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STUDY THE MECHANICAL PROPERTIES OF SESBANIA ROSTRATA FIBER REINFORCED POLYMER COMPOSITES

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Abstract

Researchers have recently become interested in natural fibers because they are accessible, affordable, and can be utilized to reinforce composite materials. The aim of the paper is to develop composite materials using Sesbania Rostrata (SR) fibers, Unsaturated Polyester resin (UP) and Calcium carbonate ($CaCO_3$) fillers. Before being reinforced with a hydrophobic matrix, 5% NaOH is used to treat the SR fibers in order to lessen their hydrophilic ability and to improve the fiber stability. With the compression moulding technique, composites are created while maintaining their weight of the 20 wt% treated SR fiber constant and altering the UP resin and $CaCO_3$ correspondingly. The samples are made in compliance with ASTM standards, and they are used to study the effects of fillers on fiber reinforced polymer composites. Among the several samples, the sample with 4% $CaCO_3$ addition in the UP matrix reinforced with treated SR fiber achieved the highest tensile strength (15.78 MPa), flexural strength (25.54 MPa), compressive strength (49.25 MPa), and impact strength (1.14 J). Moreover, $CaCO_3$ enhanced the water absorption (1.28 %) of the SR/UP composite due to the hydrophilic properties of the filler. The mechanically fractured samples are subjected to SEM (scanning electron microscope) for analysis internal structure to identify the reason for failure.

Keywords : Sesbania Rostrata fiber (SR), Unsaturated Polyester resin (UP), Sodium Hydroxide (NaOH), Calcium Carbonate ($CaCO_3$).

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1.Introduction

Researchers are searching for an alternative material as a result of the numerous environmental issues that synthetic fiber use has caused, since they are biodegradable and have a lower density than metals. natural fiber reinforced polymer composite materials interact more deeply than polymer matrix composite materials. Research has been done on natural fibers to discover their growing benefits and application. utilizing both plants and animals as well as a mineral base, natural fibers can be made. Plant fibers that are used as reinforcement in natural fiber composites are essential. Sesbania Rostrata fiber, a type of plant fiber, are rigid and have a robust structure, giving them exceptional mechanical properties. An identical method to enhance mechanical properties is fiber modification. Poor bonding caused by hydrophobic matrix reinforcement of plant fibers lowers the mechanical properties. This will enable the fiber to absorb more ambient water and create new hydrogen bonds on its surface, increasing its hydrophilicity. By subjecting the fibers to various chemical procedures, this hydrogen bond production can be minimized. Moreover, a greater amount of constituents including lignin, wax, pectin, and oily substances will be removed, improving the fiber's stability. It is concluded that treated fibers perform mechanically and permeability better than untreated fibers. The fiber is separated and its lignin content is reduced during the NaOH treatment of the fiber. According to Ganesan et.al, The effects of eggshell powder and nanoclay filler on the jute fiber/polyester composite's mechanical properties were assessed [1]. The author came to the conclusion that even though the composite had not undergone any chemical change, adding filler improved its mechanical qualities. NaOH-treated jute fiber has been strengthened with eggshell powder (1.5 %), nano clay (1.5 %), and polymer binder was able to reach a flexural strength of 39.52MPa. The use of filler stopped the crack from growing, which caused the rise.

The alkaline (NaOH) treatment strengthens the bond between the SR fiber and the matrix; also, the fiber becomes more brittle after 30 minutes of immersion in the NaOH solution. The treated SR fiber that was chopped into 5mm lengths and reinforced 20% wt SR Fiber's good bonding was achieved by combining unsaturated polyester resin with the SR fiber. By using fillers, it is feasible to further improve the polymer matrix's mechanical properties. According to Cheng et.al, adding $CaCO_3$ to bamboo fibers improved their compatibility with polypropylene matrix materials [2]. In comparison to composites reinforced with untreated bamboo fibers, the tensile strength and modulus of composites reinforced with treated fibers increased by 14.58% and 19.66%, respectively.

The main goal of the reinforcement are to make the composite material more rigid and powerful. composites with natural fiber reinforcing are commonly made with unsaturated polyester resin. According to S.M.Sapuan et.al, 100% UP resin without adding fiber, filler it gives result of tensile strength 8.14 ± 1.23.[3]. UP resin can, however, occasionally display low impact resistance, poor fracture toughness, and limited resistance to fatigue crack propagation. One can increase the toughness and strength of UP resin by fortifying it with various materials such glass fiber, natural fiber, glass powder, fly ash, etc. and hybridising them with $CaCO_3$, MnO_2, ZnO, egg shell, zinc powder, etc. Since the composite has improved physical and mechanical properties due to a specific type of matrix, it is employed in high-performance transportation systems, window panels, aerospace industries, and car parts.



2. Experimental Details

2.1 Materials: Sesbania Rostrata stems were used to manually collect fibers from farms around the Salem district of Tamil Nadu, India. Mercury Chemicals, located in Salem, Tamil Nadu, provides the chemicals, including sodium hydroxide, calcium carbonate, and acetic acid. Acetic acid and sodium hydroxide are used to treat the fiber router surface in order to increase fiber roughness.

Unsaturated polyester resin with MEKP as a catalyst serves as the matrix for creating the composite material. At the same time, cobalt octoate was used as a reaction accelerator. the catalyst, accelerator, and matrix (unsaturated polyester) were bought from covai seenu & company coimbatore, Tamil Nadu, India

2.2 Treatment of SR fibers: Sesbania Rostrata plant fibers were taken out and subjected to acetic acid and alkaline (NaOH) for surface treatments. For one hour, the SR fibers were submerged in 6 litres of purified water to wash away any unwelcome contaminants. The fibers are then permit to dry naturally for 24 hours. The extraction of SR fiber is shown in figure 1. To more effectively remove hydrophilic character, dried SR fibers are soaked in 5% NaOH. This composition of 5% NaOH is made by soaking 30 ml of NaOH for 30 minutes in 6 litres of water as shown in Figure 2(a). SR fibers that have been treated are extensively rinsed in distilled water while being added 1% acetic acid to get rid of the extra NaOH and extra chemicals After that, the fibers are left to air dry for a full day. as shown in Figure 2(b).

Figure 1

sample	**polymer**		**SR fiber (NaOH) Treated** (wt.%)
	UP resin (wt.%)	**CaCO3** (wt.%)	
S1	[illegible]	0	20
S2	[illegible]7	3	20
S3	76	4	20
S4	75	5	20

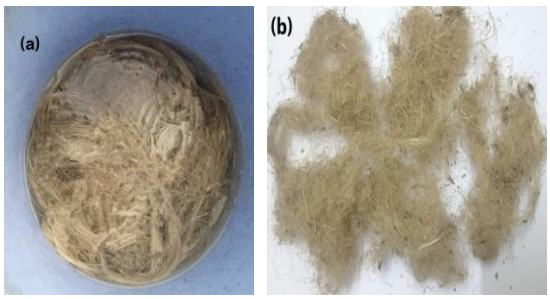

Figure 2 (a) NaOH treatment of SR fiber (b)After treatment of SR fiber.

3. Fabrication of Composite Materials

The samples were created using the compression moulding procedure after a hand lay-up. Using a cutter, the treated SR fiber was chopped into 5mm (the ideal fiber length) in accordance with the moulding constraints. 20% by weight of the treated SR fiber was used to create the composite samples, which were then used to build the composites.

After sealing the mould with mild steel plates, the fibers were added to the cavity and prepressed to create the chopped fiber mat. The accelerator (0.5% cobalt octoate) and catalyst (2% MEKP), which are used as binding agents, were mixed with polyester resin (97.5%). The compression moulding procedure uses aluminium plates with dimensions of 290 * 290 * 3mm.

For sample 1, the unidirectional placement of the 5% NaOH-treated SR fibers above the resin mixture. after the UP resin and hardener had been poured over the surface of the aluminum plate. The UP resin and hardener were then poured over the fiber. Further samples were made by repeating the technique described above while adding $CaCO_3$ fillers (0%, 3%, 4%, and 5%) to the UP resin. The created laminates are treated in a compression molding machinery for 45 minutes while being maintained at a constant 130 °C and 35 bpi pressure.

The laminates are then given 50 minutes to finish curing .The last laminate, measuring (290 * 290 * 3mm), is cut out of the mould using a diamond cutter.

The prepared laminate can undergo mechanical testing in accordance with ASTM standards. The composition of samples is displayed in Table 1.

Table 1: The composition of the samples

4. Mechanical and water absorption Test

4.1 Mechanical Test

From sample 1, Test specimen are displayed in figure 3.

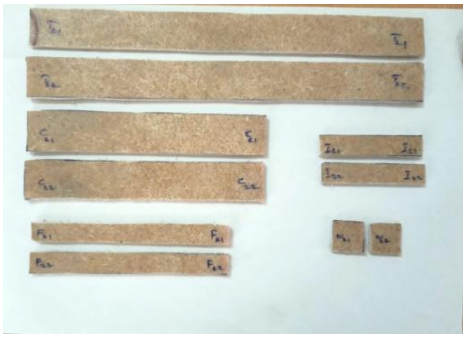

Figure 3 Test specimen

4.1.1. Tensile Test : It is a particular kind of mechanical test that evaluates how a material will respond to a load. The samples are produced in line with ASTM D3039 requirements and have the following dimensions: 250x25x3mm, crosshead speed: 2mm/min. It was tested using a computerized multipurpose testing device. The samples are mounted on the apparatus prior to testing, and a hydraulic mechanism is used to grab them in order to prevent dislocation. Each sample that is evaluated has its quality indicated. Four specimen of each composition of sample were evaluated in total, and the study makes use of the mean values.

4.1.2 Flexural Test: By performing this testing, a material's ability to bend under load is determined. The samples are constructed in compliance with ASTM D790 requirements and feature 125x13x3mm dimensions with a 2mm/min crosshead speed. Every sample testing outcomes are documented using a computerised universal testing device. Four specimen were utilized to evaluate each composition of sample and the analysis used the average value.

4.1.3: compression Test: The purpose of this test is to predict how the substance will react under compression. The test samples' 150* 25* 3 mm dimensions are produced in line with ASTM D3410 standard. A computerised universal testing apparatus was used to evaluate it, and the results for each sample were recorded. Each composition of sample was assessed using four specimen and the analysis used the mean.

4.1.4. Impact Test. It establishes the amount of tensile strength an object can resist when loaded. The samples for this test have dimensions of 65 * 13 * 3 mm and were produced in line with ASTM D256 requirements. Data for each sample were recorded and the Izod impact test was digitalized. The average value from four specimen of each composition samples is used for the analysis.

4.2 Water Absorption

This test allows for the determination of the material's water absorption resistance. The samples are 20*20*3mm in size and made in line with ASTM D5229 requirements. Samples are kept in purified water at ambient temperature for two days prior to the changes being noticed. Immersed specimen pieces After removed then allow for a specific time frame, the samples were cleaned using a cloth, and their weight is then determined. The following formula, in which Wb stands for the ultimate weight following immersion, Wa for the sample's starting weight, and W for the amount of water absorbed can be used to determine how much water was absorbed in a sample.

$$W = \frac{W_b - W_a}{W_a} * 100.$$

4.2. SEM Analysis: A scanning electron microscope (SEM) JEOL JSM-6510LA was used to examine the surface flaws, structural alterations and imperfection coating of the processed materials. The 25kV operational voltage necessary for this method.

5. Result and Discussion

5.1 Mechanical Properties

The manufactured composite materials underwent a variety of mechanical tests, and their qualities are assessed. The $CaCO_3$-filled SR/UP composite have a tensile strength of 15.78 MPa, as illustrated in Figure 5. Also, It exhibits a considerable amount of deflection while bending up until fracture, which increases bending power. According to Figure 11, the $CaCO_3$-filled SR/UP composite have a flexural strength of 25.54 MPa. Figure 15 demonstrates that, an $CaCO_3$-filled SR/UP composite has increased compression strength and a maximum strength of 49.25 MPa. With an impact strength of 1.14 J, the $CaCO_3$-filled SR/UP composite material is shown in Figure 18 to have good resilience to unexpected loads.

5.1.2. Tensile Strength. The mechanical behaviour brought on by a material's deformation as a result

of applied forces is referred to as tensile strength. A stress-strain analysis can be used to calculate tensile strength, Elongation at break and other properties. Test specimen is shown in Figure 4.

Figure 4 Before Tensile test specimen

The tensile values of each composite under varied loads is displayed in Figure 5. The maximum value for treated SR/UP composite reinforced with 4 weight percent $CaCO_3$ fillers was 15.78 MPa, and 0 weight percent $CaCO_3$ fillers has the minimum value was 9.81 MPa. moreover tensile strength improve when addition of $CaCO_3$ fillers and after a certain point, it starts to decline. The sample S3 with 4 weight percent $CaCO_3$ fillers had the highest tensile strength and best content, according to the results. Fillers made of calcium carbonate prevent water molecules from penetrating the fiber, resulting in good merging of the matrix and fiber. because the C-C bond in calcium carbonate filler is strong and it is challenging to rearrange, it is brittle by nature. Also, the treated SR/UP composite's 4 wt.% $CaCO_3$ reinforcement successfully bonded, and the calcium carbonate particles were distributed evenly throughout the matrix, increasing tensile strength compared to other $CaCO_3$ variations. A stronger interlock with fiber-matrix attachment was made possible by the 4 wt% $CaCO_3$ fillers, and if stresses is applied, they are shared evenly throughout the composite.

A tensile strength of 14.68 MPa was demonstrated in sample S4 by 5 wt% $CaCO_3$ fillers reinforced in treated SR/UP composite, outperforming the samples with 0 wt% and 3 wt% $CaCO_3$ fillers. The agglomeration of particles tends to develop with an increase in $CaCO_3$ fillers, and fracture propagation is prevented, indicating that the calcium carbonate fillers actually increase the composite's brittleness rather than its tensile strength. Due to the fragility of calcium carbonate, materials containing 5 wt.% $CaCO_3$ fillers will quickly begin the process of necking and eventually fracture

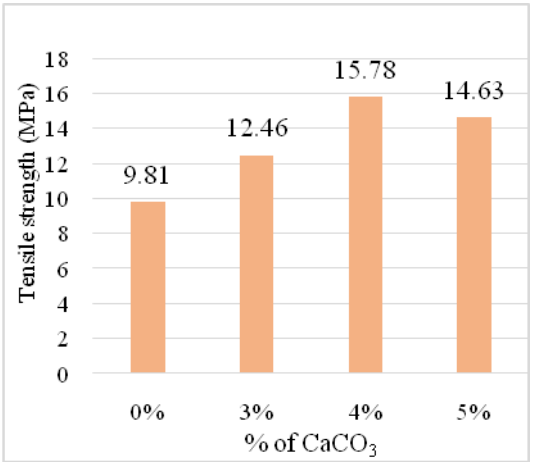

Figure 5 The tensile properties of $CaCO_3$-filled SR/UP composites.

The result for 3 wt.% $CaCO_3$ fillers was 12.46 MPa, which is higher than the values for 0 wt.% $CaCO_3$ and lower than those for 4 wt % $CaCO_3$ and 5 wt.% samples. This reduction is due to that, as refer to the 4% $CaCO_3$ filler sample, hence the concentration are insufficient to prevent void formation in the polymer. The tested specimen is shown in Figure 6. The tensile strength of the 5 wt% $CaCO_3$ filler sample was 14.63 MPa, it is higher than the tensile strength of other calcium carbonate samples but lower than that of 4 wt% $CaCO_3$. Comparatively less empty content was reduced at this concentration than in other $CaCO_3$ samples.

Figure 6 Tested specimen of Tensile Strength

The SR fiber in sample S1 is reinforced with UP resin and treated with 5% NaOH to eliminate the non cellulosic components in large part. The elimination of contaminants is what allows for the tensile strength of 9.81 MPa to be achieved, however some constituents tend to deteriorate and

generate voids, making it easier for water to penetrate and losing tensile strength.

The stress-strain curve as shown in Figure 7 that represents the highest values ever observed in relation to the four different composite versions. The composite's increased stiffness from the addition of filler may be the cause of the decrease in strain observed with an increase in tensile stress.Young's modulus of tensile test is shown in Figure 8

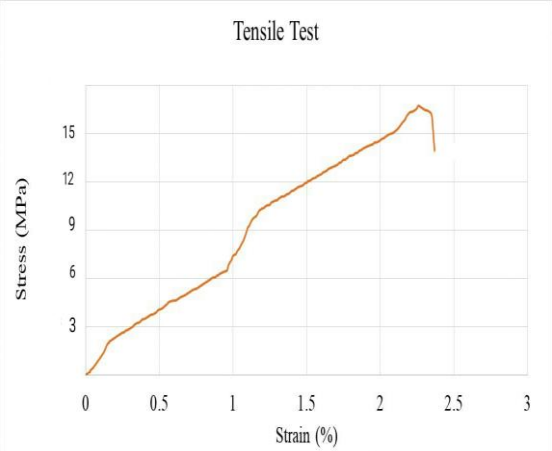

Figure 7 Stress-strain variation comparison of composite variants.

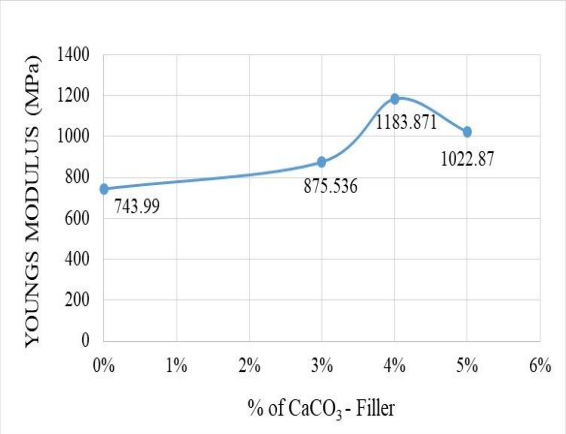

Figure 8 Young's Modulus of Tensile Strength

Sample S1 had the lowest average value of 2.06%, as shown in Figure 9, while sample 3 had the highest value of 4.13%.

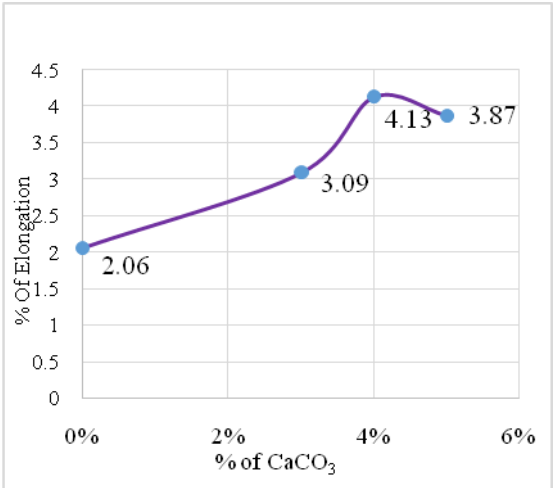

Figure 9 Elongation at break of $CaCO_3$-filled SR/UP composites

5.1.3 Flexural Strength. The test specimen for flexural strength is shown in Figure 10.

Figure 10 Before Flexural test specimen

The results of the flexural test for each sample is displayed in Figure 11.

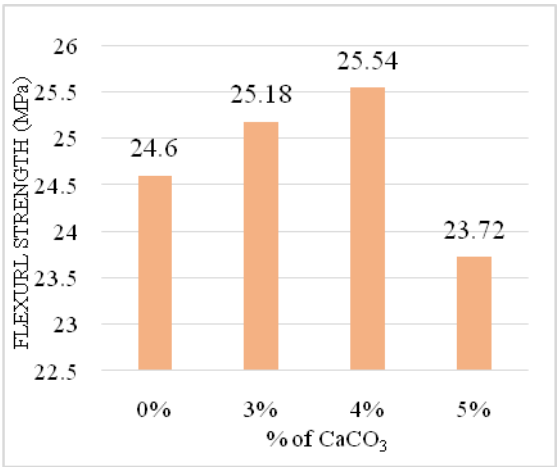

Figure 11 Flexural strength of $CaCO_3$-filled SR/UP composites

With a flexural strength of 25.54 MPa, sample S3 is the strongest, followed by samples S4 (23.72 MPa), S2 (25.18 MPa), and sample S1 (24.6 MPa). Because the 4 weight percent $CaCO_3$ fillers enhanced contact bonding and achieved higher load sharing, Sample S3 displayed the highest flexural strength. Also, the addition of 4 weight percent of calcium carbonate found to be the ideal concentration since the fillers are evenly distributed throughout the matrix, decreasing holes and improving flexural characteristics. Sample S2 has a flexural strength of 25.18 MPa, it is higher than all other samples but lower than sample S3, was produced using 3 wt.% $CaCO_3$ fillers. This is because 5 weight percent $CaCO_3$ fillers generated agglomeration in that matrix and caused inappropriate contact bonding in the middle of the fiber and matrix when reinforced with treated SR fiber.

The flexural properties of the composite begins to deteriorate with the addition of 5 wt% $CaCO_3$ due to delamination between the layers. Moreover, the 5 weight percent $CaCO_3$ fillers did not spread evenly, resulting in some debris in that area. The tested specimen is shown in Figure 12.

Figure 12 Tested specimen of Flexural Strength

The sample showed that the composite had decreased flexural properties and increased brittleness when the load was applied. When contrast to samples with 4 wt% CaCO3 and 3 wt% $CaCO_3$ filler, samples 4 and 1 have filler concentrations of 5 wt% $CaCO_3$ and 0 wt% $CaCO_3$ that are insufficient to prevent void formation, This results in surface fiber pull-out and reduced flexural strengths of 23.72 MPa and 24.6 MPa, accordingly. In sample S1, treated SR fibers eliminated that fiber's hydrophilicity and had a strong connection to the matrix. However, the microgaps in the composite prevented the load from being distributed evenly, which caused a reduction in flexural strength of 24.6 MPa when compared to samples of $CaCO_3$ filler with different porosities. Young's modulus is shown in Figure 13. Sample S1 has the lowest value, 877.849 Mpa, while sample S3 has the highest value 1727.119 Mpa.

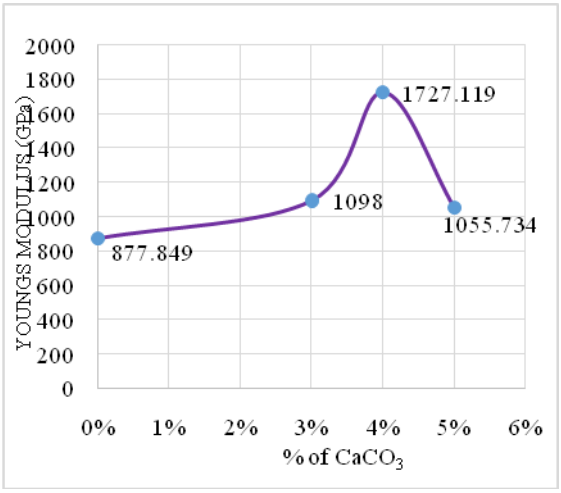

Figure 13 Young's modulus of $CaCO_3$ filled SR/UP composites**.**

5.1.4 Compression Tests. The test Specimen are shown in Figure 14.

Figure 14 Before Compression test specimen

The results of each sample's Compression test values are displayed in Figure 15. Sample S3 has a compression strength of 49.25 MPa, which is higher than Sample S4's (46.63 MPa), Sample S2's (40.2 MPa) and Sample S1's (34.51 MPa). Because the matrix's 4 wt% CaCO3 fillers enhanced the interface's bonding and enabled superior load sharing, Sample S3 displayed the maximum compression power. Moreover, 4 weight percent of calcium carbonate addition found to be the ideal concentration since the fillers are evenly distributed throughout the matrix decreasing holes and improving the compression properties as a result. Sample S4 has a compression strength of 46.63 MPa, it is lesser than sample S3 and greater than all other samples because it was made with 5 wt%

$CaCO_3$ fillers. This is due to the reinforcement of treated SR fiber with fillers containing 5% $CaCO_3$ in the matrix caused agglomeration and poor bonding strength between the fiber and matrix.

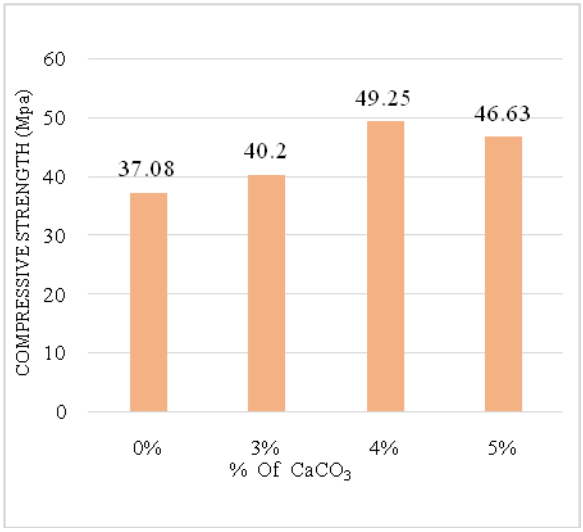

Figure 15 Compressive strength of $CaCO_3$-filled SR/UP composites

The Tested specimen for compression Strength is shown in Figure 16.

Figure 16 Tested specimen of Compression Strength

5.1.5 Impact Strength. The test specimen is shown in Figure 17.

Figure 17 Before Impact test specimen

The amount of energy that a substance can absorb while loaded is determined. Figure 18 displays the results of this test for each sample. Maximum and minimum impact strengths for Sample S3 and S1 were 1.14 KJ/m^2 and 0.96 KJ/m^2, respectively. The sample S3 4 wt% $CaCO_3$ fillers had the highest impact strength (1.14 KJ/m^2) as 4 wt% $CaCO_3$ fillers. Before brittle behaviour started, the calcium carbonate addition absorbed more energy. This occurs due to increased interaction between the matrix and fibers brought about by the matrix's optimal concentration of calcium carbonate.

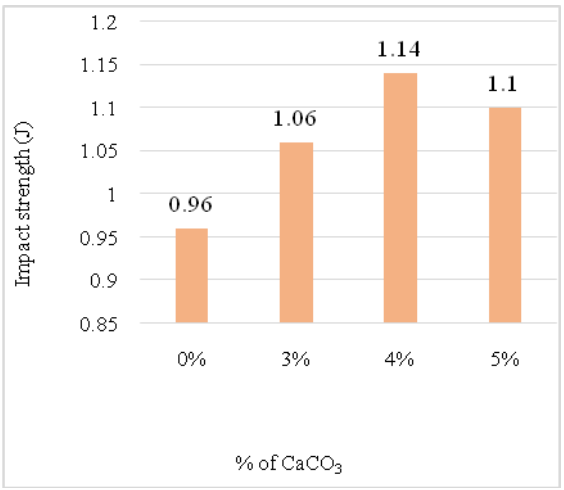

Figure 18 Impact strength of $CaCO_3$-filled SR/UP composites

The composite's toughness, the compatibility of the fiber & matrix, the appropriate dispersal of the filler substance into the matrix are all factors that affect the increase in impact strength. The impact strength of sample S4's 5 wt% CaCO3 fillers was 1.10 KJ/m^2, which is higher than the impact strength of the samples with 3 wt% $CaCO_3$ fillers. 4 wt% More energy was absorbed by $CaCO_3$ fillers than 5 wt% $CaCO_3$ fillers. The tested specimen is shown in Figure 19.

Figure 19 Tested specimen of Impact Strength

The impact strength of the 4wt.% $CaCO_3$ filler in Sample S3 was (1.14 $KJ/m^{2)}$, which is greater than the impact strengths of the 0 wt.% $CaCO_3$, 3 wt.% $CaCO_3$, and 5 wt.% $CaCO_3$ filler samples. This is due to the composite becoming less ductile as a result of $CaCO_3$ particle aggregation in the matrix area, which also reduced the composite's impact strength.

5.2 Water Absorption Tests. To find out whether the fibers are hydrophilic, use this test. The specimen during water absorption test is shown in Figure 20.

Figure 20 specimen for water absorption

The results of testing for water absorption in each sample are shown in Figure 21. In comparison to other samples, Sample S4's treated SR/UP composite reinforced. with a 5-weight percent $CaCO_3$ filler demonstrated a greater ability for water absorption.

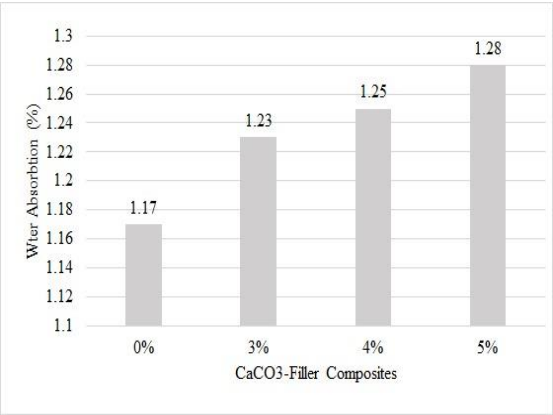

Figure 21: water absorption of CaCO3-filled SR/UP composites

5.3 Scanning Electron Microscope (SEM) Analysis:. SEM pictures showed that SR fiber and UP resin were not sufficiently bonded. Sesbania Rostrata fibers treated with UP resin demonstrated fiber pullout, matrix fracture, and matrix-fiber debonding under tensile and impact stress. It was evident from the findings of the tensile and impact fractography that NaOH-treated SR fiber with unsaturated polyester was effective. In short NaOH-treated SR fiber with UP composites, matrix and fiber breakage was the most frequent failure mechanism under tensile and impact loading.

The SEM Analysis: The SEM image of Sample S1 is displayed in Figure 22, whatever is made up of 20% SR fiber reinforced with UP resin and treated with 5% NaOH. The removal of the noncellulosic components in this sample left it with a rough surface, but the treatment also left a few microholes in the matrix. These microholes could cause stress concentration, which would deteriorate the composites mechanical properties. The 3 wt.% $CaCO_3$ addition in sample S2 as shown in Figure 23 combines effectively also with matrix by partially preventing voids development, increasing water absorption, and improving the interfacial binding over the 0 weight percent $CaCO_3$ filler sample. Figure 24 illustrates the sample S3, treated SR/UP composites with 4 wt% $CaCO_3$ filler reinforcement demonstrated good bonding and low matrix void content.

The SEM image of sample S3 is shown in Figure 24, which demonstrates appropriate Between the fiber and matrix, there is interfacial attachment, no fiber pull-out, and well- dispersed $CaCO_3$ with the matrix. Pull-out fiber results from $CaCO_3$ inclusion in the matrix of greater than 5% by weight. The SEM picture of sample S4 in Figure 25 shows that there is a 5 weight percent $CaCO_3$ integration with the matrix. Due to this aggregation in the matrix region, the fiber and matrix had weak interfacial adhesion. Because of the inadequate the fiber/matrix interaction inability to transmit enough stress, the mechanical characteristics of the composites severely deteriorated.

Figure 23 illustrates the severe fiber/matrix debonding with nanofillers that resulted from poor interfacial attachment between both the fibers and the matrix. Lower/higher weight fractions of $CaCO_3$ were observed to have excess vacuum and the composites (S1 and S2) have microscopic pores, which would reduce the mechanical properties of the nanofillers by lessening their reinforcing action.

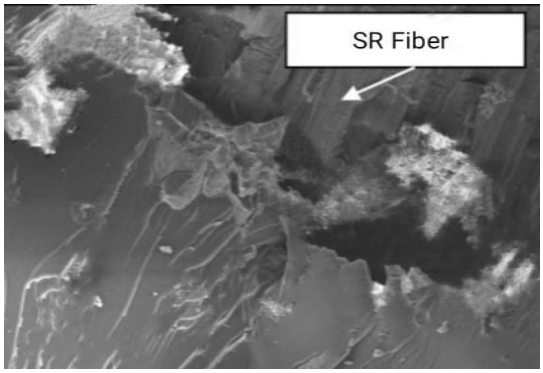

Figure 22 SEM image of sample S1

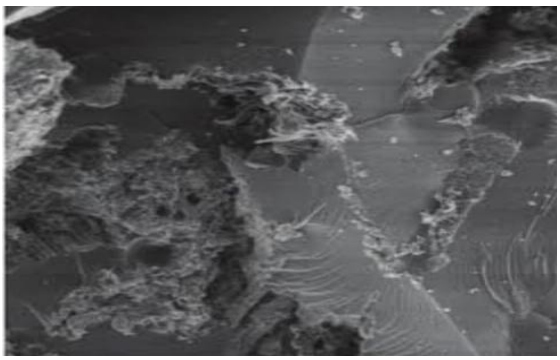

Figure 23 SEM image of sample S2

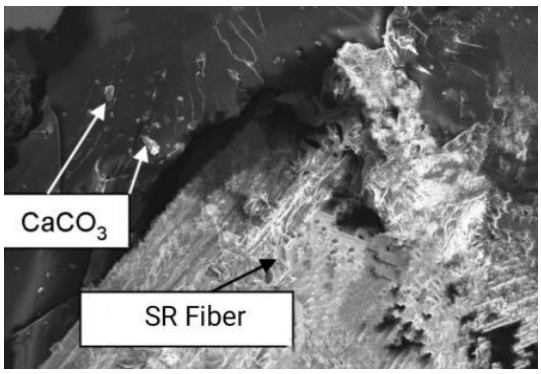

Figure 24 SEM image of sample S3

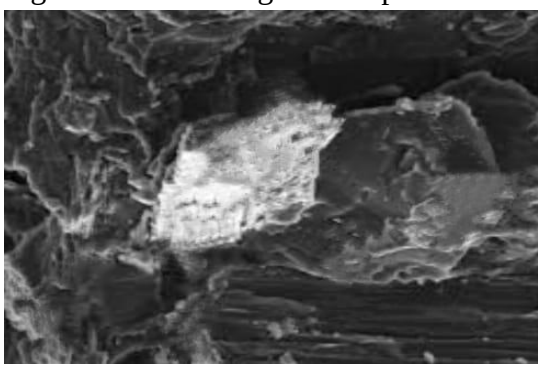

Figure 25 SEM image of sample S4

6. Conclusion

By using various Calcium carbonate filler concentration used as a reinforcement with Sesbania Rostrata/Unsaturated Polyester resin, Mechanical and water absorption test are performed. Increment in mechanical properties strongly dependent on the uniform distribution of Calcium carbonate in matrix. The major findings of incorporating Calcium filler in treated Sesbania Rostrata fiber/Unsaturated Polyester resin are discussed as follows. The investigation proved that the addition of Calcium carbonate improved the mechanical performance of the composite material stability. With 4 wt% of $CaCO_3$ reinforced in treated SR/UP composites it gives a better result While 5 wt% $CaCO_3$ filler reinforced in treated SR/UP composites, the properties like tensile, flexural, compression and impact strength start to decline. Calcium carbonate is basically hydrophilic in nature, Hence it penetrate with water. Since the composite contains 5 wt.% $CaCO_3$, It has embrittled, generating agglomeration in the matrix and a loss of mechanical characteristics. The morphological surface of different Calcium carbonate concentrations reinforced in treated SR/UP composites is investigated by SEM analysis. The perfect sample was discovered in 4 wt.% $CaCO_3$ filler and this sample showed stronger bonding in the SEM investigation with no fiber pullout.

Reference

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