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ORIGINAL PAPER

Influence of Nano-Silica on Enhancing the Mechanical Properties of Sisal/Kevlar Fiber Reinforced Polyester Hybrid Composites

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Abstract
In the fabrication of Sisal/Kevlar/Nano-silica reinforced polyester composites, the ultrasonic vibration was used in mixing the Nano-silica in polyester resin in which ultrasonic frequency of 15 kHz and with an 800 W power capacity was used. For uniform mixing of the nanoparticle in resin, an Ultrasonic probe was used. The Mechanical Properties of Sisal/Kevlar fiber, which are in mat form reinforced with polyester/Nano-silica, have been characterized. These composites have been fabricated using hand lay-up techniques by different wt.% of Nano Silica and different stacking sequences of fiber. The different wt.% are 2, 4, and 6 wt.%, and different stacking sequences are KSKS, SKKS, KSSK. The impact of the sonication effect on the mechanical properties was examined and compared. The addition of 4 wt% of Nano-silica in KSSK reported an increase of 23% of tensile strength, and 36% of flexural strength was observed. In KSKS, hybrid composites due to 4 wt.% silica addition 33% in tensile strength and 37% of flexural strength increases are found. The maximum tensile strength is obtained at 4 wt.% of Nano silica-reinforced with polyester with the stacking sequence KSSK and maximum flexural strength at 4 wt.% of Nano- silica with the stacking sequence KSKS. SEM analysis is also carried for the tested samples for failure analysis.

Keywords Ultrasonication · Hybrid composite · Kevlar · Sisal · Nano-silica · Mechanical stirring

1 Introduction

In the present generation of the composite world, hybrid composites play a vital and dynamic role in several manufacturing application areas. A hybrid composite consists of the polymer as matrix material and fiber/fibers and filler as reinforcement. A significant amount of research is going on for creating novel hybrid composites because of its lightweight, strength to weight ratio and improved mechanical properties. [1]

Synthetic fiber-reinforced composite materials have turned to be very popular overages due to its exceptional mechanical properties, lighter weightiness, unique flexibility, corrosion resistance, ease of manufacture, etc. One of the most durable synthetic fiber, known as Kevlar fiber, has very outstanding properties among synthetic fibers. Kevlar fiber is used in different industries and advanced machineries, such as helicopter blades and ballistic weapons. [2, 3] The most widely used natural fibers in polymeric composite processing are oil palms, jute, hemp, sisal, pineapple leaf, rice husk, bamboo, and wood for reinforcement. [4–6]

Natural fibers correspondingly provide high cost and processing advantages compared to synthetic fibers such as glass, nylon, and carbon [7]. But one of the downsides of natural fibers is having low mechanical properties, such as tensile and flexural. [8, 9]. The usage of natural fiber alone in the polymer matrix is, therefore, insufficient to satisfy all the methodological requirements of reinforced fiber composites. Our current objective is, therefore, to develop new hybrid composites. Many factors, such as the orientation of the fiber, the ratio of the fiber to the matrix, the physical bond among the fiber and the matrix, etc., effect the strength of the composites [10, 11]. Polymer composites are more likely to fail when applied to mechanical loads, such as tensile and bending loads. K.Palanikumar et al. [12] studied the

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Table 1 Chemical composition of Sisal fiber [21]

Fiber	Cellulose (%)	Hemicellulose(%)	Lignin (%)	Wax (%)	Moisture (%)
Sisal Fiber	60–78	10.0–14.2	8–14	2.0	10–22

mechanical properties of epoxy-reinforced sisal/glass fibers. Specimens reinforced with glass fibers showed the maximum tensile strength compared to hybrid composites. J. K. Prajapati et al. [13] determined the mechanical and dynamic mechanical analysis of glass fiber reinforced Nano-silica epoxy hybrid composites. He found that glass fiber with 25 wt.% and nano-silica with 3 wt.% have improved mechanical properties equated to other wt.%. Inclusion of Nano-silica in glass fiber enhanced the properties. O. Shakuntala et al. [14] studied the mechanical properties and tribological properties of polymer composite utilizing wood apple shell particulate as filler. And it has been detected that the amalgamation of wood apple shells as filler increased the mechanical and tribological properties. R. A. Mohammed et al. [15] have examined the mechanical properties and tribological properties of Nano silica-reinforced glass fiber polyester composites. The optimum value is for 5% of Nano SiO_2, with the addition of 4% of woven glass fiber.

Mixing of Nano-Fillers into the matrix is an essential aspect in the fabrication of composites; there are various ways to blend the Nano-fillers, such as Shear blending, Mechanical stirring, and Ultra sonicating. Shear blending requires two-roll mills or three roll mills, wherever intense shear stress is exerted on the resin and nanoparticles. However, this approach has a downside of having a limited resin quantity in the mill. Moreover, mechanical stirring helps in the creation of voids [16]. Nano-fillers are to be first to be blended with a mechanical stirrer followed by ultrasonication. The results obtained by this combined have high mechanical properties compared to the individual alone [17]. Ultrasonication is the most common technique which has shown tremendous promise in breaking down particle clusters, contributing to improved suspension stability. Ultrasonic processing is used for various reasons, such as the dispersion of nanoparticles into the base liquids, particle de-agglomeration, particle size reduction, particle blend and precipitation, and surface functionality [18]. One of the critical aspects of the Sonicator is the behavior of solutions shifted from non-Newtonian to Newtonian concerning sonication time [19]. Ultra-Sonication uses ultrasonic energy for the dispersion of Nano-fillers in the polymer matrix, as ultrasonic high-frequency waves pass through smaller packets form. Such smaller packets of nanofillers slowly exfoliate into smooth reduced bundles as the sonication period rises and become fully dispersed as individual Nano-fillers in the polymer [20]. Thus from the literature, it is evident that there is less work carried out in hybrid composites and particular stacking sequence and nano-silica as filler.

Therefore, in this work main aim is to develop a new hybrid nanocomposite, which is a grouping of natural and synthetic fibers, with an altered stacking sequence of Sisal/Kevlar mat fiber reinforced with Nano-silica reinforced polyester composites for making low-cost engineering materials has produced considerable attention recently.

2 Experimental

2.1 Materials

Matrix materials chosen were polyester and Nano-silica as a particle material, Sisal Fiber, Kevlar Fiber, as fiber material in

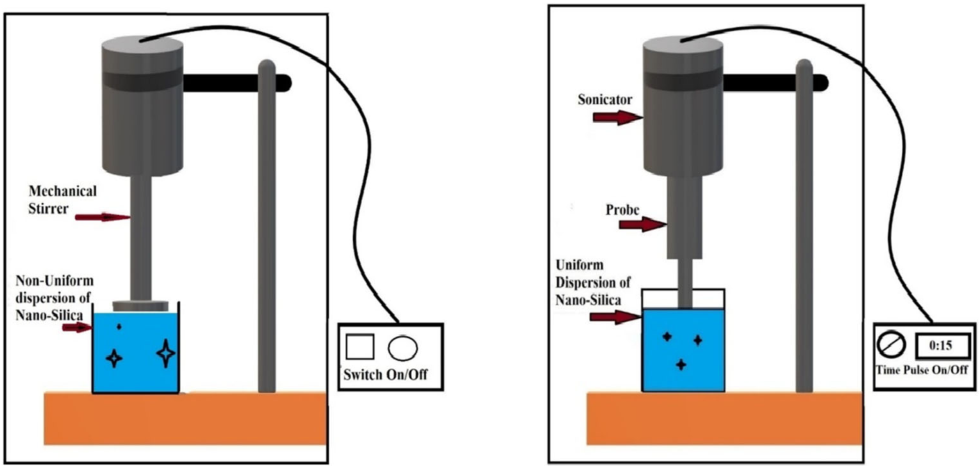
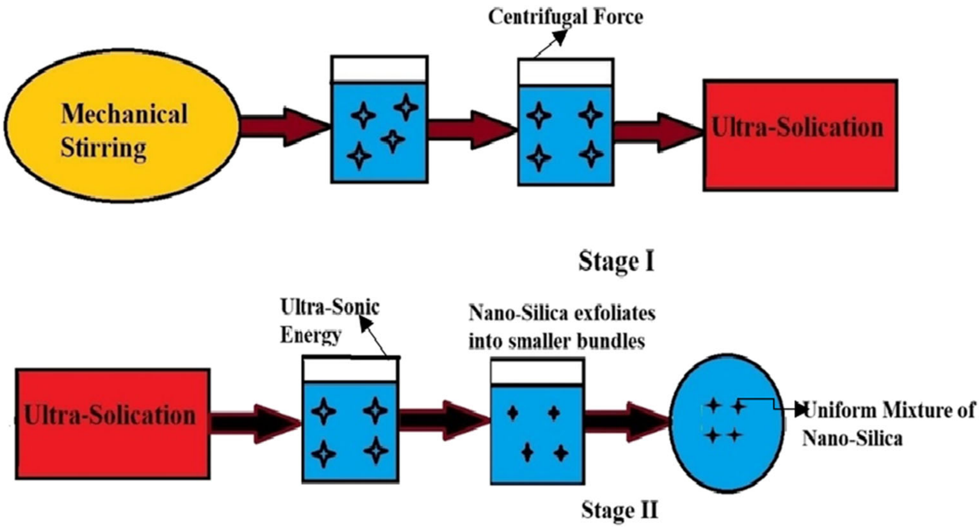


Fig. 1 **a** Schematic diagram of the mechanical stirring process **b** Ultrasonication process

Fig. 2 Schematic Diagram of particle distribution



the fabrication of polymer composite. The density of polyester, Sisal Fiber, Kevlar Fiber, Nano-silica is 1.12 g/cc, 1.50 g/cc, 1.44 g/cc, and 2.4 g/cc. The chemical composition of Sisal fiber is shown in Table 1.

2.2 Specimen Preparation

In the initial step, the Nano-silica and polyester were mixed with the mechanical stirring process for 10 min to mix matrix and filler. In the next step, ultrasonic vibrations are used by ultrasonicator for proper dispersion of filler into the matrix, Fig. 1a and b shows the schematic diagram of the mechanical stirring process and UltraSonicating of polyester/Nano-silica. The different weight percentages of Nano-silica filler content such as 2, 4 & 6 wt.% were used to fabricate composites. Nano silica and polyester mixture were placed in a glass beaker and then mixed with a mechanical stirring process and kept in high-intensity for 30 min with pulse mode (15 s on/15 s off) in UltraSonicator.

Figure 2 shows the sketch of the filler distribution in different steps. Step-1: a mechanical stirring process that is performed at room temperature and stirred for 10 min, which mixes the powder and polymer, but due to density differences and centrifugal action, all the particles are distributed in the corner or near the glass beaker. Step-II by ultrasonication process, the particles are distributed uniformly due to Ultrasonic vibration. The Sonication process creates high pressure, many vibrations, and acoustic wave streaming, which persuade the silica nanoparticles to homogeneous distribution in polymer.

After completing the process, polyester / Nano-silica / Kevlar(K) / Sisal(S) composites were prepared using the hand lay-up method. Four layers of fiber changing the layer sequence of Kevlar (K) / Sisal(S) as KSKS, SKKS, and KSSK were prepared. Kevlar and Sisal fiber layers are placed in the mold. The mixture of polyester / Nano-silica, which was previously mixed, was then applied to the mold. The first layer was laminated until the resin was completely wet. Additional polyester / Nano-silica blend was added, and the second ply was laminated until wet. This progression was repeated until four-folds had been overlaid. The sample was then hard-pressed with a roller to fa thickness of about 3 mm.

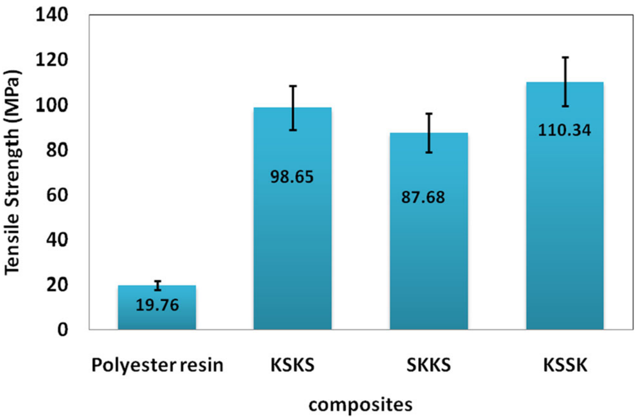


Fig. 3 Tensile test results of hybrid composites

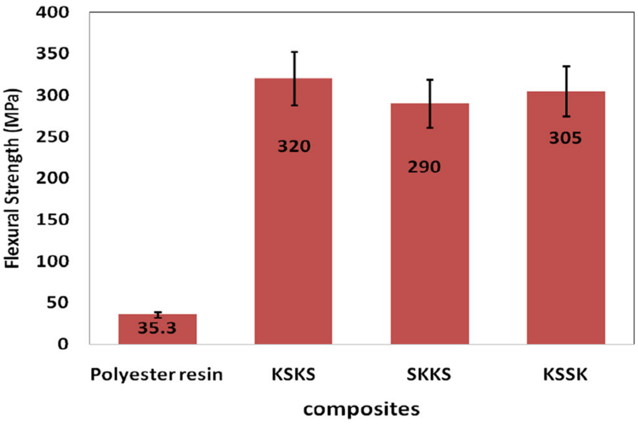


Fig. 4 Flexural test results of hybrid composites

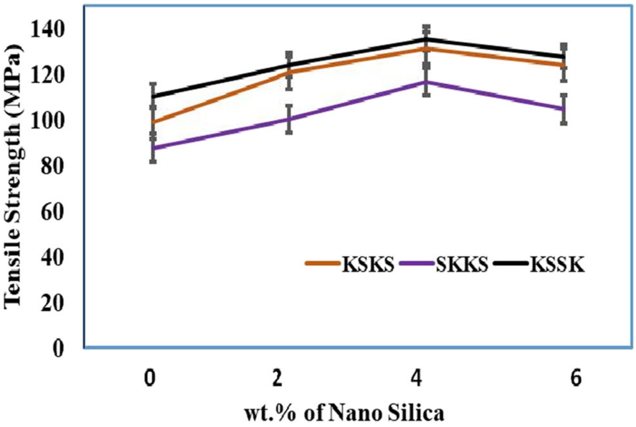


Fig. 5 Tensile strength with different stacking sequences with different wt.% of Nano silica

Composite samples were dried at room temperature for 24 h, and the dried composites were then cut in an appropriate Geometry as per the ASTM standard for tensile and flexural tests.

2.3 Tensile Properties Characterization

The most important and commonly calculated characteristics for composite material and structural applications are tensile strength [22]. The tensile tests are carried out using a tensometer at room temperature, which contains a load capacity of about 0–2000 kgs, elongation 0–200 mm, and accuracy 0. 001. The size of the specimen used in the test was 165 × 13 × 3 mm, as per ASTM D638.

2.4 Flexural Property Characterization

A 3-point bending test technique was used to calculate the bending strength of the composite on a tensometer [23]. The size of the specimen used in the test was 100 × 25 × 3 mm. All tests were performed at room temperature as per ASTM D790.

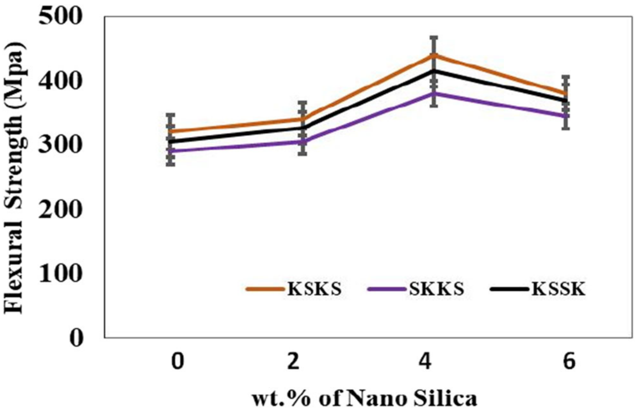


Fig. 6 Flexural strength with different stacking sequences with different wt.% of Nano-silica

The average of five samples is considered for calculating the Tensile strength and flexural strength.

2.5 SEM Analysis

Scanning electron microscopy (SEM) was used to detect the fiber failure analysis in the composite. SEM study was conducted using the Nova Nano SEM 450 by an enhanced voltage of 15 kV.

3 Results and Discussion

3.1 Mechanical Properties of Hybrid Composites

The tensile properties of the neat polyester resin and Sisal/Kevlar hybrid unfilled composites are presented in Fig. 3. The results exhibited that the tensile properties of the hybrid composite were found more significant in KSSK stacking sequence composites than neat polyester and other hybrid laminated composites. Composites with Kevlar in the outside layer were found to have improved mechanical properties than other hybrid composites. Because Kevlar fibers are more durable, stiffer, and interlaminar shear strength is better than sisal fibers. The load resisting capacity is also better as compared to sisal fiber. So it does not break easily after applying load. Due to the addition of sisal and Kevlar, the tensile strength of polyester has enhanced to 399% in KSKS, 343% in SKKS, and 458% in KSSK when compared to pure polyester.

From the results, it is also observed that the outer layer is sisal fiber; the strength is less compared to kevlar. This may be due to the presence of higher hemicellulose and lignin content in the sisal fiber, which is not making a suitable bond with the matrix [24]. Hence it cannot resist the load and break easily after applying load the decrease of strength value due to the fiber breaking and delaminating of the composite.

Figure 4 shows the flexural strength of Sisal/Kevlar polyester hybrid composites and pure polyester resin. It is evident from the result that the flexural properties of the hybrid composite were found higher in KSKS stacking sequence composites than neat polyester and other hybrid laminated composites. But the strength of KSSK and KSKS is almost equal. The strength is 806% in KSKS, 721% in SKKS, and 764% in KSSK compared to pure polyester. The better strength is observed in KSSK. This may be due to the interphase bonding among the polymer and fiber and bending stress transfer from matrix to Kevlar fiber, which may carry the load at loading conditions.

The enhancement of strength not only depends on the hybridization of fibers; it also depends on the stacking sequences; in three different sequences, Kevlar as outer shows better positive mechanical results. Salman S. D et al. [25], in their investigation, also confirmed that Kevlar as outer and

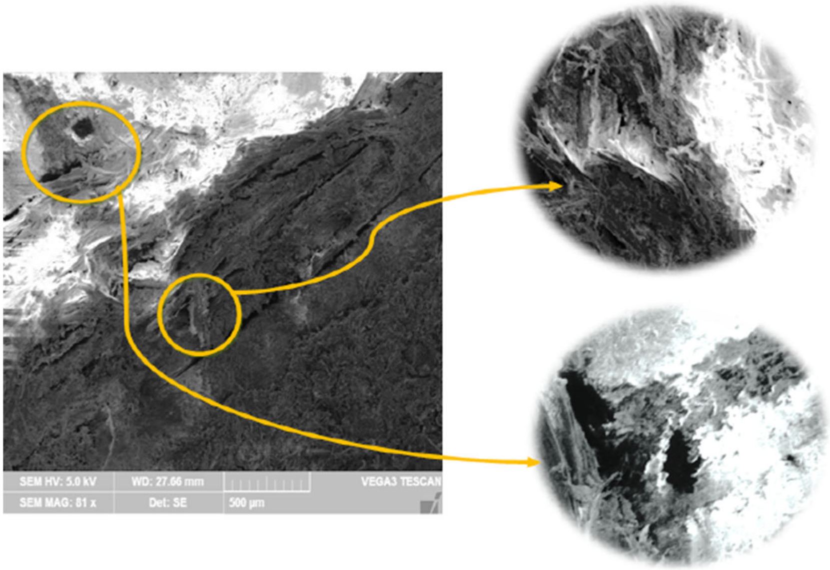


Fig. 7 Shows the SEM images of polyester/KSSK composite

kenaf as inner hybrid composites show higher resistance and more energy absorbed (penetration) and maximum load.

3.2 Tensile Strength of Nano-Silica Reinforced Hybrid Nanocomposites

The tensile strength of the hybrid composites for different stacking arrangements for different wt.% of Nano silica is shown in Fig. 5. From Fig. 5. it is clear that the nano-silica by double-stirring process improved the tensile performance of polyester/Sisal/Kevlar composite because of the better Nano-silica dispersion, which results in good interfacial interaction with the matrix. In different stacking sequences, there is a change in tensile strength. Also, upon an increase in Nano-silica content, there is an increase in tensile strength and decreases with further increase in Nano-silica. I.D.G. Ary Subagia et al. observed a similar result [26].

The tensile strength of Nano silica-reinforced hybrid composites, with an increase in wt.% of Nano-silica from 0 wt.% to 4 wt.%, there is an increase in tensile strength and a further increase in silica content, i.e., 6 wt.%, there is a decrease in tensile strength. This is because of agglomeration, which is caused by poor dispersion of nanomaterials, may cause dishomogeneity and, eventually, uncured resin zones while imposing extra energy into the mixing process. Shu-Xue Zhou et al. [27], in their studies confirmed that the adding of a small amount of Nano-silica enhanced the tensile properties of the polymer. These tensile properties could, however, worsen with higher Nano-silica contents.

The highest tensile strength is achieved at 4 wt.% of Nano-silica/ KSSK stacking sequence, which is increased by 23%

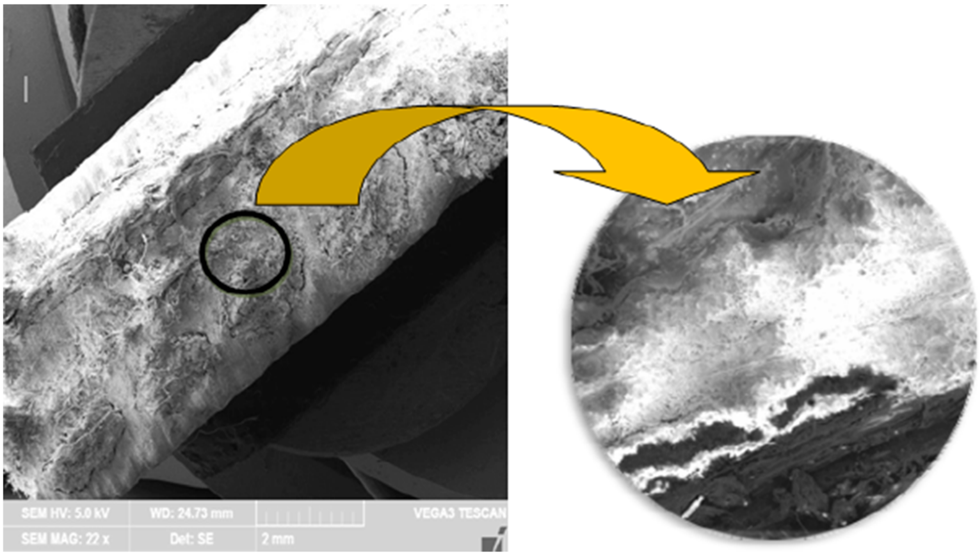
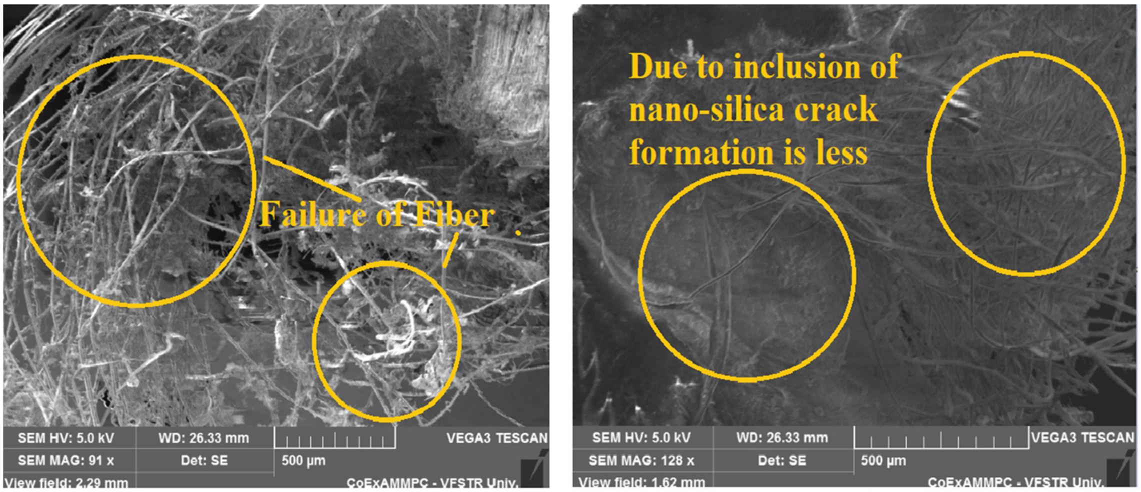


Fig. 8 Shows the SEM images of the Particulate distribution of tensile specimens of Nano-silica 4 wt% of KSSK stacking sequence



(a) (b)

Fig. 9 SEM Images of tested flexural specimens **a** polyester / KSSK stacking sequence hybrid composite with 0 wt.% of Nano-silica **b** polyester/KSSK / Nano-Silica hybrid composite with 4 wt.% of Nano-silica

and a further increase in silica content there is a reduction in tensile strength this is due to the viscosity of the polymer increases as wt.% of silica is increased [28]. This result can be seen in any of the stacking sequences. The addition of 4 wt% Nano-silica reduced the porosity, and the reduction of porosity significantly increased the nanocomposites' resistance. The higher amount of Nano-silica concentration caused agglomeration and poor dispersion, which showed the increment of porosity.

3.3 Flexural Strength of Nano-Silica Reinforced Hybrid Nanocomposites

Figure 6 shows the flexural strength for different stacking sequences and different wt.% of Nano silica. The maximum flexural strength was obtained at the 4 wt.% of the Nano-silica/KSKS stacking sequence. Up to 4 wt.%, there is an increase in the bending strength and further increase in Nano silica content; there is a decrease in strength. A similar trend of flexural strength for nanofiller loading can be observed in N. Merah et al. [29].

It is observed that due to the addition of 4 wt.% Nano-silica in KSKS composites, the flexural strength increases to 6%, 37% for 2 wt.%, and 4 wt.%, and 19% for 6 wt.%. There is a 37% increase in the bending strength in KSKS stacking sequence from 0 wt.% to 4 wt.%. The decrease in flexural strength of more than 4 wt.% of silica may be due to the agglomeration of silica in the resin, which serves as stress concentrates and decreases flexural strength.

3.4 SEM Studies

Figure 7 shows the SEM images of the KSSK stacking sequence with 0 wt.% Nano-silica under 2 μm magnification. From the figure, it can be seen that voids are present in the composites with which we can clearly say there is no interfacial bond among the fiber and matrix. Figure 8. Shows the SEM images of the Particulate distribution of tested tensile specimens of KSSK stacking sequence 4 wt.% Nano-silica in which there are no voids present in the composites and from which we can conclude that there is an excellent interfacial bond between the fiber and matrix due to the inclusion of Nano-silica. Thus, SEM images also support the results of mechanical. In Fig. 8. It shows the uniform distribution of particles in the composite. This is due to the mixing of silica particles utilizing ultrasonication, and low porosity can be observed from the images which are similar to Pagidi Madhukar et al. [30].

Figure 9a-b shows the SEM images of tested flexural specimens of polyester / KSKS stacking sequence hybrid composite and polyester/KSKS / Nano-silica composite with 4 wt.% of Nano-silica. There is an evident variation among the specimens with Nano-silica and without Nano-silica. Fiber pullout can be seen in both the tested specimens. This shows the brittleness of the sisal fiber. Figure 9b demonstrates the results of the introduction of fillers in hybrid composites. The crack formation before the breakage is observed to be lower compared to Fig. 9a due to flexural load. This shows that the fillers increase the composite's strength [27]. The fracture material fails under stress; the failure planes are always natural to the load. Nevertheless, cross-section failure alone does not affect the composite failure mode. Composite failure mode depends on various variables, including the type of fiber, type of matrix, fiber/matrix communication, reinforcement transfer place of failure, etc. [31].

4 Conclusions

Sisal/Kevlar fiber/Nano-silica reinforced polyester Composites were fabricated by the hand lay-up process with mechanical stirring and ultrasonic vibration techniques. Mechanical and microstructures were studied to comprehend the effect of Nano-silica on the hybrid composites.

1. Mechanical properties were significantly enhanced with Nano-silica addition due to the Ultrasonic stirring process in the fabrication of composites, which helps for the proper distribution of nanofillers in hybrid composites.
2. The mechanical properties are reduced after 4 wt% filler addition in hybrid composites due to improper wetting of the filler and difficulty in fiber/filler handling.
3. The highest tensile strength and flexural strength were observed for the composites KSSK/4 wt.% Nano-silica and KSKS/4 wt.% Nano-silica composites.
4. The double stirring process (mechanical and ultrasonic) in the fabrication of composites shows a 37% increase in flexural strength to hybrid composites(KSKS) due to the addition of 4 wt.% fillers and 23% increase in tensile strength.
5. SEM analysis confirms the ultrasonic stirring process leads to the proper distribution of fibers in the hybrid composites.
6. The performance indicates the excellent adhesion strength and chemical compatibility of the Nano-silica particles with polyester/Sisal/Kevlar composite systems.

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