Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 5 (2023)

# Experimental Investigation on Mechanical Behaviour of Jute/ Vinyl Ester Composites Impregnated with Alumina Filler

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**A B S T R A C T**

The present paper discovers an impact of alumina filler inclusion on mechanical behavior of chemically treated (alkali treated) bi-directional jute natural-fiber-reinforced vinyl ester composites. In practice, the extremity of moisture resorption and poor dimensional stability are the pivotal hindrances of using natural fibers. Currently, chemical treatments assure fiber modifications that increase their resistance when utilized in composite products. Jute fibers are subjected to chemical modifications to the interfacial linkage with the matrix.
A methodic examination has been compassed to look into jute fiber and alumina filler properties when incorporated into vinyl ester matrix. Composites were prepared by using hand lay-up technique. In this study, an exploration has been done to make pre-treated jute fiber (10, 20 and 30 wt.%) and different alumina filler content (1 and 2 wt.%) with vinyl ester - based composites. The investigation reveals that, due to incorporation of jute as reinforcement and alumina as filler into polymer vinyl ester depicts superior mechanical properties ahead of resins alone.

**Keywords**: Vinyl Ester, Jute Fiber, Alumina, Flexural Strength, Tensile Strength, Hardness.

## 1. Introduction

Composites are intriguing and fantastic materials that are owing to the advancements in materials and technology, most significant and adaptable engineering materials. Fusing two or more contrary entities with distinctly different characteristics results in composite materials. The creation of novel materials is underway, and their demand is increasing daily [1]. Because of its better qualities, such as a high strength-to-weight ratio, immense mechanical strength, and little thermal expansion, etc., composite materials are superseding customary entities in all possible applications, viz., deep sea containers for electronic apparatus, military submarine outer casing, and hulls of underwater vehicles [2].

Because they may be made at very low processing temperatures, polymer matrix composites are favored over MMC and CMC. Different Reinforcement materials, such as flakes, fillers, fibers, particles, or whiskers, can be used as reinforcement. The reinforcing gives the composites its strength and rigidity. The form and arrangement of the fillers are varied remarkably while interjected to the mould. Reinforcement viable in divergent forms or arrangements, relying on the manufacturing route and application [3]. The stringent environmental regulations incite the researchers to enact newest appliances arising out of traditional resources. NFRP Composite, the popular portable commodity possessing good dimensional stability with corrosion audacity, design resilience and minute moisture resorption features can replace the conventional polymer composites which tends to lighten the weight by 60 to 80 percent [4].

Developing bio-based products from agricultural byproducts and co - products has the potential to increase income from the crops and benefit the farmers and industries like automotive, textile, packaging etc. economically and reduce the dependence on inorganic based resources [5]. In a particulate-filled polymer composite, the mechanical strength strictly depends on fiber and particle size, shape, dispersion of particle into the matrix of the composite and also fiber or particle-polymer matrix interfacial bonding [6]. The wide array of

micronized fillers that are predominantly adopted includes aluminum oxide, silicon dioxide, metal oxides, silicon carbide, carbon dark mud and graphite. By using such fillers, the friction coefficient is increased, which scrapes the counter surface [7]. The customized properties of a composite material are usually attained by the addition of fillers (particles) during fabrication. The presence of fillers reduces the void fraction and prevents cracks from spreading throughout the composite by reducing its shrinkage and also act as crack stoppers. The addition of nano fillers also results in improved tensile and abrasive wear properties. As the mechanical performance of a composite material is determined by its interfacial adhesion, the increase in strength of composite shows good interface and stress transfer efficiency [8].The importance of tribological properties paved the way to researchers to concentrate on the wear properties of the polymeric composite material. Recent trends have noticed an escalation in employment of hybrid polymeric composites in many mechanical applications that are subjected to wears such as gears, cams, automobile brakes and clutches and bearings [9]. By using the non-toxic materials, augmentation of earth's trash production is reduced, guaranteeing safer living conditions. [10]. Tribological, mechanical, fire hindrance and thermal attributes of fiber reinforced polymer composites are enriched by useful fillers [12].

## 2.Experimental Program

### 2.1. Materials

Vinyl Ester is used as matrix in PMCs. VE resins are highly resistant to acids, alkalis, solvents, hypochlorites, and peroxides. Its cost is in between the polyesters and epoxies. Vinyl Ester resin used is supplied by Naptha resins and chemicals (P) Limited, ≠491, phase 4th, Peenya industrial area, Bangalore – 560058, Karnataka, India under the trade name polyflex GR-200-60. Few properties of Vinyl Ester resin adapted in the study are provided in the table-1.

**Table 1. Physical and Mechanical Properties of Vinyl Ester Resin**

| **Property** | **Vinyl Ester Resin** |
|---|---|
| Purity | 99.9 % |
| Tensile strength (MPa) | 70 |
| Young's modulus (GPa) | 3.2 |
| Elongation | 350 % |
| Melt Point | 314 deg C |
| Density g/cm$^3$ | 1.07 |

**Table 2. Density of Hardener and Accelerator**

| **Density of Hardener and Accelerator** | |
|---|---|
| Cobalt napthalate as accelerator | 0.98 g/cm$^3$ |
| Methyl Ethyl Ketone Peroxide (MEKP) as catalyst/Hardener | 1.17 g/cm$^3$ |


**Figure 1. Vinyl Ester and Accelerator**

Specimens with vinyl ester matrix incorporating advanced elastic and crescent strength that could offer ample lifetime correlated to the same composites based on unsaturated polyester [13]. Vinyl ester resin of density 1.23 g/ml as matrix along with the curing agents such as methyl ethyl ketone peroxide, cobalt octovate and dimethyl acetamide [14]. Vinyl ester and for polyester, 2% methyl ethyl- ketone-peroxide (MEKP) and 2% cobalt napthalate (as accelerator) [11].The composites with three constituents were fabricated in the study including reinforcement, matrix and fillers. The matrix material was Vinyl Ester with curing agents Cobalt Octoate (0.1% by weight) and Methyl Ethyl Ketone Peroxide (1.0% by weight) [15]. Vinyl Ester Resin adapted as the matrix, Cobalt Naphthenate and Methyl Ethyl Ketone Peroxide (MEKP) were utilized as accelerator and catalyst respectively [9].

The proposed research work emphasizes the use of natural fiber for the fabrication of laminate for fiber reinforced polymer matrix composites. Jute is selected as fiber reinforcement owing to their expansive usage in structural engineering application. Jute fibers were supplied by Hanuman Poly Sacks & Jute Products, Hosur road, Bommasandra Industrial Area, Bangalore-562158, Karnataka, India.

**Table-3. Physical and Mechanical Properties of Jute fiber**

| **Property** | **Jute Fiber** |
|---|---|
| Density (g/cc) | 1.4 |
| Tensile strength (MPa) | 80 - 120 |

**Figure 2. Jute Fibers**

The mechanical properties of jute fiber hybridized with a glass fiber-based epoxy matrix are similar to those of clean glass epoxy composite. The prosthetic composite was created using woven mats made of the well-known plant fiber jute. Jute fiber mat made from prosthetic composites exhibits greater strength in contrary to wood polymer composite [11]. Jute fibers were used to prepare composite. Jute is readily available, very cheap and known as golden fiber due to its color. The jute fiber is extracted from the stem and ribbon of the jute plant [3].

In this current investigation, Fiber reinforced polymer nanocomposites are created using $Al_2O_3$ nano-fillers. $Al_2O_3$ nano nano-fillers used with a diameter of 30 nm.

$Al_2O_3$ nano-fillers were supplied by AdNano Technologies Pvt Ltd, #31L, 2nd Cross, KIADB Machenahalli Industrial Area, Shimoga-577222 Karnataka, India.

**Table-4. Mechanical properties of $Al_2O_3$ nano-fillers**

| **Property** | $Al_2O_3$ nano-fillers |
|---|---|
| Purity | 99 % |
| Average Particle Size | 30 nm |
| Melt Point | 2055 deg C |
| Density g/cm$^3$ | 3.9 |


**Figure 3. $Al_2O_3$ Nano Particles**

Good mechanical and tribological properties of polymers infused with nano-scale fillers are correlated to those that are filled with micro-scale particles [18]. The glass/vinyl ester composites which are extensively adopted in naval applications whose mechanical properties were enriched with infused filler particles (2 & 5%) [22]. Hardness, flexural and compressive strength were enhanced with elevated vinyl ester based nano $TiO_2$ particulates [17]. The tribo-fillers were (Poly Tetra Fluro Ethylene) PTFE, Poly Oxymethylene (POM )and Molybdenum disulfide ($MoS_2$) in 2 or 4 wt% filler content. This range of filler contents is based on literature survey and is expected to be sufficient to promote adequate transfer layer formation. Higher tribo-filler content not took into account, the reason being it cut down the mechanical properties significantly [13].

The investigations of the failure mode revealed that composites without any particles have exhibited matrix cracking, delamination and reinforcement failure in tensile and flexural mode. The incorporation of fillers also affects the abrasive wear behaviour of glass/vinyl ester composites. The addition of $SiC$ microparticles was found to reduce the wear volume and specific wear rate of the composite material [15].Comparison between hardness values measured for composites reinforced with micro and nano powders at similar concentrations shows that reinforcement with $Al_2O_3$ nano-powders result into higher hardness [18].The addition of $Al_2O_3$

Nano-particles (NPs) is enhancing the hardness, impact strength and tensile strength of the bamboo fiber up to 27%. Because, the presence of $Al_2O_3$ NPs improves the interfacial bonding between fiber and epoxy matrix [19]. The addition of $Al_2O_3$ and WC-Co particles could improve the hardness of epoxy coating while maintaining the toughness of the substrate, which is one of the reasons for the improvement of wear resistance [20].

### 2.2 Alkaline Treatment

The Figure 4 depicts the chemical reagents used for surface modification of jute fibers.

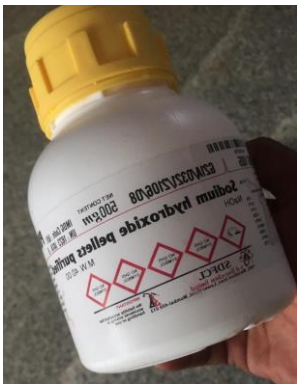



**Figure 4. Sodium Hydroxide Pellets**

**Figure 5. Chemical Treatment of Jute Fibers**

The surface modification by alkali (NaOH) treatment can improve fiber-matrix interfacial bonding, roughness, wettability, and the hydrophilic nature and can decrease moisture absorption, which can enhance the mechanical and dynamic properties [21]. A NaOH treatment process was exercised to optimize the mechanical properties of Jute fiber with variety of alkali concentrations and shrinkages. Shrinkage of the fibers unveiled the greater impact on the fiber structure that effectuates the elaborated mechanical properties [1]. Improved adhesive potentiality of the areca fiber with the matrix results in greater tensile strength of the composite material, particularly in the different densities of alkali, 5% alkali treatment produced the highest tensile

strength. Similarly, the effect of 4% alkali treatment on the tensile behavior of areca nut fibers was studied, for untreated areca nut / unsaturated [5]. On treating jute fiberwith5% NaOH solution leads to better interfacial adhesion and hence betterment in mechanical properties. The fiber was then dried in oven for about 1 h at $80^0$ C [11]. Alkali treatment is a powerful and cost-effective surface treatment for an extraction of cellulose. The solution for the alkali treatment was prepared by infusing 25 gm of NaOH pellets in half liter of water and stirred well until the complete diffusion of pellets and execute it on sisal and jute fibers for 12 h. Eventually, fiber samples were neutralized by cleansing with distilled water and finish off with bleaching. The cellulose emerges in whitish color at the instant hemicelluloses were the pulled out [4].

## 3. Fabrication of Vinyl Ester Composite

### 3.1. Hand Layup Method

Hand lay-up is a molding process (Figure 4) in which the fiber reinforcement is manually placed and then wet with resin matrix. The manual nature of hand lay-up process enables almost any reinforcement material to be considered, mat. In the same way, the blend of resin and catalyst can be manipulated to enable ideal processing conditions.

Mat Jute fibers are reinforced in vinyl ester resin of three different weight proportions (10wt%, 20wt% and 30wt%) to prepare the composites S1(vinyl ester +10wt% Jute fiber+1wt% $Al_2O_3$), S2 (vinyl ester +20wt% Jute fiber+1wt% $Al_2O_3$) , S3(vinyl ester +30wt% Jute fiber+1wt% $Al_2O_3$), S1(vinyl ester +10wt% Jute fiber+2wt% $Al_2O_3$), S2 (vinyl ester +20wt% Jute fiber+2wt% $Al_2O_3$) and S3(vinyl ester +30wt% Jute fiber+2wt% $Al_2O_3$) respectively. $Al_2O_3$ nano particulate filler is used in these composites.

**Figure 6. Hand lay–up process**

The composite slabs are made by conventional hand-lay-up technique. A mould box having dimensions of 260 × 260 × 5 $mm^3$ is used. A releasing agent (Silicon spray) is used for effortless elimination of the composite from the mould after curing. The curing of the Vinyl Ester Resin was accomplished by incorporation of 2% cobalt nephthalate (as accelerator) mixed thoroughly in the vinyl ester resin and then 2% methyl-ethyl-ketone-peroxide (MEKP) as hardener prior to reinforcement.

**Figure 7. Fabrication Details**

Hand lay-up is the oldest and simplest way of making fiber resin composites. Fibers can be laid onto a mold by hand and the resin is brushed on. Frequently, resin and fibers are densified with rollers. Curing may be done at room temperature or at a moderately high temperature in an oven [22]. The two specimens Bamboo Fiber Composite (BFC) and Nano particle ($Al_2O_3$) Bamboo Fiber Composite (NBFC) can be prepared with epoxy resin made by using hand lay-up technique [19]. Infusion of ZnS micro particulate has chosen in hand lay-up technique for the extensive fabrication of Jute fiber reinforced polymer matrix composites [1]. The manual hand lay-up process was used to create Jute/coir fiber reinforced polymer matrix composites. The wire hacksaw was used to cut the composite in the desired shape for testing of mechanical properties of fabricated composites [3].

## 4. Experimental Investigation

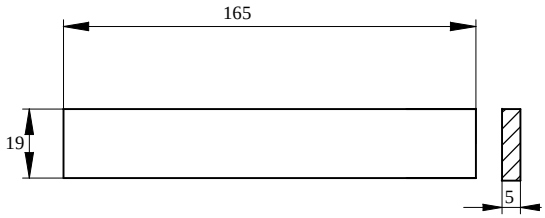
### 4.1. Tensile Strength

A tensile test machine can verify whether candidate materials pass the required strength and elongation requirements for a certain product. The digital UTM used for experimentation. All strips were attached at the tips of the specimen to prevent slipping. Figure 3.1 displays the digital tensile test machine.

$$\sigma_t = \frac{P}{A} \qquad (1)$$

$P$ = peak load in N, $A$ = Area in mm.

**Figure 8. Specimens for Tensile test**




**Tensile Test Specimen ( ASTM D - 638)**

Note: All Dimensions are in mm

**Figure 9. Digital UTM for tensile test**

### 4.2. Flexure Strength

The flexural test measures the force required to bend a beam under three-point loading conditions. A three-point bend test is conducted for finding out the curvilinear strength of the specimen. Crosshead speed is maintained at 1 mm/min (ASTM D 790-03, 2003). The attachment of 3-point bending is shown in Figure 3.6. The specimen has to be mounted only on the support so that, the center of the specimen touched the point of application of load on the specimen. Load is applied to the specimen at a particular time at the breakpoint of the specimen. At that point, the reading is taken as the load and deflection of the specimen. Five samples are chosen for every test and the results are averaged [5].

The specimens were fabricated as per ASTM-D790 standards to carry-out flexural tests using three-point-bending method. The flexural strength was with a relation shown below.

$$\sigma_f = \frac{3\,P\,L}{2\,b\,d^2} \qquad (2)$$

$P$ = peak load in N, $b$ = width in mm, $L$= span length, $d$ = thickness of the specimen in mm.

Under the flexural loading condition top layer under compression and bottom layer under tension, failure begins at the tension side of the specimen. Failure occurs due to matrix cracking and fiber breakage and Delamination at the compression side [2].

The fabricated specimens as per ASTM-D790 standards were adopted for flexural tests using the attachment of 3-point bending showcased in the figure 6.4. The specimen has to be mounted only on the support so that, the center of the specimen touched the point of application of load on the specimen. Load is applied to the specimen at a particular time at the breakpoint of the specimen. At that point, the reading is taken as the load and deflection of the specimen.

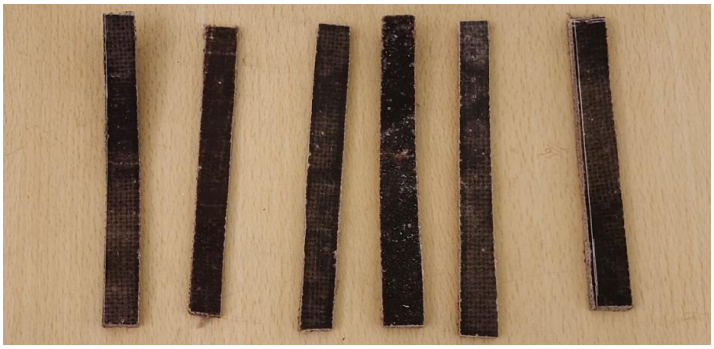
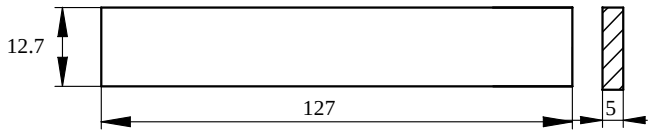


**Figure 10. Specimens for flexural test**




**Flexural Test Specimen ( ASTM D - 790 )**

Note: All Dimensions are in mm

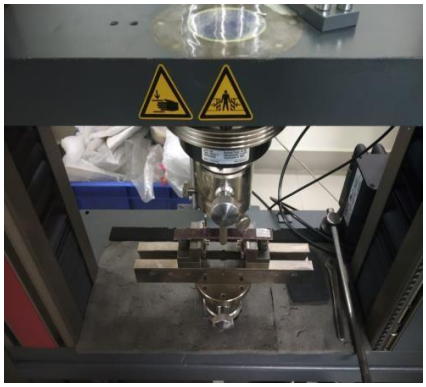


**Figure 11. Digital bending test machine**

### 4.3. Hardness

Hardness is the quality or condition of being hard or it is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials (Example: Metals) are harder than others (Example: Plastics) [5]. Hardness was calculated by Rockwell hardness (HRL) machine in accordance with the ASTM D785 standard [11].

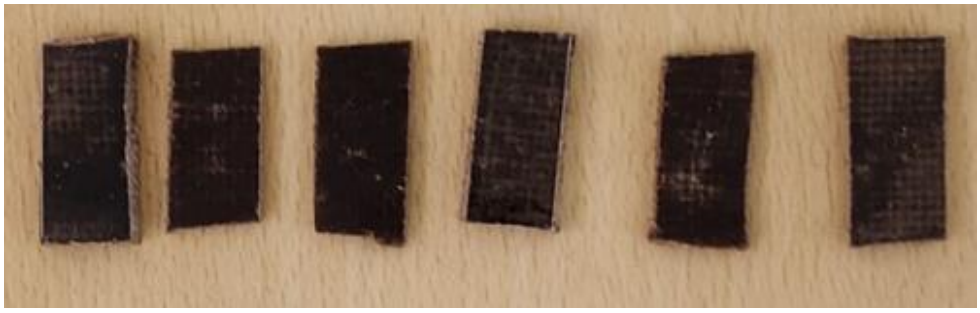
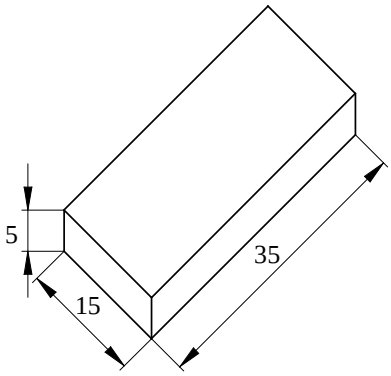


**Figure 12. Specimens for Hardness test**




**HardnessTest Specimen ( ASTM D - 785)**

Note: All Dimensions are in mm

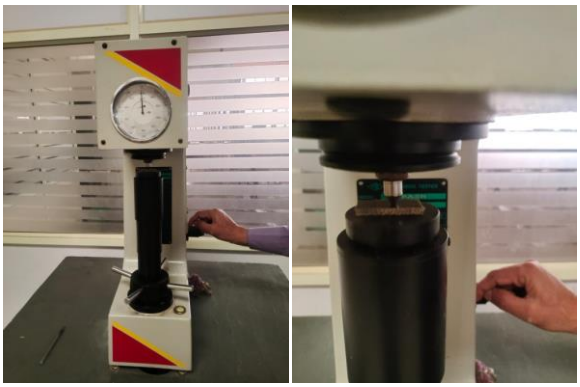


**Figure 13. Rockwell Hardness Test Machine**

## 5. Result and Discussion

### 5.1. Tensile Test

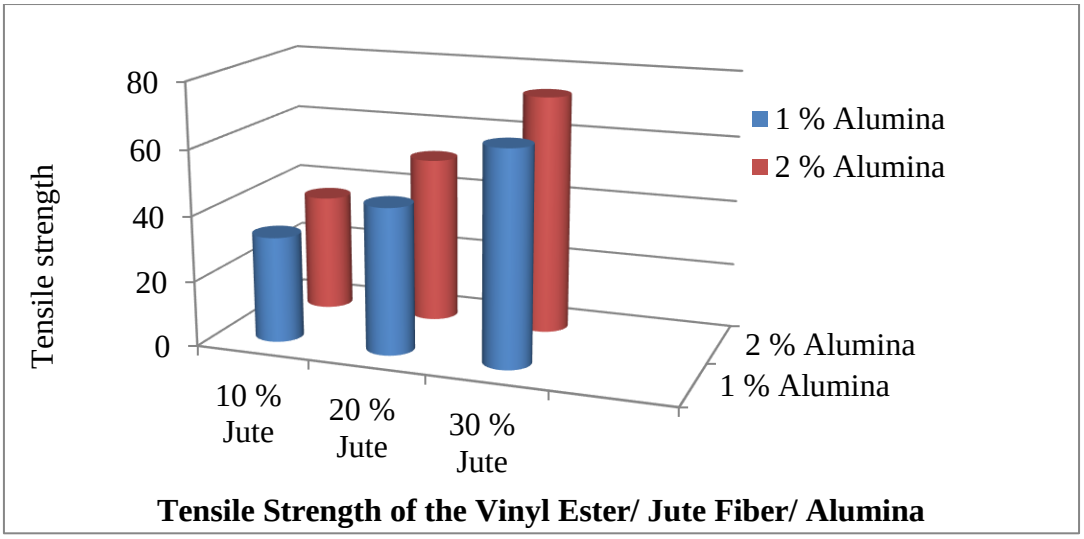



**Table 5. Tensile Strength of Composites**

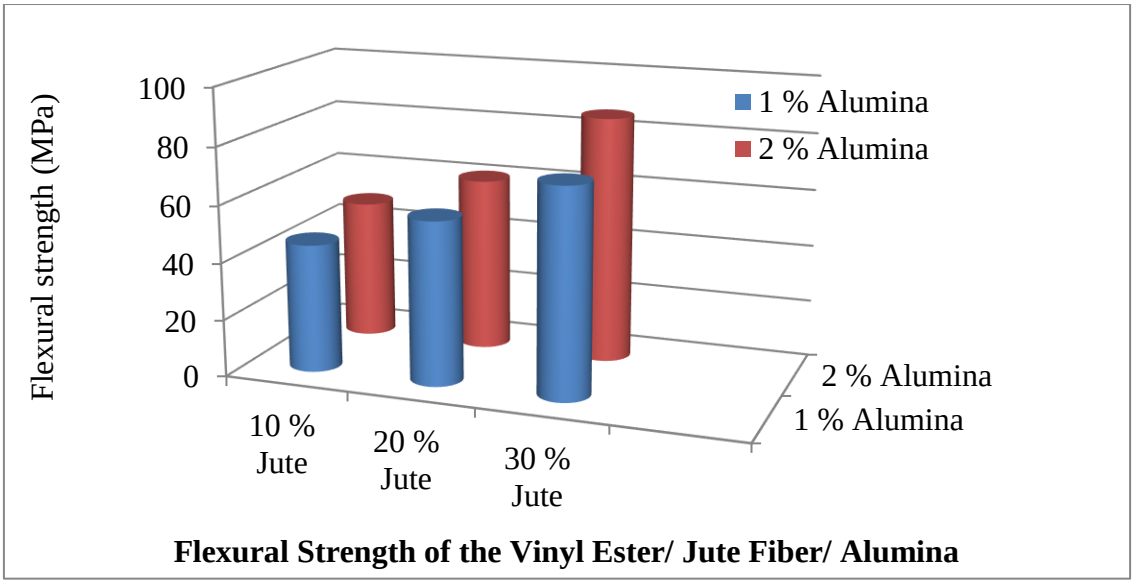
| Material ID | Tensile strength $\sigma_t$ (MPa) |
|---|---|
| S1 | 32.4 |

| | |
|---|---|
| S2 | 44.8 |
| S3 | 65 |
| S4 | 36 |
| S5 | 51 |
| S6 | 73 |

It is apparent that the sample has 30% of jute/ 2 % $Al_2O_3$ exposition maximum tensile strength 73 MPa)(6.9 kN) and specimen with jute 10% of jute/ 1 % $Al_2O_3$ exposition least tensile strength (32.4 MPa i.e., 55.6 % decline compared to specimen A6) among 6 specimens. Thus a material with maximum percentage of jute (30%) & $Al_2O_3$ (2%) can withstand higher tensile strength.

The specimen 30% of jute/ 2 % $Al_2O_3$ with the highest observed strain percentage at the fracture point and it's clearly shows that it reduces as the sample's percentage of jute reduced.

### 5.2. Flexural/Bending Test




**Flexural Strength of the Vinyl Ester/ Jute Fiber/ Alumina**

**Table 6. Flexure Strength of Composites**

| Material ID | Flexure strength $\sigma_f$ (MPa) |
|---|---|
| S1 | 45 |
| S2 | 57.4 |
| S3 | 73 |
| S4 | 49 |
| S5 | 61 |
| S6 | 86.3 |

It has been discovered that the material cannot sustain an increase in load such that the specimen fractures as soon as the load exceeds its maximum.

It is evident the sample has 30% of jute/ 2 % $Al_2O_3$ as reinforced fiber (specimen S6),

exposition maximum bending strength (86.3 MPa).

The maximum strain percentage at the fracture point is reported for specimens having 30% of jute/ 2 % $Al_2O_3$ it's clearly shows that it reduces as the sample's percentage of jute reduced. Specimen with less percentage of jute gives minimum strain percentage.

### 5.3. Hardness

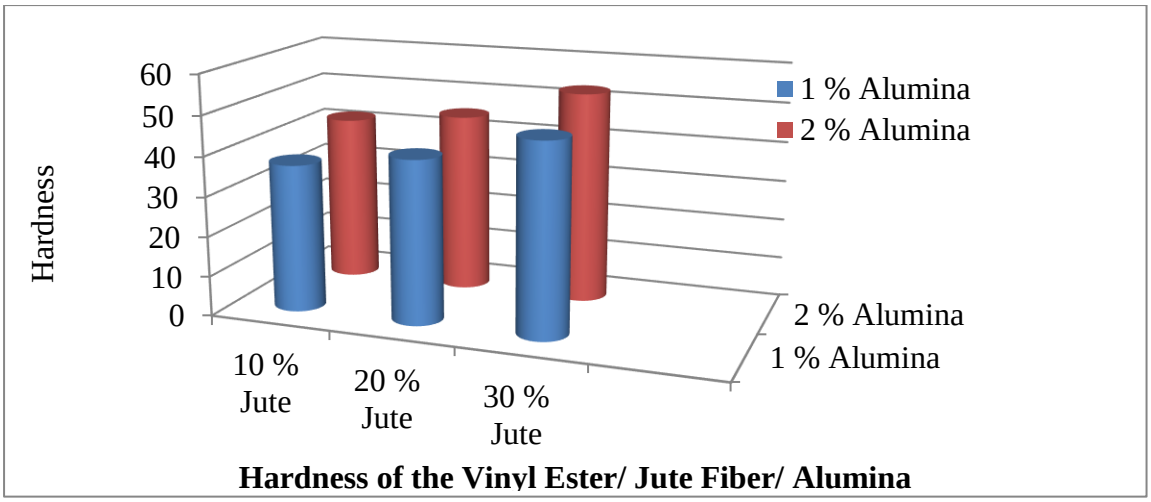



**Table 7. Rockwell Hardness Number of Composites**

| Material ID | Hardness (HRL) |
|---|---|
| S1 | 37 |
| S2 | 41 |
| S3 | 48 |
| S4 | 42 |
| S5 | 45 |
| S6 | 53 |

It is perceptible that material having 30% of jute/ 2 % $Al_2O_3$ material (specimen S6) recorded a hardness value of 53. The hardness value of this material increased among all evaluated composite materials, as a function of filler loading, especially with 2 wt% of filler content can be ascribed to the even distribution of the filler particles and a good fiber matrix interfacial bonding. From this the value of hardness is 53 and it is 1.43 times more than the specimen S1 impact strength. As a result, it may be said that this combination suits excellent for applications in which materials are subjected to indentation/penetration.

Also, it is noticeable that the composite material with combination of jute and $Al_2O_3$ as reinforced fibres yields a good Hardness value.

## 6. Conclusion

Tensile, flexure and hardness experimental investigation work has been proficiently effectuated regarding the creation of a natural composite employing jute as a reinforcing material, Vinyl ester resin as matrix material and $Al_2O_3$ nanoparticles as filler material in the ratio 10-30%:70-90%:1-2% respectively by hand lay-up method.

The prepared samples have been cut according to ASTM standards and following conducted tests viz. tensile, flexural, and hardness tests and the following conclusions have been made.

i. It is concluded that, the sample containing 30% of jute/ 2 % $Al_2O_3$ withstands maximum tensile strength.

ii. The sample containing 30% of jute/ 2 % $Al_2O_3$ withstands maximum flexural strength. It is perceived that, 1.9% increase in curvilinear strength of the sample containing 30% of jute as compared to the sample containing 10% of jute.

iii. Also, it is concluded that, the sample containing 30% of jute/ 2 % $Al_2O_3$ have maximum hardness number. It is observed that, 1.43% increase in hardness of the sample containing 60% of jute as compared to the sample containing 10% of jute.

It is highly recommended that, the composite containing 30% of jute, 68% of Vinyl ester % and 2% of filler material results highest bending and tensile strength in comparison to the other composites samples. It is also propose that, the composite containing 30% of jute, 68% of Vinyl ester and 5% of filler material gives impressive resistance against the surface indentations as compared to other.

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