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Experimental Analysis of Strength Prediction of Jute Reinforced Glass Fibre Composite Material

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ABSTRACT— Conventional materials are being replaced by composites due to their superior qualities, such as high tensile strength, high strength-to-weight ratio, and low thermal expansion. The development of natural composites materials is accelerating and expanding day by day. In this investigation, jute-reinforced epoxy composites were fabricated at different jute volume faction, and their tensile strength was predicted using nondestructive technique. An acoustoultrasonic testing was used to evaluate the interfacial characteristics, such as internal fractures and internal flaws in the structure from the stress wave factor (SWF). Further tensile strength was evaluated from the universal testing machine UTM. Correlation factor was predicted on comparison of SWF and UTS. It has been predicted that with the increase in the jute volume fraction there is an increase in SWF and UTS compared to initial lower jute volume fraction. The findings indicate that natural (jute-polymer) composites may be utilized as an alternative to polymer composites reinforced with synthetic fibers. Due to their high specific strength, low weight, and biodegradability, natural fiber composites such as kenaf and jute polymer composites became increasingly desirable and can be used for an applications of an automobile parts made up of proposed jute-reinforced polymers replacing conventional materials.

Keywords—composite; glass fiber; nondestructive testing; acoustoultrsonic; young's modulus

I. INTRODUCTION

Natural fibers were first used in composite structures 3000 years ago in ancient Egypt, where straw and clay were combined to create walls. Polymer composites reinforced with natural fibers have got a lot of recognition in the last decade, both from academia and from different industries. Natural fibers come in a wide range and can be used in a multitude of ways which can be used for different applications [1].

Due to their properties and availability, flax, hemp, jute, kenaf, and sisal are the most used natural fibers in composite materials [2-3]. Jute is a common bast fiber with a variety of benefits. Jute has high specific properties, like lower fiber diameter, less abrasive to manufacturing devices, has excellent structural consistency, and is non-toxic. Jute is a low-cost, environmentally sustainable fiber product and is abundantly available, easy to transport and has superior drapability and moisture retention capacity [4-6]. It's a common natural option for plant mulching and rural road pavement development. The biodegradable and low-cost jute materials blend into the soil, giving nourishment to the soil [9-10]. Jute does not produce poisonous gases when burned because it is made of cellulose. Both thermosetting and thermoplastic matrices may benefit from natural fiber reinforcement. Epoxy, polyester, polyurethane, phenolic, and other thermosetting resins are widely used in natural fiber composites that require higher performance applications [7-8]. They provide adequate mechanical properties, especially stiffness and strength, at a cost that is acceptable. Thermoset compounds have more thermal stability and less water absorption than thermoplastic polymer-based compounds. However, thermoplastic polymers are expected to replace thermoset polymers in the case of increased recycling and in conjunction with modern long fiber reinforced thermoplastic (LFT) manufacturing. Natural fiber composites may be a highly economical material for the following applications: Building and construction industry: panels for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, transportable or prefabricated houses used during natural disasters such as floods, cyclones, earthquakes, etc. Storage devices: post-boxes, grain storage silos, bio-gas containers, etc. Furniture: chair, table, shower, and bath units, etc [9-10]. Electric devices: electrical appliances, pipelines, etc. Daily use applications: lampshades, bags, helmets, etc.

Transportation: automotive and railcar interiors, as well as boats, etc. [1,8]. In addition to the benefits, natural fiber composites have a few disadvantages. The most significant disadvantage is the incompatibility of hydrophilic fibers with a hydrophobic polymer matrix. Therefore, weak interfaces and contacts occur, resulting in composites with low mechanical characteristics. Another notable disadvantage of natural fiber composites is their low strength compared to metals, water sensitivity of natural fibers and their comparatively low heat stability. Water absorbed by composite's fibers may induce swelling, dimensional instability, and a loss of mechanical qualities owing to fiber breakdown and the interface between the fiber and matrix. Thus, the water absorption on composites is a major concern for the applicability of such natural composites. It was found that the tensile and flexural characteristics of jute epoxy were better. Estimation of the tensile strength and internal flaws plays important role in the characterizing the applicability of such natural fiber based composite materials. A significant technology developed for metallic engineering materials and same has been adapted for use with fiber composites. Some of these approaches are more effective than others, and it is generally recommended to utilize a backup strategy wherever feasible, rather than relying just on one way. Gholizadeh [31] have provided reviews of some of the most prevalent technologies in use, although there is a high effort of R & D on fiber-optic sensors designed for use with reinforced polymers. Several NDT tools like optical inspection, radiographic, thermal imaging are some of the methods used for the detecting the internal flaws and cracks. Some of the techniques like ultrasonic and acoustoultrasonic method are NDE techniques used to evaluate the tensile strength as well internal flaws. Ultrasonic examination is the most common NDE approach. The amplitude and attenuation of an ultrasonic pulse travel through the composite sample reveals the general physical qualities and composition (i.e., defect/damage state) in a material. Most composites have similar structural patterns (fibers, fiber tows, fabric weave, laminate stacking sequence), a variety of interfaces (fiber/resin contact, interlaminar interface), and an inherent fault. Therefore, ultrasonic waves in composites are significantly attenuated, and their velocity and attenuation are both impacted by frequency. The laminate's architecture effects frequency of attenuation. Composite composition, structural flaws, and stress hinder ultrasonic wave transmission. Use of broad-band transducers and low wave frequencies overcomes considerable attenuation, resulting in shorter, more penetrating bursts of less prominent near-field. Due to low pulse intensities in composites testing, larger amplification is required than for other materials, however composites may be evaluated using most classic ultrasonic techniques, such as pulse velocity measurements, echo methods, goniometry, and ultrasonic interferometry. Structural change in a composite, such as resin splitting, fiber fracture, debonding, or interlaminar cracking, dissipates energy as elastic stress waves. Using proper transducer/amplifier systems, acoustic emissions (AE) technique may be identified, and can be used to detect, and analyze defects in the composite materials. There are several approaches for analyzing AE monitoring data from structures under load. Some give quantitative procedures for evidence verification or life prediction, while others provide a better knowledge of damage progression in composites. Thus, this technique become more promising for the strength prediction of the natural composite materials. Due to high mechanical qualities, jute epoxy is well suited for use in automobiles. Although the composite has various benefits and drawbacks, it combines the advantageous qualities of two distinct materials to facilitate a faster fabrication and manufacturing operation. Time, cheaper production costs, etc., making them a versatile material in the fields of engineering and technology. The technology clearly demonstrates that composite is the most desired material in the current market. Hence, in this work an approach was made to measure the tensile strength using nondestructive testing and determination of the correlation factor using SWF and UTS.

II. METHODOLGY

Sample Preparation

Preparation of specimen is one of an important components, and there are several vital variables involved in specimen preparation, including concentration of resin and hardener, setting time, fiber orientation, etc. Glass Fiber composites are considered in this work. There are two primary varieties of glass fibers, E-class, and S-class, which are available in a variety of forms, including Yarn, Woven Fabric Yarn, and Continuous-Strand Roving. In addition to Glass fibers, epoxy is an essential component that creates the matrix of a composite. Epoxy is a copolymer, meaning that it consists of two molecules. These terms refer to the "resin" and the "hardener" or "activator." The solvent is composed of monomers or short-chain polymers with an epoxide group at either end. Hardener is composed of polyamine monomers. The amine and epoxide groups react to produce a covalent bond. Each NH group in amines may react with an epoxide group, resulting in a polymer that is highly cross-linked and hence make composite stiff and robust. This work utilizes E class Glass Fiber and Jute

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fiber woven sheets combined with araldite epoxy and triethylenetetramine (TETA) to make composites. The Hardener concentration should be between 5 and 10 percent by volume of the epoxy concentration. Curing is the process of polymerization, which may take minutes to hours depending on temperature, resin and hardener, and ratio of those compounds. Certain preparation of composite benefit from heating during the curing process, while others need time and ambient temperatures. Adjust the quantity of hardener used depending to the ambient temperature. In this study, hand layup was used for specimen preparation. Using this method, Glass fibers are guided in the proper direction. The thickness requirement determines the dimensions and number of layers of jute and glass for the test specimen. These layers are stacked, and a combination of epoxy and hardener is placed by hand between the two fiber layers to enable the composite to cure. Final fabricated composite laminate is shown in the Figure 1.

Figure 1. Fabricated jute reinforced glass fiber composite laminate

A. Experimental Setup

A function generator creates electrical waveforms across a wide frequency range. The sine, square, triangle, and sawtooth waveforms are typical function generator outputs. Waveforms may be recurring or single shot (which necessitates the use of an internal generator). Ultrasound transducers convert ultrasound waves to electrical impulses or vice versa. Ultrasound transceivers can send and receive ultrasound signals; certain ultrasound sensors may also transmit. Transducers used in radar and sonar systems to interpret radio or sound wave echoes. Active ultrasonic sensors create high-frequency sound waves and detect the echo back to the sensor to determine the distance to an object. Passive ultrasonic sensors are microphones that detect ultrasonic sounds and convert it to an electrical signal for a computer. A digitizer translates analogue objects, images, or signals to digital form. This bridge sensor conditioner module regulates current to a grounded load. To linearize and compensate a differential bridge sensor voltage, the first stage uses a mixed-signal programmable gain amplifier (PGA). In the second stage, the PGA output voltage is converted to current across a 4mA to 20mA loop. The module is protected against electrostatic discharge (ESD), electrical fast transients (EFT), radiated and transmitted EMI, and lightning surge.

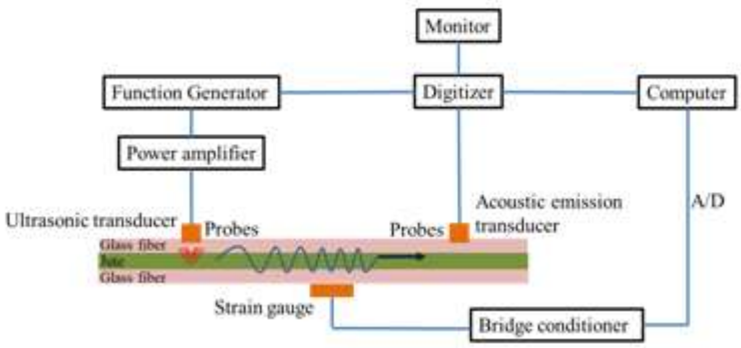

Figure 2. Detailed layout of acoustoultrasonic testing

An ultrasonic-acoustic technique was used to indicate the strength variations of tensile specimens of a jute reinforced fibre composite. A "stress wave factor" was determined and its value was found to depend on variations of the fiber-resin bonding as well as fiber orientation. The stress wave factor can indicate variations of the tensile and shear strengths of composite materials. The stress wave factor was also found to be sensitive to strength variations associated with micro porosity and differences in fiber-resin ratio. [16-17,30].

Figure 2 depicts the equipment used for the acousto-ultrasonic testing [27-30]. Sender and receiver probes were used. The probes are coupled to the material in a way that prevents direct echoes. The received signals are more of intricate functions depends on boundary conditions, and microstructure of the composite. The objective of the acousto-

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ultrasonic technique is to use the elastic waves that interact with material morphology and boundary surfaces in a similar way to that of spontaneous stress waves that develop at the start of microcrack nucleation, fracture, etc. Sample signal as seen in figure 3, represent the output waveform (time domain signal) that mimics a type of acoustic emission [27-29].

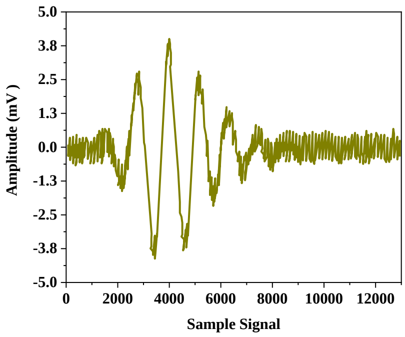

Figure 3. Time domain signal of a composite using acoustoultrasonic test.

The acousto-ultrasonic waveform conveys information on the medium through which it travels. It depends on multimode velocities, attenuations, dispersions, multiple reflections, etc. It has been experimentally shown (figures 2) that the acousto-ultrasonic waveform reveals substantial connections with mechanical qualities. To analyze acousto-ultrasonic signals, a "stress wave factor" is measured (SWF) [20-21]. To provide a numerical value to the acousto-ultrasonic waveform, the SWF may be measured in one of many methods. For instance, the SWF may be assessed as a "ringdown" oscillation count, which is used to measure acoustic emission signals [21-23]. Alternately, the SWF may be interpreted as the root-mean-square (RMS) voltage of the output waveform [23-28].

The most significant finding of this study was that the stress wave factor correlates strongly with ultimate tensile and shear strengths that accompany different fiber orientations and fiber-resin matrix bonds. Correlations that were obtained probably arose because stress wave propagation is a function of material stiffness which in turn controls ultimate strength in the composites tested. Also, by making equally- spaced measurements along the specimen axis, it was possible to predict where fracturing would occur. None of the specimens contained intentional defects. Fracture apparently initiated at loci that was weakest because of micro structural variations rather than overt defects. The locations of the lowest stress wave factor values coincided with the locations of actual fractures.

III. RESULT AND DISCUSSION

Acoustoultrasonic testing

Geometrical parameters for the prepared sample for the testing are shown in the table 1. We considered the three samples for each composition. We kept the 4 layer of glass fibre constant for all the sample and varied the jute layer. Samples are designated by 4G3J,4G4J and 4G6J for the 3 layers, 4 layers and 6 layers of jute in the specimen respectively. Glass fiber volume fraction keeps on decreasing while jute volume increases from the 30% to 50%. We kept the length of the sample 140 mm for all the specimens. Although there is some variation in the width corresponds to the hand layup process and is in the acceptable range used for the compassion. There is a need for NDE (nondestructive assessment) technology to measure changes in microstructure, extrinsic mechanical properties (e.g., strength, toughness), and diffuse defect populations that regulate the mechanical performance of a component or structure. Specification of flaws and prediction of structural reliability rely on knowledge of mechanical characteristics and morphological circumstances, such as moduli of elasticity, strength, fracture toughness, hardness, porosity, phase structure, fatigue, and creep damage, etc.

It is feasible to employ ultrasonic NDE methods to determine whether a structure contains the qualities expected during design analysis. By examining the signal-modulating effects of material microstructures, this will be shown to be possible. The composite specimens were studied by AU technique to determine the SWF. The table 2 shows the result of the analysis. It has been found that the SWF increases with the increase in the jute volume fraction in the composite specimen.

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Table 1. Geometrical parameters of the various samples

Parameter	Composition 1 (4G3J)			Composition 2 (4G4J)			Composition 3 (4G6J)		
	Sp. 1	Sp. 2	Sp. 3	Sp. 1	Sp. 2	Sp. 3	Sp. 1	Sp. 2	Sp. 3
Thickness(mm)	5.7	5.9	5.5	6	6	6	7.6	7.6	7.7
Width (mm)	27	27	27	27	27	27	27	27	27
GlassVol.Fraction	30%			25%			20%		
Jute Vol.Fraction	30%			40%			50%		
Matrix	40%			35%			30%		
Length	140 mm			140 mm			140 mm		

Table 2. Stress wave factor for different specimens of different composition evaluated by AU technique

Parameter	Composition 1 (4G3J)			Composition 2 (4G4J)			Composition 3 (4G6J)		
	Sp. 1	Sp. 2	Sp 3	Sp. 1	Sp. 2	Sp. 3	Sp.1	Sp. 2	Sp.3
SWF (mV)	773.8	900.8	800.8	1187.3	1280.9	1020.7	1385.8	1314.7	1239.8

Universal Testing Machine

Tensile strength was predicted from the tensile testing in the universal testing machine. Table 3 shows the breaking load, maximum displacement, and the ultimate tensile strength (UTS) of the different compositions of the samples. It has been observed that with the increase in the jute volume fraction UTS increases. Figure 4 shows the variation in SWF and UTS for different % of jute volume for all three specimens.

Correlation was evaluated from the SWF and UTS plot. Same has been shown in the table 4. It has been found that with the increase in the jute volume fraction correlation factor is increases with the higher slope while further adding higher jute fraction (50%) shows small amount of increase in the correlation factor. Results shows that the higher percent of jute contribute to higher flaws and voids results in lower increase in the strength of the composite materials.

It has been observed that the natural reinforcement increases the strength with the increase in the % of jute volume fraction. Although the strength is very less compared to the polymer reinforced composite as per the previous studies. Through the manufacturing of fibre-based composite materials, jute play a key role in the evolution of modern age composite manufacturing. Jute needs to be revitalised and diversified into a promising new future of composites and need to throw combined efforts into it.

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Table 3. Obtained strength from the universal testing machine

Parameter	Composition 1 (4G3J)			Composition 2 (4G4J)			Composition 3 (4G6J)		
	Sp. 1	Sp. 2	Sp. 3	Sp. 1	Sp. 2	Sp. 3	Sp. 1	Sp. 2	Sp.3
Breaking Load (KN)	6.135	8.86	9.7	10.74	13.685	12.945	16.625	17.6	17.2
Max Disp. (mm)	12.6	12.15	11.59	10.79	11.86	10.75	11.63	14.04	10.22
Elongation	9%	8.68%	8.28%	7.71%	8.47%	7.69%	8.31%	10.03%	7.30%
UTS (MPa)	81	86	82	90	84	84	95	87	85

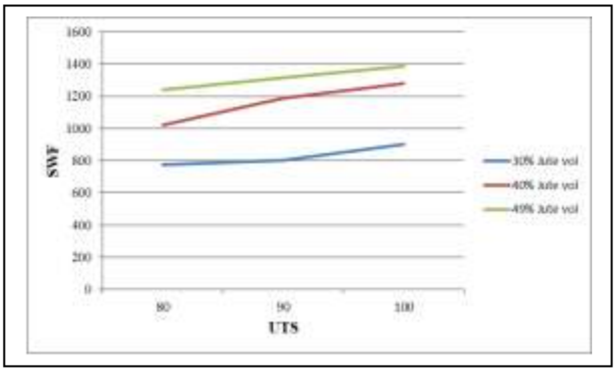

Figure 4. SWF vs UTS for different jute volume fraction for 3 samples of each concentration.

IV. CONCLUSION

Variable compositions of jute-reinforced glass-fiber composites and its mechanical characteristic were evaluated in this study. The specimens were made using the hand lay-up technique. Consequently, it is difficult to achieve the same accuracy that achieved from machining and mechanical coatings. Due to the non-uniform cross-section of jute fibers, there is a great space for research into the influence of all these characteristics on the mechanical behavior of jute-based composites. Jute plays a vital part in the advancement of contemporary composite manufacturing via its use in the production of fiber-based composite materials. Jute must be revitalized and diversified future of composites and must need to devote collective intellect and efforts to this endeavor. Findings predict that the poor mechanical qualities of jute fiber (tensile resistance, bending load, and hardness) were improved by reinforcing it with E-glass fiber and epoxy resin. As the number of layers rises, tensile strength and bending loads increase, yet the material's hardness stays unaltered. After reinforcing with E-glass fibers, the tensile strength of jute fibers may be greatly increased, enabling the fibers to withstand most stresses and, consequently, enhancing the composite material's strength. The tensile strength rises in proportion to the number of material layers. The flexural strength of the material may be enhanced to match that of the producing material. Due to the high modulus of elasticity of these fibers, high loads may be carried, and the strength is increased. High specific strength, low weight, and biodegradability of natural fiber composites such as jute polymer composites became more desired and can be utilized to replace traditional materials in automobile industries.

Table 4. Evaluated correlation factor for the prediction of UTS from the SWF

Sr. No.	Composition	Correlation Factor
1	Composition 1 4G3J (30%)	9.93
2	Composition 2 4G4J (40%)	13.52
3	Composition 3 4G6J (49%)	14.75

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