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Mechanical, Thermal Conductivity and Water Absorption of Hybrid Nano-Silica Coir Fiber Mat Reinforced Epoxy Resin Composites

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Abstract: *The goal of this research is to show that epoxy resin (ER) / coir fiber mats (CFM) hybrid composite laminates with nano-silica particle (NP) reinforcement improve mechanical characteristics and water absorption. Lately, it has been employed in automotive, aerospace, and structural industries where coir fiber-reinforced polymers are safe for ecologically friendly composite applications. The Compression - Hand layup technique is used to make the epoxy composites reinforced with natural coir fibres and nano-silica particles in various weight fractions (5, 10, 15, 20 and 25% by weight). Mechanical parameters such as tensile, flexural, compressive, impact strength, thermal conductivity and also water absorption of composites are evaluated in this study. Scanning electron microscopy is also used to analyze the surface morphology of cracked surfaces (SEM). Hybrid nanosilica-coir fiber mat reinforced epoxy resin has decreased water absorption (percent) suggesting better mechanical qualities. Furthermore, the hybrid epoxy-containing 20% nano-silica coir mat improves all the said mechanical properties.*

Keywords: *coir fibre mat, epoxy resin, hand layup method, limestone, hybrid composites*

1.Introduction

FRP composites are made by incorporating fibers into a polymer matrix (polyester, epoxy, etc.) [1]. Fibers such as E-glass fiber [2, 3], aramid fiber [4, 5], etc., are reinforced polymer composites that give outstanding mechanical qualities in all aspects. But at present, a minor disadvantage is owing to degradability, renewability, and environmental considerations. It is possible to include both natural and synthetic fibres into the polymer matrix to increase the tensile strength of hybrid composites.

Recently, adding renewable and nonrenewable natural fibres to polymeric materials has produced composites with improved physical and chemical characteristics [5]. Fibers from plants like sisal and pineapple are used to reinforce the current trend of making green composite materials instead of synthetic fibers like glass fibers [6]. Naturalfibers are made from renewable resources. So, they help provide a natural, ecologically friendly environment. which alsoimproves corrosion and surface-related tribological performance. Fiber-reinforced plant and animal-based composites are still employed daily for specific structural and non-structural applications. Cellulose, hemicelluloses, and lignin make up the bulk of natural fibers [7]. Natural fibers are used to make loops, belts, wires, ribbons, mats, blankets, caps, baskets, and sacks [8, 9]. It has been shown that natural fibre is less stable at high temperatures and may not be suitable for matrix reinforcement in particular fibres" [10], which may lead to higher

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water absorption by the thread and weaker interactions between the thread and the surfaces.

The chemical modification of fiber surfaces is critical for improving matrix binding and lowering fiber moisture content [11]. Incorporating natural fibers into epoxy resin, such as Prosopis juliflora, Abuliton Indicum, and Tapsi (T), creates straws formed from these fibres. The composite's tribology (wear) and mechanical characteristics are greatly enhanced due to their addition. For natural fiber composite materials with more incredible mechanical qualities and environmental compatibility, hydrophobicity of the natural fibers must be achieved either by chemical changes with suitable adhesion promoters or by coating them with appropriate resins. Fiber lengths, coarse architectures, and cell wall rigidity all play a role in connecting cells in plants [12]. The link between natural fibers and matrix is strengthened by chemical and physical treatment of natural fibres [13]. The physical-chemical treatment removes wax, lignin, and oil from natural fibers. The bonding of fibers to a polymer matrix is improved by increasing the fiber's surface roughness [14].

Using Lapox L-12 matrix resin composites and NaOH to remove lignin and hemicellulose from Setaria italic fibers, the mechanical properties of the composite have been enhanced. Prosopis juliflorafibre and epoxy matrix resin composite, interlayer bonds are strengthened by alkali treatment, reducing fat on the fibre surface. Agro waste fillers may be used as reinforcing agents in polymer composites to alter their tribological and mechanical characteristics [15]. Hybrid natural fillers such as coir (rice hull), wheat raw materials (gum rosin), pine bark, and rosin are excellent for cost-effective mechanical property enhancement. Most rice is grown in India, Indonesia, and China [16]. Therefore, rice husks are a significant issue in this agricultural industry. Rice hulls may be used as a natural filler in polymer composites because of their high water content [17]. As a result, the number of natural fibres with improved mechanical qualities has increased dramatically.

Agave grass sisal fiber is a durable and long-lasting alternative to cotton-polyester resin with sisal fibers. Handmade mats have a lower elastic modulus than machine-made ones [18]. Composites made of polymer and agricultural waste may have better sliding wear and impact energy [19]. Micro-and nano-sized white bamboo fibers, steam detonation, alkaline curing, and micro-grinding have been utilized to improve mechanical properties [20]. The mechanicalattributes of coconut/cotton fiber bonded with unsaturated polyester make it suitable for packaging [21]. It was shown that the chemically treated coir pith is reinforced with nylon/epoxy composites. Alkaline treatment of coir pith increased its mechanical characteristics. The link between coir, nylon, and epoxy resin was improved by Narendar et al [22]. Different concentrations of NaOH were used by Huang Gu to determine the tensile behaviour of the coir and related composites after NaOH treatment. According to this study, Coir tensile strength is increased in 2 per cent NaOH solutions [23].

With this in mind, in this research paper,

1) The compression hand layup method is used to make hybrid composites from coir fiber mats with nano-silica particles (5, 10, 15, 20, and 25 wt %) in each compositionally reinforced epoxy matrix.

2) To investigate the mechanical characteristics, such as tensile strength, compression strength and flexural strength of hybrid composite materials.

3) To investigate the thermal conductivity and the water absorption of hybrid composite materials.

4) The morphological study of the hybrid composites is evaluated using SEM.

2.Materials and methods

2.1. Materials

Matrix materials used in this investigation are the epoxy resin (Araldite LY556) and hardener (Aradur HY951) used in this investigation for chemical reaction. Reinforcement materials used in this investigation are 450 g/m^2 coir bidirectional woven roving mat (WRM) and Nanosilica with a *p*H value of 3.8.

2.2 Preparation of laminates

Laminates are constructed by stacking three layers of unprocessed coir fiber mats (300mm length, 300mm wide and 3mm thick). First, the nano-silica and hardener (HY951) weight fractions (5%) are combined with epoxy resin (ER) in a high shear mixing process at an optimal speed of 1050 rpm for 30 min. The resulting mixture is then applied to coir mats for coating. Next, 500-600 N weight is put over the mould to compress the composite laminate; the resin filler mixture has been poured into the mould. Next, a pressure of 5 bar is applied to the mould. For 10 h, the laminates are cured in a vacuum at a temperature lower than room temperature. Next, the laminates are collected and then cured at 65°C for two hours to create coir mats reinforced with nano-silica particles. ER is also used to strengthen coir matting (10, 15, 20 and 25% by weight). Figure 1 shows the compression hand layup technique used to make each volume percentage of nanoparticle loading.

Table 1. Composition of natural fiber mats (Coir fiber mats) reinforced epoxy resin blender nanosilica particles composite

Primary material	Laminates specification	Matrix	Reinforcement
Coir Fiber Mat (CFM)	L 1	Epoxy Resin (ER)	Untreated CFM + 5 wt% (NP)
	L 2	Epoxy Resin (ER)	Untreated CFM + 10 wt% (NP)
	L 3	Epoxy Resin (ER)	Untreated CFM + 15 wt% (NP)
	L 4	Epoxy Resin (ER)	Untreated CFM + 20 wt% (NP)
	L 5	Epoxy Resin (ER)	Untreated CFM + 25 wt% (NP)

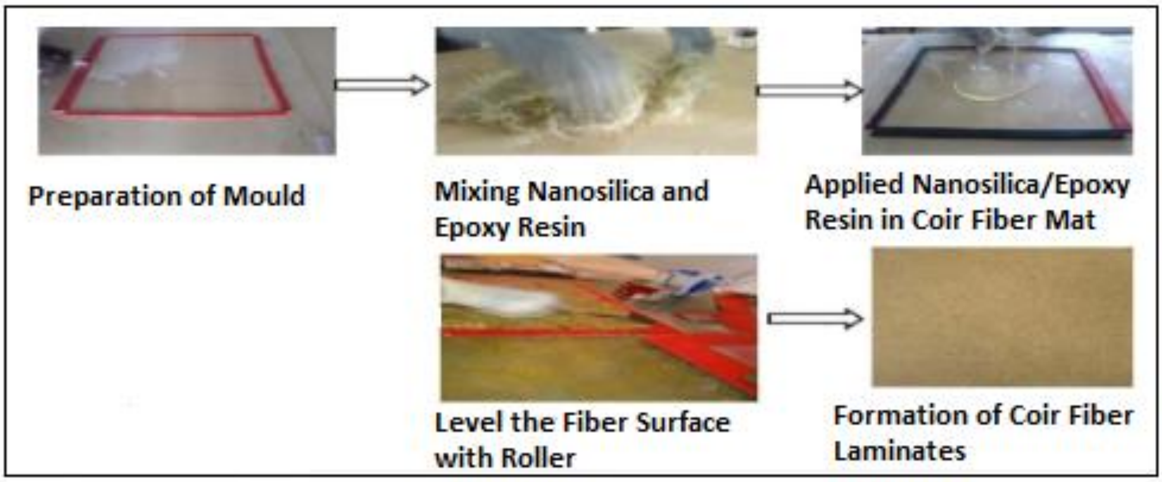

Figure 1. Hand layup technique for manufacturing of natural fiber mats (Coir fiber mats) reinforced epoxy resin blender nano-silica composite

2.3. Composite characterization

A series of tests, including impact, tensile, compression, and flexural tests, are used to evaluate the mechanical properties of the composites. For each category, the mean values are computed using five specimens. All the testing standards and equipment utilized in this project are described here:

2.3.1. Tensile and compression testing

On a piece of universal electromechanical testing equipment, the composites are subjected to tensile and compressive strength tests following ASTM D638, as seen in Figure 2, accessible from Met Mech Engineers Laboratory. Chennai.

Figure 2. Universal Testing Machine

2.3.2. Flexural testing

Using the Electromechanical Universal Testing machine using three-point flex mode, the composites are tested for flexural strength and flexural modulus as per ASTM D790. Figure 3 show the sample dimensions and samples. In addition, the test specimens' deflections are measured until they break under compressive stress.

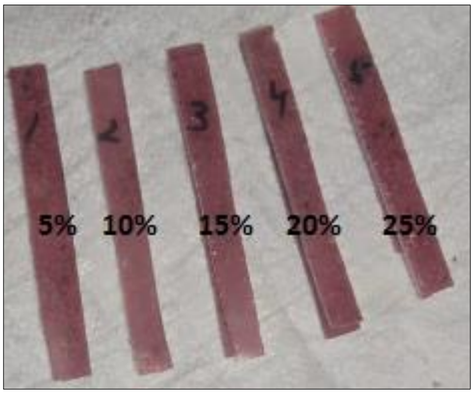

Figure 3. Flexural Specimen of Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

2.3.3. Impact test

ASTM D256 impact testers (Model: TM IT:30 and Manufacturer: EIE Instruments PVT LD) is used to determine the impact strength of the composites. The Izod Impact Machine has the following specifications: pendulum weight 1.3 kg, drop height 0.204 m and impact speed 3.857 m/s. The sample size is 65.5 mm in length, the width is 12.7 mm, and the thickness is 3.32 mm. The depth of V-Notch is 2 mm with an angle of 45°. The dial gauge on the Izod Impact machine displays the impact energy of various samples.

2.4. Water absorption test

Water absorption (%) is calculated according to the ASTM D570 standard for composite samples. The dimension utilizedsample specimen is 25.4 x 7.62 x 3 mm. Equation 1 for computing the percentage of water absorption is:

$$\% \text{ Water absorption} = \left(\frac{(W_f - W_i)}{W_i}\right) \times 100 \qquad (1)$$

where: W_i -sample's initial weight (gm) before immersion and
W_f - the sample's final weight (gm) after water immersion.

2.5. Fractography study

Using a HITACHI-S3400N scanning electron microscope (SEM), researchers examine the mechanical characteristics and morphological analyses of gold-coated composite samples that have been exposed to a sputter coater for 20 min. Magnification ranges from 5X to 30000X, and resolutions vary from 0.3 to 30 kV. (3nm -10nm).

3.Results and discussions

3.1. Tensile strength and Compression strength

Coir fiber mats reinforced epoxy resin matrix composite's response to the addition of NP (nano-particle filler) is seen in Figure 4a, b. ER composites reinforced with coir mat and 20% nanoparticle filler have a maximum tensile and compressive strength of 183.2 N/mm^2 and 163 N/mm^2, respectively. However, despite the inclusion of nanoparticle filler in the untreated fiber reinforcement, the tensile and compressive strengths increased linearly up to a weight addition of 20% by weight of nanoparticle filler and then decreasing by addition of 25% by weight of nanoparticles. The enhanced, durable fiber matrix adhesion and more excellent matrix bonding cover the entire fiber surface [24] are blamed for this improvement. However, the resin has a more challenging time impregnating the fibers when there is a large proportion of reinforcement, which results in poor interfacial bonding and the corresponding reduction in tensile strength [25].

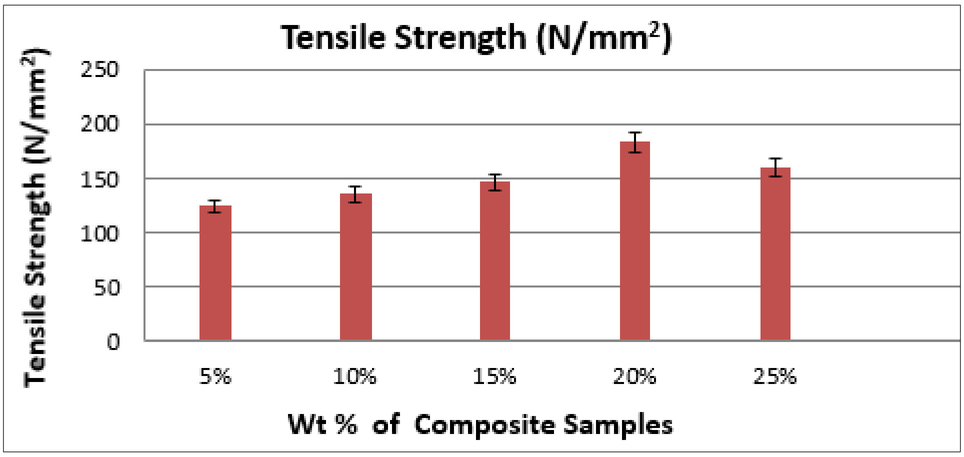

Figure 4a. Tensile Strength results for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

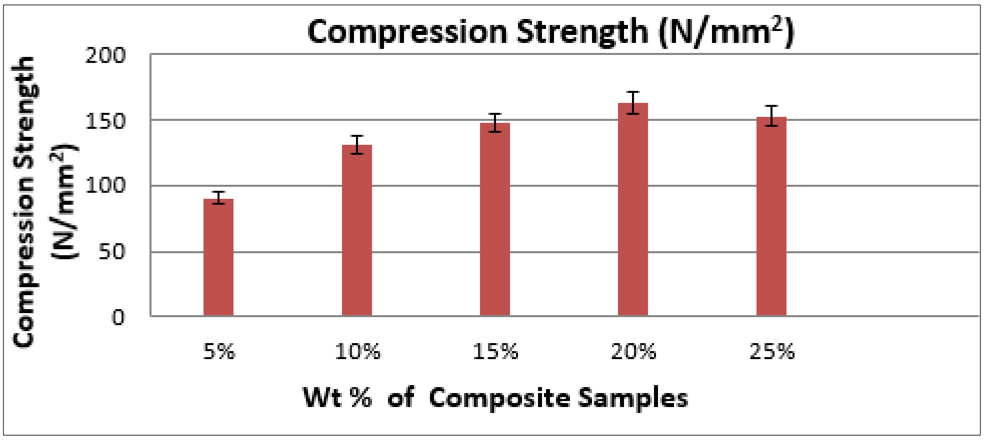

Figure 4b. Compression Strength results for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

3.2. Fractography observation

SEM Interpretation were made for all the specimens prepared with various weight percentages. Tensile strength may be enhanced by employing coir matting with ER resin reinforced to 20% by weight. Natural fibres and nanofiller are evenly distributed throughout the epoxy matrix illustrated in Figure 5a. Coir mats are mixed with 20% NP to strengthen the interfacial bonding between fiber, matrix, and filler. They, therefore, boost tensile strength owing to the increased well-built fibre matrix interface over the whole fibre surface [19]. A weak coir mat/filler/matrix link is seen in Figure 5b in the SEM image of the ER reinforced with 10% wt NP in the epoxy matrix composite, which accumulates and aggregates coir and filler. Because of the lower tensile strength caused by the non-uniform dispersion of fibers and tiny spaces in the matrix [21].

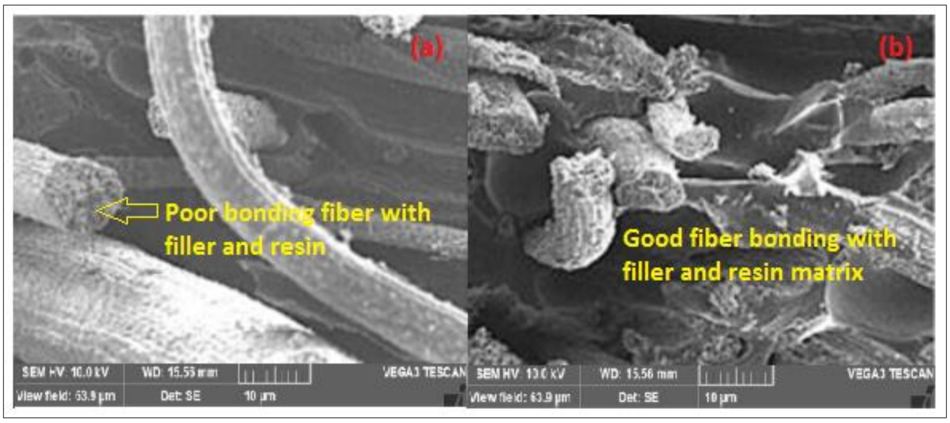

Figure 5. SEM image of (a) poor bonding (10% nano-silica) and (b) good bonding (20% nanosilica) for Coir fiber mats reinforced ER composites

3.3. Flexural strength

Improved composite strength is achieved using 20% weight-reinforced ER resin-infused coir matting as depicted in Figure 6. Coir mats are mixed with 20% NP to promote interfacial bonding between fiber, matrix and filler and therefore increase flexural strength owing to the improved well-formed fiber matrix interface over the whole fiber surface. The fiber direction in the composites' outermost surface may account for the composites' higher flexural strength values as compared to their tensile strength [19].

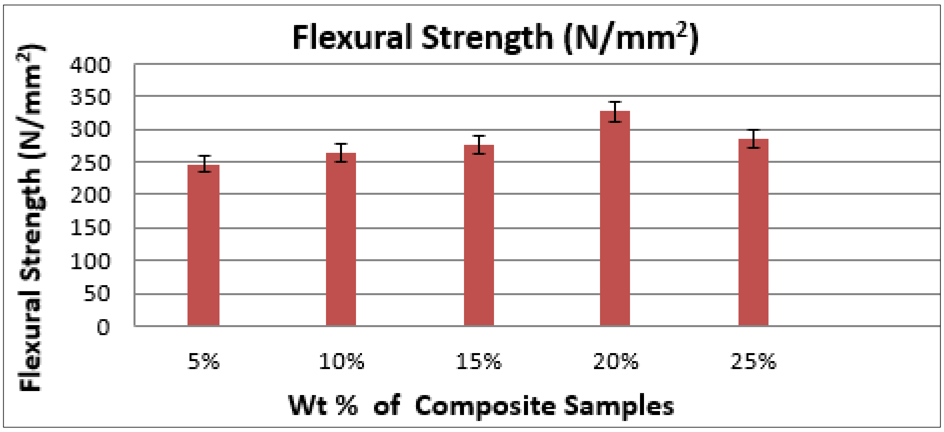

Figure 6. Flexural Strength results for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

3.4. Impact strength

The maximum impact resistance, 2.8 J, is found in hybrid composites formed from untreated coir mats reinforced with 20 weight percent ER containing nanoparticles as depicted in Figure 7. When compared to other hybrid coir mat compositions, the impact resistance of ER 25% nanocomposites is more significant because of ductility characteristics, which results in higher impact strength of the fibers [26]. A composite's higher energy absorption capacity is its higher impact strength. A solid interfacial connection between the fiber, resin, and filler is blamed [4]. Filling coir mat reinforced epoxy resin with nanoparticles causes the fracture to spread more complicatedly and absorb more energy [1,11].

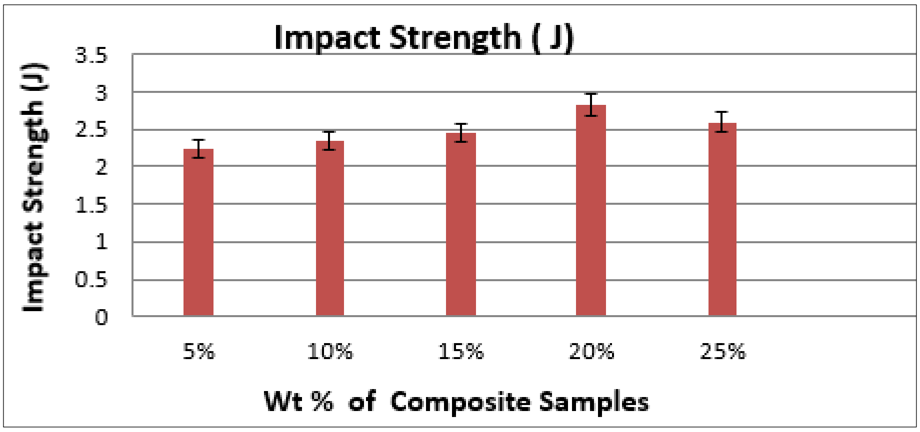

Figure 7. Impact Strength results for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

3.5. Thermal conductivity

The thermal conductivity of epoxy and its composites is shown in Figure 8. It's worth noting that the heat conductivity of pure epoxy glue is 0.21 W/mK. Heat conductivity was improved with the addition of coir fibre and nanosilica particles. The thermal conductivity of the L1, L2, L3, L4, and L5 composite designations is 0.23, 0.27, 0.29, 0.33, and 0.31 W/mK, respectively. These substantial gains in thermal conductivity are responsible for the nanosilica particle's efficient heat transfer bridge development. Despite the large pores of coir fiber, proper carbonization during char preparation improves electron transmission. The thermal conductivity of composites was significantly improved by the addition of nanosilica particles [27].

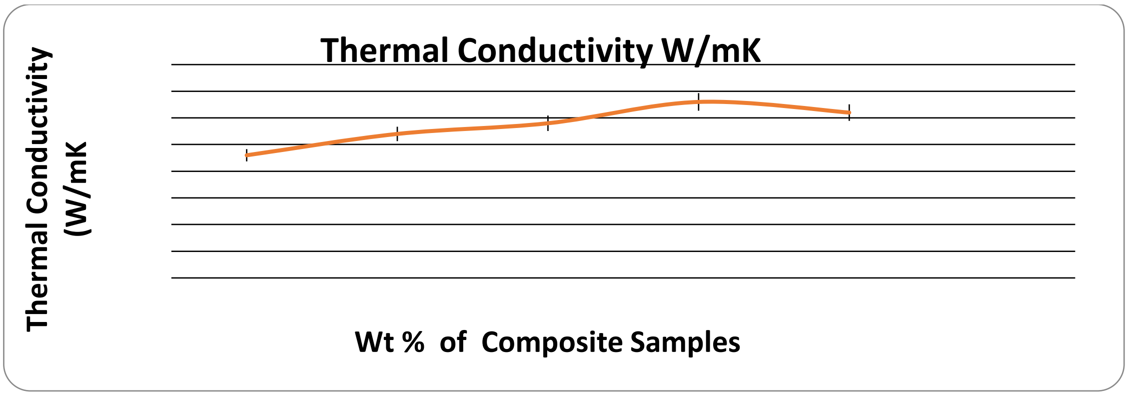

Figure 8. Thermal Conductivity for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

3.5. Water absorption

Hybrid composite water absorption has been plotted in Figure 9 with time. Nanoparticle-reinforced coir fiber mats (20 %) with nanoparticles had the lowest water absorption rate of all fibre composites. Generally speaking, natural fibers can absorb a lot of water [28]. Therefore, the water absorption rate in composites and the natural fibre-matrix interface might also affect the water-induced deterioration of mechanical characteristics [29].

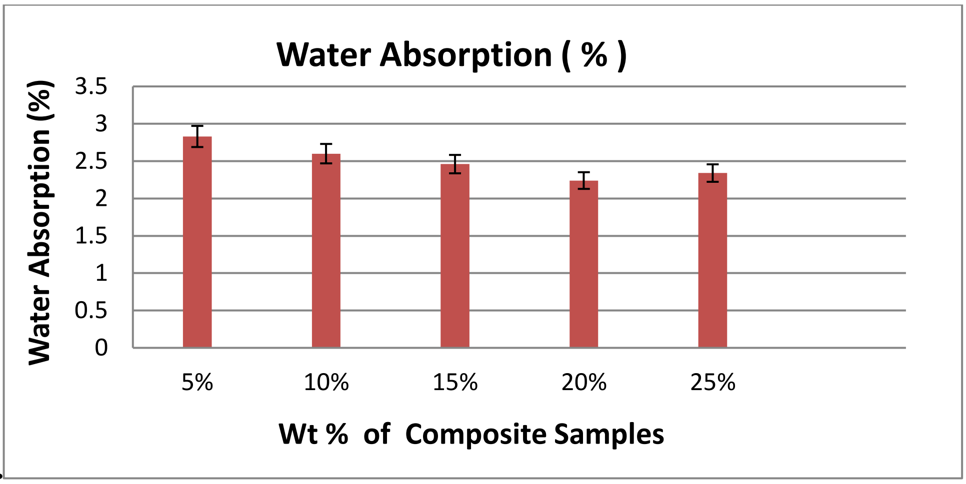

Figure 9. Water Absorption % for Hybrid Composites (Weight % of Nanosilica Particles (NP) reinforcement on Epoxy Resin (ER) / Coir Fiber Mats)

4.Conclusions

Compression hand moulding creates untreated coir mats with NP filler loadings of 5%, 10%, 15%, 20%, and 25% in each compositional reinforcement in ER matrix composites.

By doing these tests (tensile strength, compressive strength, flexural strength, impact strength and water absorption), the hybrid epoxy containing 20 % nano-silica coir mat obtained the best mechanical properties comparing with other composites.

Compared to previous hybrid coco coir composites, the ER composites reinforced with coir mats with 20% nanoparticle filler had a lower water absorption rate of 2.24%.

The maximum tensile strength of 183.2 N/mm^2, compressive strength of 163 N/mm^2, the flexural strength of 327.1 N/mm^2, and impact strength 2.83 J for the 20 wt % nanofiller hybrid ER matrix coco coir composites were achieved. These values are comparatively higher than the other hybrid nanocomposites

In the hybrid nanocomposites of coconut fibre mats with 20% nanofiller reinforcement in ER matrix composites, microstructural study reveals that the enhancement in binding strength between fiber, resin and filler has led to homogenization, which increases the tensile strength of composites.

I recommend for use in more practical applications, hybrid coco polymer composites with high mechanical qualities now on the market. For example, according to the findings of this research, these hybrid cocopolymer composites might be utilized to make car components like fenders and bumpers and furnishings.

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