

K_2O	1.46%	Cr_2O_3	0.06%	Na_2O	3.34%
TiO_2	1.38%	SiO_2	52.8%	CaO	8.59%
P_2O_5	0.28%	Al_2O_3	17.5%	MgO	4.63%
MnO	0.16%	Fe_2O_3	10.3%		

Table 3. Mechanical characteristics of basalt fiber [30-31]

Property	Value
Elongation at break	3.15%
Tensile strength	4.84GPa
Density	2.65g/cm^3
Maximum service temperature	650°C
Elastic modulus	89 Pa

- *Nanoparticles in polymer composites (jute & basalt).* The addition of nano particles as reinforcing agents in the polymer composites gives better electrical, optical, and mechanical properties [32].

Nano materials are classified based upon following parameters:

a) Carbon based such as fullerenes, graphene, carbon black, carbon tube, carbon fiber; organic such as ferritin, micelles, liposomes, dendrimer.
b) Inorganic such as metal based, metal oxide, lipid based, ceramic, semiconductor.
c) Based on number of dimensions classified such as 0, 1, 1, pore dimension such as microporous, mesoporous and macro-porous.
d) Based on origin such as artificial and natural based on potential toxicity CMAR, bio persistent granular & fiber like [33].

Uses of nanoparticles in various polymer composites

Functionalized nanoparticle-loaded nano-composites have emerged as a highly promising technology in terms of property improvements. These materials are garnering considerable attention in scientific circles due to their unique ability to enhance various properties even at low particle concentrations. This remarkable characteristic has made them a popular subject of study, leading to an influx of research articles detailing their applications and benefits. These materials have proven their mettle in a wide array of power-related processes, exhibiting exceptional performance metrics that point towards a transformative impact on various industries [34]. The automotive, aerospace, marine, and construction industries are becoming increasingly interested in fiber-reinforced polymer composite materials (FRPs) because of their exceptional mechanical qualities, adaptability, and exceptional resistance to fatigue and corrosion [35].

Table 4 represents various nanoparticles used as reinforcement particles to enhance the properties of polymer composites: [36] evaluated the effects different nano particles on mechanical properties, flammability and thermal degradation of polyester/jute fiber composite. The graphical abstract representing the methodology of composite fabrication along with the results are depicted in Figure 3 [36].

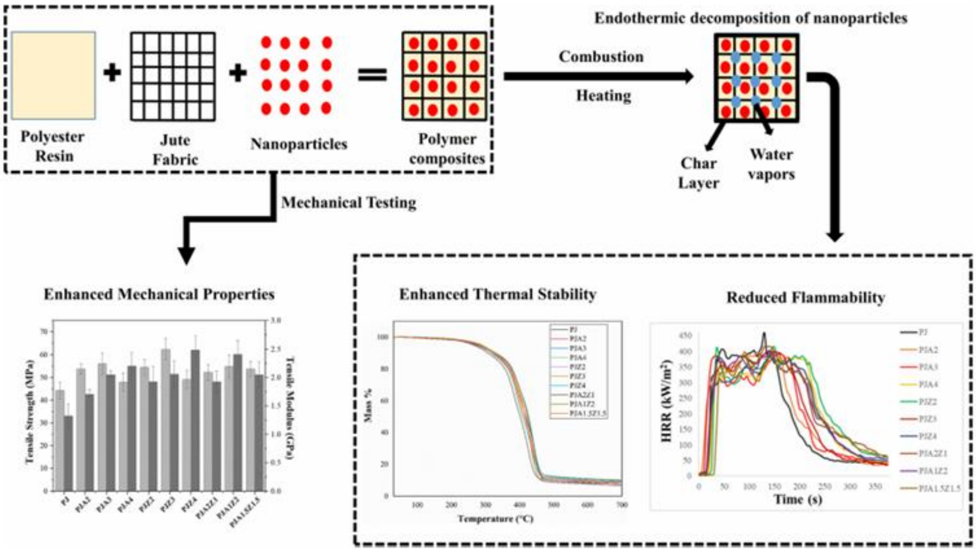

Figure 3. Graphical abstract representing the effects of various nanoparticles on different properties of polymer composites (open access) [36]

Table 4. Effects of various nanoparticles on mechanical properties of polymer composites

Nano-particles	Concentration	Composite materials	Conclusion	Reference
$Al(OH)_3$, $Zr(OH)_4$	2%, 3% and 4%	Polyester/jute composite	The results demonstrated that adding three weight percent of either kind of nanoparticles significantly improved the polyester/jute composite's tensile, flexural, and impact characteristics.	[36]
SiO_2	5%	Basalt/ epoxy	When compared to a pure epoxy coating, the SiO_2 epoxy nanoparticle composite coating significantly increased the tensile strength of the fibers of basalt. Additionally, the coating gave the fibers of basalt a promising interfacial property in the resin matrix composite reinforced by the basalt fibers.	[37]
ZrO_2	10%, 15%, 20%	Polyether-etherketone / carbon fiber	In a composite with 70% PEEK, 20% carbon fiber and 10% ZrO_2, maximum tensile strength and young's modulus was observed.	[38]
Graphene	0%, 1%, 3%, 5%	Carbon fiber	Maximum performance was observed at the optimal value of 3 weight percent GnPs, where improvements in modulus and flexural strength of 16.8% and 16.2%, respectively, were attained.	[39]
SiO_2	0%, 5%, 10%, 15%	Jute/polyester	10% silica powder, 10% jute and 80% polyester showed increased mechanical properties.	[40]
ZnO_2	0.5%, 1%, 3%, 5%	Jute/ epoxy	Of all these specimens, the compound that is 3weight% ZnO_2-filled has the best qualities. In the short-beam shear test, adding ZnO_2 to the composites increased the compressive property by 43%.	[41]
Silica and clay	0%, 1%, 2%, 3%	Rice straw/ polypropylene	Addition of up to two weight percent of nano clay increased the flexural and tensile moduli. Nevertheless, noted qualities reduced after this point. Reduced interfacial adhesion between the matrix polymer and filler is typically caused by high concentrations (3 weight percent) of nanoparticles in composites, which restricts their potential uses.	[42]

SURFACE MODIFICATION OF FIBER

In recent years, researchers have shifted towards using natural fibers instead of synthetic ones due to their advantages such as lower density, easy availability, and cost-effectiveness. However, natural fibers do have certain limitations when used in composites, including poor compatibility and drawbacks. To address these challenges, various surface modification techniques have been developed. These techniques play a crucial role in enhancing the performance and durability of natural fiber composites. By modifying the natural fibers' surface, researchers have shown the improvement in their compatibility with other materials, enhance their mechanical properties, and increase their environmental resistance factors. This advancement in surface modification techniques has allowed for the broader and more efficient use of natural fibers in various industries, contributing to the sustainable development of materials and reducing the reliance on synthetic fibers [43].

Alkali treatment

Treating the surface of natural fibers is an essential practice that significantly enhances their ability to bond with the polymer matrix in composite materials. Among the array of treatments available, alkali treatment, which involves the use of sodium hydroxide (NaOH), stands out as a highly effective and economical option. This specific treatment method operates by effectively eliminating lignin, pectin, hemicellulose, and oils present on the fibers, thereby greatly improving their affinity to the matrix through interactions with cellulose molecules. The successful outcome of the alkali treatment process hinges on several key factors, which include the concentration of sodium hydroxide, the duration of the treatment, and the temperature at which it is carried out.

In essence, the alkali treatment utilizing sodium hydroxide should be viewed as a fundamental step in the enhancement of natural fibers for composite materials. By ridding the fibers of impurities and enhancing their bonding capability with the polymer matrix, this treatment methodology not only ensures superior mechanical characteristics but also contributes to an overall elevation in the quality and performance of the composite material as a whole.

Cell - OH + NaOH ⇒ Cell- O^- Na^++H_2O+ surface impurities (Mohanty *et al.,* 2001) (1)

Benzene treatment

The process of treating raw fiber with a solution containing sodium hydroxide (NaOH) and O-hydroxy benzene diazonium represents a significant advancement in the enhancement of mechanical characteristics when equated to leaving the fiber untreated. By immersing the raw fiber into the NaOH solution first and then subsequently applying the diazonium solution, a remarkable transformation takes place within the fiber structure, leading to a notable increase in its strength and durability. This method involves subjecting the fiber to a precise sequence of treatments that optimize its physical characteristics for industrial applications that demand superior mechanical properties.

The processed jute fiber, once dried, demonstrates exceptional enhancements in its mechanical attributes, making it a desirable material for a wide range of industrial applications that require high tensile strength and durability. The successful completion of this treatment process underscores the pivotal role of chemical interventions in heightening the intrinsic qualities of raw fiber, thereby unlocking its full potential for various industrial uses. This sophisticated treatment method underscores the importance of leveraging chemical processes to elevate the functional properties of raw fiber, paving the way for broader applications across multiple industries that rely on robust and resilient materials [44].

Glycine treatment

The process of applying aqueous glycine onto untreated fiber strands serves as a crucial preliminary step in assessing and understanding the characteristics of the fibers thoroughly. Researchers engage in subjecting these untreated fiber strands to varying concentrations of glycine for a duration of 1.5 h at a temperature of 100 ºC, enabling them to closely observe and analyse the interaction dynamics between the fibers and the glycine solution. Moreover, by conducting tests on the samples using four different pH values and maintaining a consistent mass to liquid ratio of 1:20, researchers gain a comprehensive and in-depth insight into how the fibers behave under diverse environmental conditions.

Post-treatment, once the samples have undergone the glycine application process, they are meticulously dried in an oven at a constant temperature of 50 degrees for a duration of five hours. This significant observation underscores the essential role that both pH levels and glycine concentrations play in influencing the efficacy and outcomes of the glycine treatment on the fiber strands, offering valuable insights for further research and development in this area [45]. Figure 4 represents the various treatments of the jute fibers [45].

Silane treatment

The cellulosic fibers, renowned for their inherent qualities in the natural realm, were subject to an intricate treatment process characterized by the meticulous application of a 3% concentration of a specific silane in an ethanol/water solution with an 80/20 v/v ratio. This elaborate treatment plan, impeccably carried out over a carefully monitored two-hour timeframe, played a pivotal role in priming the fibers for subsequent transformations. Post the initial treatment, a methodical filtration procedure was implemented, followed by a period of natural air-drying spanning two days under standard room temperature settings.

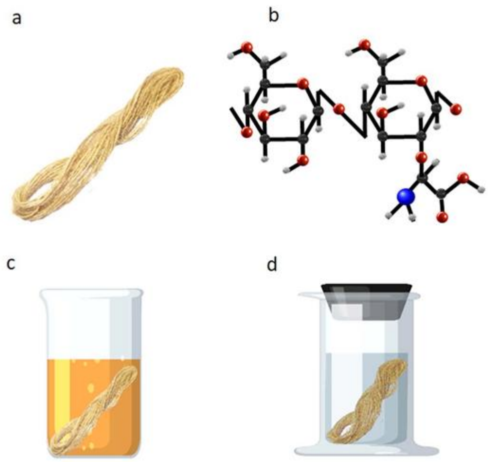

Figure 4. a) Untreated jute yarns, b) chemical interaction of jute fiber with glycine, c) alkali treatment of jute yarn, d) glycine treatment of jute fiber (open access) [45]

This detailed and comprehensive treatment plan underscored a profound commitment to elevating the characteristics of the cellulosic fibers and harnessing their full potential for a diverse array of uses [46-49].

Alkali bleaching

The study extensively delved into the impact of hydrogen peroxide bleaching and alkali treatment on the tensile properties of short jute fiber composites, revealing valuable insights that contribute significantly to the field. Experimental procedures involved the meticulous mixing of different weights of treated and untreated jute fibers with the PLA matrix, highlighting the meticulous approach undertaken in the research [50-54]. Notably, the composite materials treated with a combination of 10% NaOH and hydrogen peroxide bleaching exhibited remarkable enhancements, with the tensile strength surging by 7.5% and the modulus soaring by an impressive 40% compared to the untreated counterparts [1], underscoring the efficacy of the treatment methods employed.

Moreover, beyond the scope of treatments, the structure and chemical composition of jute fibers are affected by various environmental factors such as climate, age, and digestion, underscoring the intricate dynamics that shape their properties. It is fascinating to note that these fibers primarily consist of 60% cellulose, accompanied by 12% lignin, in addition to pectin, moisture, and ash content, painting a comprehensive picture of their composition. Remarkably, jute fibers exhibit exceptional resilience, capable of withstanding air temperatures of up to 100°C without undergoing degradation, further highlighting their robust nature and suitability for diverse applications [55]

Furthermore, the pivotal role played by alkali bleaching in augmenting the quality and performance of jute fibers for various applications, especially in the realm of composite materials, cannot be overstated. Through the intricate process of alkali bleaching, the fiber surface undergoes a transformative refinement, thereby ridding it of undesirable components and enhancing its overall utility, making it an indispensable step in optimizing the properties of jute fibers for numerous industrial applications. This meticulous treatment method not only enhances the physical properties of the fibers but also improvises durability and applicability in a wide array of scenarios, underscoring the importance of such treatments in the realm of materials science and engineering [56-60].

Plasma and alkali-plasma treatment

Plasma treatment and alkali-plasma treatment represent cutting-edge methodologies utilized in altering the surface characteristics of natural fibers such as jute, aimed at improving the bonding interface with the matrix material. One notable investigation by [61] delved into the realm of jute fiber/high-density polyethylene (HDPE) composites, with a primary focus on enhancing the inherent properties of jute fabrics through meticulous surface modification via oxygen plasma treatment. In their comprehensive study, a combination of low-frequency (LF) and radiofrequency (RF) plasma systems was seamlessly employed, with the plasma power meticulously fine-tuned to 30, 60, and 90 W for a duration of 15 minutes. An in-depth analysis utilizing X-ray photoelectron spectroscopy (XPS) served as a pivotal tool in evaluating the transformative effects on the functional groups treated with oxygen plasma residing on the surface of jute fibers. Subsequently, composite materials were meticulously developed by blending 20% jute with 80% polylactic acid (PLA) through the intricacies of the injection molding process. A comparative evaluation brought into light that the mechanical properties of plasma-treated jute/PLA composites showcased a remarkable uptick in performance metrics when compared to their untreated or alkali-treated counterparts. Particularly, the plasma-treated jute/PLA composite displayed substantial enhancements, which included an impressive 28% surge in tensile strength, a notable 17% augmentation in Young's modulus, and a commendable 20% amplification in flexural strength. These findings underscore the profound positive influence of plasma treatment methodologies on the overall mechanical prowess and structural integrity of jute/PLA composites, thus establishing a solid foundation for the utilization of plasma treatment techniques in revolutionizing the landscape of composite material engineering [62].

Permanganate treatment

In the process involving the utilization of permanganate, a potent chemical compound characterized by the presence of the permanganate group denoted by the chemical formula MnO4, alkaline-treated jute fibers undergo immersion in a neatly concocted solution that comprises 50% permanganate acetone, which is then meticulously carried out for a specific time duration. Subsequently, to eliminate any residual solvent and moisture, the treated fibers are subjected to a thorough drying process meticulously maintained at a temperature of 40°C for a set time span of 5 hours [63-65]. This method of treatment with permanganate effectively diminishes the innate hydrophilic properties of the jute fibers, leading to a tangible decrease in the overall water content contained within the Jute fiber reinforced polymer composite (JFRPs), as precisely highlighted by a study reference [66]. Consequently, as a direct result of this particular treatment process, the moisture content inherently present in the fibers is entirely eradicated, consequently facilitating a notable enhancement in the material's strength characteristics, thus further validating the efficacy of the permanganate treatment as a viable approach in manipulating and fortifying the properties of jute fibers within composite materials [

Hydroxybenzene diazonium salt treatment

Typically, treatments of jute fiber are conducted to modify the surface properties, with one such treatment involving the use of benzene diazonium salts. Specifically, the jute fibers undergo a series of steps to enhance their characteristics. First, the fibers are immersed in a 5% NaOH solution for 10 minutes while placed in an ice bath to ensure proper penetration and absorption. Following this initial treatment, a cooled solution of o-hydroxy benzene diazonium chloride is added and stirred for 10 minutes, facilitating a chemical interaction that alters the fiber's surface properties. To remove any residual substances, the fibers are then washed sequentially with soap solution and water before being dried thoroughly. The process is repeated with p-hydroxy benzene diazonium chloride and m-hydroxy benzene diazonium chloride under both alkaline and acidic conditions, presenting a comprehensive examination of the treatment effects [49]

The outcomes of these treatments have revealed significant differences in the physical properties of the jute fibers. Notably, the treated jute fibers exhibited a decrease in tensile strength, tenacity, and moisture absorption compared to their untreated counterparts. This observation suggests that the modification process impacts the fiber's structural integrity and absorption capabilities, potentially influencing its performance in various applications. Further analysis of the treated fibers revealed distinct variations based on the type of hydroxy benzene diazonium salt used. Among the treatments with ortho, meta, and para hydroxy benzene diazonium salts, the most promising results were obtained with o-hydroxy benzene diazonium salts, showcasing the highest tensile strength and tenacity. In comparison, the fibers treated with m-hydroxy benzene diazonium salts demonstrated slightly lower performance, while those treated with p-hydroxy benzene diazonium salts exhibited the least improvement in mechanical properties. These findings highlight the importance of chemical treatments in tailoring the properties of jute fibers for specific applications, showcasing the potential for enhancing their performance through strategic modifications [47].

Silane and alkali-silane treatment

Silane treatment using reactive silane molecules holds a pivotal role in augmenting the bond between fibers and polymers within composite materials. Specifically, alkali-silane treatment enhances the reactivity with the fiber surface, which ultimately leads to a superior bonding mechanism. Both types of silane treatments contribute significantly to the enhancement of interfacial adhesion, subsequently fortifying the overall performance, durability, and strength of the composite material [50]. This heightened bond between fibers and the polymer matrix not only elevates the mechanical properties but also reinforces the material's ability to withstand environmental stresses, making it an indispensable technique in the fabrication of composite materials. Silane molecules possess distinct ends that collaborate to construct a bridge between the water-attracting segments of the jute fiber and the water-repellent components of the polymer matrix. When natural fibers undergo silane treatment, the molecules react with the fiber's surface, forming stronger bonds. This reaction occurs through the hydrolysis of silane molecules, resulting in the formation of silanol groups that bond with the hydroxyl groups present on the fiber surface, establishing either covalent or hydrogen bonds. Various types of silanes, such as alkyl, amino, methacryl, and glycidoxy, are commonly utilized to enhance the strength of fibers and increase their resistance to water, especially when a robust bond exists between the silane and the matrix [60].

DEVELOPMENT OF JUTE/ BASALT COMPOSITES

Jute and basalt epoxy-reinforced composites are at the forefront of material science, offering a fascinating avenue for creating high-performance materials with exceptional properties. The combination of these fibers with epoxy resin has led to the development of composites that strike a perfect balance between mechanical strength and sustainability. These composites are not only strong but also lightweight, showcasing impressive strength-to-weight ratios that make them highly desirable for a range of applications. Moreover, the production of bio-composites using traditional manufacturing methods has paved the way for environmentally friendly materials that can be utilized across various industries. Techniques such as moulding, resin transfer, compression moulding, extrusion, injection moulding, hand lay-up, spray lay-up, filament winding, and pultrusion have been employed to create these bio-composites, demonstrating the versatility and adaptability of these materials. In conclusion, the development of reinforced composites represents a significant advancement in the quest for sustainable and high-performance materials. With their unique properties and environmentally friendly nature, jute and basalt epoxy composites are poised to revolutionize industries and offer innovative solutions to complex challenges [51]. Figure 5. depicts the view of compression moulding machine. Table 5 presents methods used and mechanical properties of developed polymer composites.

Figure 5. Compression moulding machine

Table 5. Various methods used and mechanical properties of developed polymer composites.

Matrix	Reinforcement	Process	Outcomes	Ref.
Epoxy	Jute epoxy (treated with 20% NaOH)	Compression moulding technique	It was reported that comparative to raw jute has poor mechanical characteristics than jute treated with sodium hydroxide, later tested tensile strength of 97 MPa and flexural strength of 80 MPa.	[50]
Epoxy	Jute/basalt reinforced hybrid epoxy composites	Laminates of hybrid composite are prepared by hand lay-up method	The findings suggest that hybridizing jute fiber with basalt fiber led to enhancements in the tensile strength, bending resistance, in-plane shear strength, and bearing capacity of the composite.	[52]
Epoxy	Jute/basalt hybrid epoxy composites	Vacuum-assisted resin infusion	The findings revealed that jute/basalt hybrid laminates displayed superior impact energy absorption and flexural properties compared to those composed solely of jute fibers. Additionally, they exhibited greater resistance to aging over time. The results also indicated that jute/basalt hybrid laminates, particularly those with a sandwich-like configuration, demonstrated enhanced aging tolerance when compared to hybrid laminates with an intercalated configuration.	[53]

Polyester	Jute/glass fiber reinforced polyester	Pultrusion	The research examined production of hybrid composite using polyester, jute, and glass fibers interacts with water. It was discovered that integrating glass fibers into the composite increased its ability to resist water absorption and exposure to moisture led to a significant decline in the flexural and tensile properties of the hybrid composites due to water absorption.	[54]
PLA (Poly-lactic acid)	Polylactide green reinforced with jute fiber.	Injection moulding	The findings suggest that enhancing the Young's modulus and tensile strength of the prepared composites is achievable by employing thoroughly compounded pellets during the injection moulding process. Figure 6 depicts the behavior of composites fabricated at different temperatures on the tensile fractured specimens.	[55-56]
PBS (Poly-butylene succinate)	Basalt fiber reinforced with PBS	Injection moulding method	The flexural and tensile characteristics of the PBS matrix show improvement due to the synergistic strength provided by an increasing quantity of basalt fibers, resulting in increased tensile strength from 31 to 46 MPa and flexural strength from 18 to 71 MPa.	[57]
Epoxy	Epoxy of basalt composed of (0.5–2 wt%) tourmaline micro/nano particles	Vacuum-assisted resin transfer moulding technique	The tensile and flexural strength increased by 16%, while the tensile and flexural modulus showed increases of 27% and 153%, respectively.	[58]
PLA (Polylactic acid)	Basalt fiber/ polylactic acid composite	Hot press (compression moulding) and (APGD) atmospheric pressure glow discharge for surface modification of basalt fiber through plasma polymerizatio n	The findings indicated that the composite exhibited a 45% increase in strength and an 18% increase in modulus compared to untreated one. The most effective plasma polymerization treatment for basalt fibers was observed to occur at a plasma exposure time of 4.5 min.	[59-60]

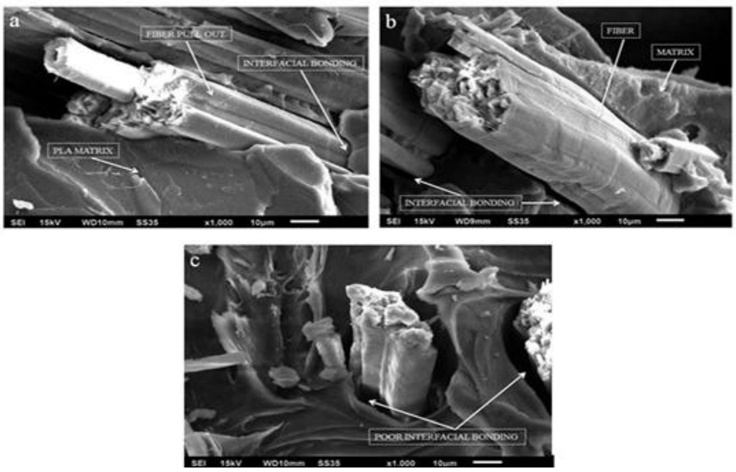

Figure 6. SEM micrographs of fractured tensile specimens of polymer composites fabricated at different temperatures (open access) [47]

MECHANICAL PROPERTIES OF JUTE/BASALT FIBER COMPOSITES

In this part of the review, different researches done on jute/basalt composites are discussed. [61] focused their work on reinforcing basalt and jute fabrics into a general-purpose poly ester matrix using the compression moulding process, poly ester-based polymer composites are created. Study showcases varied stacking sequence in reinforced composites with poly-ester resin, basalt fiber and jute fiber. The findings showed that in both the flexural and tensile tests, the pure basalt fiber combination maintained higher values. However, basalt fiber performs somewhat worse in impact tests than composite reinforced with jute fiber. [62] utilized Jute and basalt as reinforcements to get the benefits of both jute and basalt fiber. The composites made of jute and epoxy were created. Additionally, jute and basalt fiber hybrid composites were created. A variation in the percentage of the natural filler (walnut shell) material was also examined in the generated composites. The walnut shell was utilized as filler in different proportions: 0%, 5%, 10%, and 15% of epoxy resin. The use of walnut shell fillers increased the produced hybrid composites' tensile and flexural strength. Because of better impact energy absorption, the impact strength of the created composites rose as the filler concentration increased. [63] using compression moulding processes, and created basalt/jute fiber-reinforced hybrid polymer composites with a variable fraction of fiber. Basalt fiber was added to the composites at rates of around 10%, 20%, and up to 90%, while the amount of jute fiber was decreased from 90%, 80%, to 10% in accordance. Jute fiber incorporation resulted in improved tensile and flexural strength for 90% basalt and 10% jute fiber hybrid composites. Out of all the specimens made using polyester matrix, the composite material with 50% basalt and 50% jute exhibits the highest impact strength according to the impact test. Tables 6 and 7 represent the mechanical properties of jute and basalt fibers, respectively.

The influence of fiber volume fraction and curing temperature was evaluated on the mechanical properties of Jute/PLA fabricated composites [48] These effects are represented in Figure 7 at different temperatures. The tensile tests were correlated with the SEM micrographs (Figure 8) and it was concluded that the weak fiber matrix bonding resulted in less tensile strength at 50% fiber volume fraction.

There are changes for the better, through the uses of surface treatment and nanoparticles on natural fiber composites, mainly jute and basalt composites.

These enhance various mechanical and chemical properties making it useful for manufacturing products with different needs [75-78].

CONCLUSION

Basalt and jute fibers get along well with one another, and various surface treatments—such as silane, alkali, etc. produce various benefits. Likewise, this holds true for nanoparticles. Different surface treatments and nanoparticles might be employed for different needs. Just in the last few years various researches have been done in the sector of natural fiber composites, a lot of which include surface treatments to improve the bonding, as well as nanoparticles in order to improve mechanical properties of these composites, and yet there is a vast number of possible variations and enhancements that can be applied in order to get more out of these composites. The easy availability and inexpensiveness of jute and basalt fibers make them ideal for all the researches. A lot of possible variations for improving the properties are possible, and we are just a few steps from finding these improvements.

Table 6. Mechanical properties of jute fiber

Properties	Jute fiber							
	[64]	[65]	[66]	[67]	[68]	[69]	[70]	[71]
Tensile strength (MPa)	393-773	450-550	-	290	393-773	400-800	393-773	393-773
Young's modulus (Gpa)	13-26.5	10-32	-	28	26.5	10-30	19.0-26.5	13-26.5
Elongation at break (%)	1.16-1.5	1.1-1.5	1.56	-	1.5-1.8	1.5-1.8	1.16-1.80	1.16-1.5

Table 7. Mechanical properties of basalt fiber

Properties	Basalt fiber		
	[72]	[73]	[74]
Tensile strength (MPa)	2900-3100	2800-4800	2200-2500
Young's modulus (GPa)	85-87	86-90	85-100
Ultimate elongation (%)	3.15	-	-

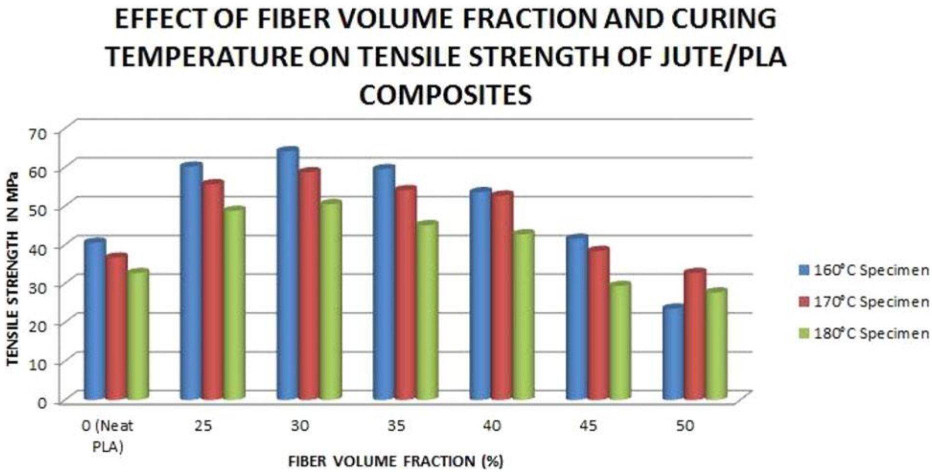

Figure 6. Effect of fiber volume fraction and curing temperature on tensile strength of Jute/PLA composites (open access) [78]

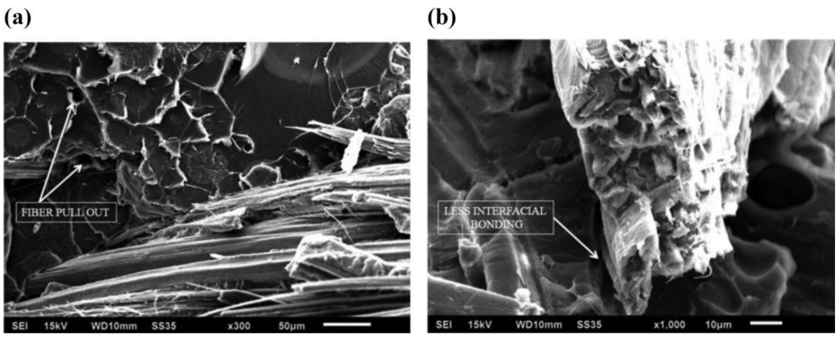

Figure 7. SEM images of tensile fractured specimen developed at 160_C with 50% fiber volume fraction (open access) [78] at a) x300 magnification and b) x1000 magnification.

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