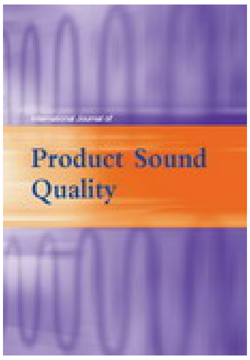

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Effect of granite filler on the mechanical and damping behaviour of silk-sisal hybrid composite for automobile applications

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Abstract: Composite materials are a better replacement for conventional materials due to their acceptable mechanical properties. Notable characteristics of composites play an important role in automobile applications like a bumper beams in passenger cars. The paper was developed to fabricate a silk/sisal hybrid natural fibre composite material that can replace the conventional composite material. Both silk and sisal fibre was woven together using a traditional weaving machine. Four samples of composites are fabricated in which one sample is fabricated without filler material and the other three samples of the composite are fabricated by changing the volume percentage of filler material by 2%, 4%, and 6%. The hand layup method was followed for making the composite. The fabricated composites are evaluated for their properties, viz., tensile, flexural, and impact strength, and also the free vibrational behaviour of the composite.

Keywords: natural fibre; granite filler; mechanical properties; modal damping.

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1 Introduction

Plastics, ceramics, and composite materials have dominated the field of developing materials over the last 30 years, to improve the mechanical properties of low carbon steels (Venkateshwaran et al., 2011; Murugan, 2020; Sripriyan et al., 2022). Commercial applications of composite materials' volume and the number have steadily increased, with the material relentlessly entering and dominating recent markets. Modern hybrid composite materials represent a important portion of the engineered materials market, with applications ranging from simple everyday items to complex specialist applications. The present problem is to make composites cost-effective, even though they have already demonstrated their value as materials that reduce weight (Murugan, 2020; Sripriyan et al., 2022; Sripriyan and Ramu, 2016). The composites industry is now using several novel production techniques developed to make economically appealing composite components (Li et al., 2019). The cost barrier cannot be cleared just by improvements in manufacturing technology, especially for composites. To compete with metals, composites must undergo a various integrated steps viz., design, material, process, tooling, quality assurance, manufacturing, and even programme management (Alavudeen et al., 2011; Sripriyan et al., 2021, 2016; Kumar et al., 2015; Saba et al., 2015).

Natural fibres are renewable, cost-effective, and environmentally friendly resources that have seen a surge in popularity in recent years (Siva et al., 2020). They already have a history of being used as basic filler in car parts. Due to environmental concerns, natural fibres are increasingly being used as a replacement for other traditional materials in composite construction (Muthalagu et al., 2020; Davoodi et al., 2011; Selwyn, 2020; Kumar et al., 2014). For the fabrication of natural fibre reinforced composites, fibres including jute, silk, flax, banana, kenaf, sisal, and bagasse are frequently utilised because of their excellent mechanical qualities, among other things (Gairola et al., 2020; Sripriyan et al., 2017; Prabhakaran et al., 2011; Idicula et al., 2009; Ranaa et al., 2016). This proposed study assists in developing a hybrid composite made of silk and sisal to replace traditional materials used as bumpers.

Li et al. (2019) investigated banana-coir-bagasse fibres in hybrid composites. They tested the moisture content, ash and carbon content, tensile strength, elemental analysis, and chemical analysis, to name a few. According to the test results, banana fibre had the highest concentrations of ash, carbon, and cellulose.

Venkateshwaran et al. (2011) studied the various work carried out by the researchers related to banana fibre composite. The majority of papers described the structure, mechanical, and metallurgical properties of banana and reinforced fibre composites.

Kumar et al. (2014) examined the effect of mechanical properties on oil palms with glass fibre and used phenol formaldehyde as resin. They concluded that a 40-weight percent of loading gives a maximum mechanical performance.

Recent researchers involved with the development of various hybrid composite structures viz. silk-sisal fibres, banana-sisal, glass-bamboo, and glass-sisal. All these composites pose better mechanical, chemical, and metallurgical properties (Kumar et al., 2014; Gairola et al., 2020; Sripriyan et al., 2017). Still, there may be a gap to further enhance the damping prosperity in the silk-sisal composite.

In this present work, an experimental study has been conducted to fabricate the 3 mm composite structure. Silk and sisal fibre are selected as a constant length of 25 mm and weight percentages of 60:40. Further, to enhance the mechanical and damping behaviour granite nano-filler were added at different weight percentages (2%, 4%, and 6%).

The novelty of the work is the fabrication of 3mm silk-sisal added with granite nano-filler by hand layered structure. Further addresses the fundamental findings of hardness, tensile, flexural, impact properties, and damping behaviour.

2 Materials required

2.1 Materials

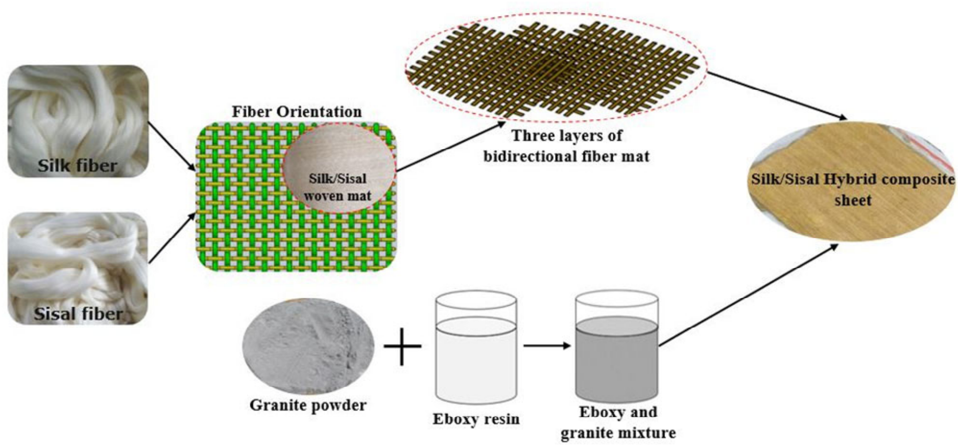
- *Silk fibre*: Silk is a very strong fibre and it has a higher tensile strength of about 75%–85%. Its extensibility is about 15% when at the break (Murugan, 2020).
- *Sisal fibre*: Sisal fibre is plant fibre and it has high strength, the ability to stretch and it has elongation of about 3.2% when at break (Sripriyan et al., 2022).
- *Granite bano-filler*: Fine granite dry fly dust particle, with a maximum size distribution of 390 μm used as a filler. Which is used to improve the mechanical properties (damping) of a silk-sisal composite (Murugan, 2020).

- *Epoxy resin (LY556)*: Epoxy has several desirable characteristics, including high strength, minimal shrinkage, strong adhesion to a variety of substrates, efficient electrical insulation, chemical insolvency resistance, low cost, and low toxicity. High compression strength and long-lasting durability are among the resin's attributes (Sripriyan et al., 2022).
- *Hardener (HY 961)*: Hardener is an epoxy or fibreglass curing agent. The component that hardens the adhesive when combined with resin is known as a hardener, sometimes known as a catalyst, and epoxy resin must begin curing. The characteristics include excellent electrical qualities, better mechanical strength, and resistance to atmospheric and chemical deterioration (Siva et al., 2020).

2.2 Preparations of the reinforced composites

Fibre orientation is one of the important factors that influence the mechanical behaviour of the fibre composite (Sripriyan et al., 2016). The optimum strength and stiffness can also be achieved in a composite by aligning the fibre. Four of the most common orientations in fibre-reinforced composites are unidirectional, randomly oriented, bidirectional, and multi-directional (Sripriyan and Ramu, 2016). The silk and sisal fibres are woven bidirectionally where silk fibre is placed vertically and sisal fibre is placed horizontally. Three layers of woven silk/sisal mat are placed one on another such that the alternate layer is rotated 90°, as detailed in Figure 1.

Figure 1 Preparation of composite (see online version for colours)



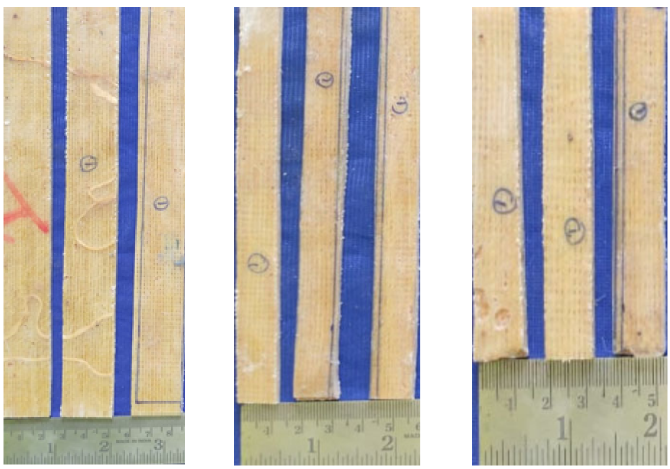
Hand lay-up is the oldest and most fundamental open moulding technique used to create composites (Sripriyan et al., 2017). Initially, woven fabric made of dry fibres is manually inserted into the mould, and the resin matrix is applied to the reinforcing material using a brush. To get the desired thickness, improve contact between the reinforcement and matrix, and promote resin uniformity, the wet composite is then rolled with hand rollers. Following that, the laminates are allowed to cure in typical air conditions as depicted in Figure 1.

2.3 Mechanical test

A universal testing machine (UTM) was used to conduct the tensile test by ASTM: D 3039 test specifications (Venkateshwaran et al., 2011; Alavudeen et al., 2011), with a crosshead speed of 1 mm/min and a specimen size of 250 mm in length and 25 mm. The flexural test is conducted using the UTM and a three-point bending technique.

All samples were tested using an ASTM: D7264 (Venkateshwaran et al., 2011; Alavudeen et al., 2011) span of 50 mm and a cross-head speed of 2 mm/min, with specimen sizes of 52 mm in length and 13 mm in breadth. The strength of the impact was determined using a Charpy Impact tester following ASTM: D256 test standards, with a specimen size of 64 mm in length and 12 mm in breadth (Muthalagu et al., 2020) (see Figure 2).

Figure 2 Typical silk-sisal hybrid composite samples, (a) tensile (b) flexural (c) impact (see online version for colours)



(a) (b) (c)

2.4 Vibration test

The dynamic features of developed hybrid composite structures (pure and different granite-nano-filler content) are studied under the free transverse vibration (Li et al., 2019; Alavudeen et al., 2011; Sripriyan et al., 2021, 2016; Kumar et al., 2015). According to the literature survey for the free vibration test, cantilever samples are prepared as per ASTM: E756 (Muthalagu et al., 2020) standard of 250 × 25 × 3 mm. The free vibration responses were uninterruptedly monitored and recorded using an accelerometer attached at the free end of the hybrid composite structure and damping ration 'ζ' (zeta) calculated based on the logarithmic decrement to experimental systems (Kumar et al., 2014).

3 Results and discussion

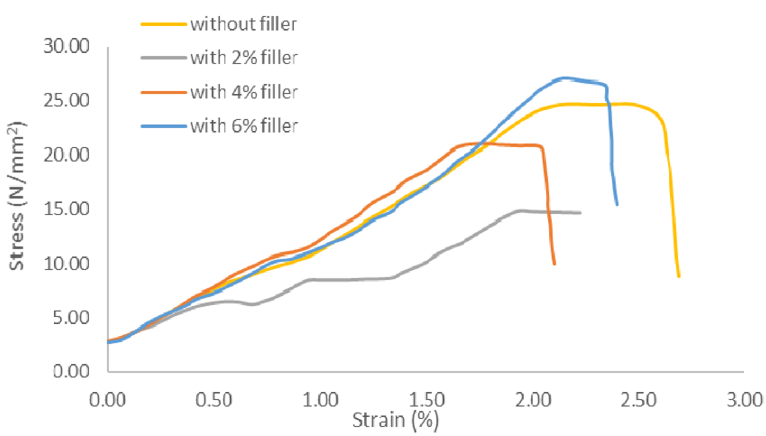
3.1 Tensile strength

The two vertical threaded shafts on the UTM allow the movable crosshead to slide along them while maintaining a consistent crosshead position. The specimen will be held in place by locking clamps on these two heads, which are primarily used for tensile tests. The specimen will be positioned between the cross head and the moveable head jaws if the test is tensile. In the case of a compressive test, the specimen will be positioned between the table and the movable head. The movable crosshead, which is controlled by a speed controller, changes the load placed on the specimen by varying the speed of the two vertical threaded shafts. Using the loading dial indicator, the load can be seen during the test. No filling, 2% filling, 4% filling, and 6% filling are the available compositions.

Table 1 Stress value for tensile test

Compositions	*Sample 1 (GPa)*	*Sample 2 (GPa)*	*Sample 3 (GPa)*	*Average (GPa)*
No filling	0.0225	0.0246	0.0232	0.0235
2% filling	0.0206	0.0148	0.0236	0.0196
4% filling	0.0271	0.0210	3.35×10^{-5}	0.0160
6% filling	0.0286	0.0193	0.0277	0.0252

Figure 3 Stress vs. strain curve for tensile strength (see online version for colours)



Testing in the UTM is used to determine the tensile characteristics of four distinct kinds of laminates. Table 1 is a list of the laminates' tensile characteristics. It has been demonstrated that including granite fillers in the composite increases its tensile strength. The sample load vs. displacement curve for the 2% filler laminate is shown in Figure 3. Up until the specimen cracks, the displacement appears to be directly proportional to the applied load. When the specimen reaches its yield strength, it begins to behave brittlely and eventually breaks. The three laminates with no granite filler had an average tensile strength of 0.0235 GPa. With the addition of granite filler, the tensile strength of the hybrid composites gradually decreases. Similar outcomes were found for granite filler laminates at 4% and 6%, or 0.0160 GPa and 0.0252 GPa, respectively. With the addition of 6% granite filler, the tensile strength of the hybrid composites has suddenly increased. The tensile strength is increased by including the remaining 2% of the granite filler. The results suggest that adding 6% granite filler to the hybrid composite improves its ability to withstand additional tensile stress and increases its tensile performance.

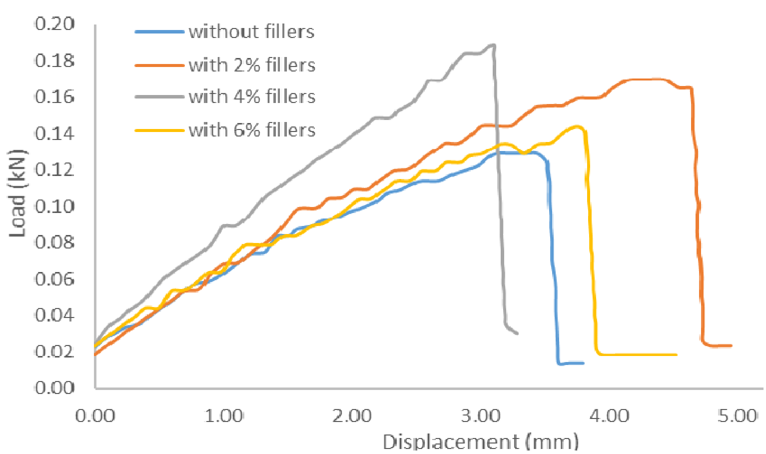
3.2 *Flexural strength*

Tensile and compressive strength is applied to the convex and concave sides of the specimen, causing shear stress along the specimen's centreline. It calculated the amount of force needed to bend the beam (Sripriyan and Ramu, 2016). Flexural tests are commonly used to determine the flexural strength or modulus of a material. Although flexural testing is less expensive than tensile testing, the results are slightly different (Sripriyan et al., 2016). Following the horizontal placement of the material over two points of contact, a force is applied to the top of the material through one or two points of contact (upper loading span) until the sample fails (lower support span). The flexural strength of that specific sample is represented by the highest force ever recorded. The flexural strength measured with the UTM machine is summarised in Table 2.

Table 2 Stress value for flexural test

Compositions	*Sample 1 (MPa)*	*Sample 2 (MPa)*	*Sample 3 (MPa)*	*Average (MPa)*
No filling	84.6	91.9	97.6	91.366
2% filling	117.9	102.8	81.64	100.78
4% filling	114.9	99.78	123.9	112.86
6% filling	87.6	93.73	90.71	90.68

Figure 4 Stress vs. strain curve for flexural strength (see online version for colours)



According to the results, the silk and sisal fibre blend that uses 4% granite powder as a filler ingredient is stronger than the other blends. It is equally distributed between the fibres and matrix in the laminates during the gradual application of load, and it begins to burst when the load reaches its limit. The whole length of the cross-section of laminates will experience cracking if the adhesion between the fibre and matrix is weak. The hybrid composite with no filler has a maximum flexural strength of 91.336 MPa. Flexural strength is increased in the composite up to 100.78 MPa with the inclusion of 2% granite filler. In comparison to the previous no filler and 2% laminate, superior results are produced by adding granite filler up to 4%. The flexural strength of the laminate with the 4% granite filler is 112.86 MPa, which is around 10% more than the strength of the composite with no filler. Figure 4 depicts the sample load versus displacement curve for the 4% filler laminate. 90.68 MPa is the flexural strength of a composite with 6% granite filler. Compared to the 2% and 4% filler composites, the improvement in the flexural characteristics of the 6% filler composite is less.

3.3 Impact strength

The impact strength of a material is defined as its ability to withstand a sudden application of load. The Charpy impact test (Selwyn, 2020) was used to determine the impact resistance of the laminates. ASTM D 256 (Prabhakaran et al., 2011) is the accepted dimension for the Izod test. Impact energy is a unit of measurement for how much force is required to break a test specimen. When the specimen is struck by the striker, it absorbs energy before eventually giving way. The test subject exerts more effort and absorbs more energy in the plastic zone at the notch. When a specimen can no longer absorb energy, it fractures (Gairola et al., 2020).

Table 3 Impact testing value

Compositions	*Sample 1 (J)*	*Sample 2 (J)*	*Sample 3 (J)*	*Average (J)*
No filling	1.0	0.5	0.8	0.76
2% filling	0.4	0.8	1.3	0.83
4% filling	0.4	0.8	0.6	0.6
6% filling	0.4	0.5	0.9	0.6

Four different laminates are put through an impact test to evaluate their impact resistance. Izod impact test equipment is used to determine the energy lost. Table 3 lists the energy absorbed while a specimen is subjected to a powerful hit. The hybrid composite with no filler material has an impact strength of up to 0.76 J, according to the results, whereas the composite with 2% filler granite has an impact strength of up to 0.83 J. The filler ingredient may have caused the composite's impact characteristics to sharply increase. Both the 4% and 6% laminates display the same impact energy values of 0.6 J. The effect of the sisal and silk together with different ratios of filler material does not have a positive trend on the impact performance. The readings of the impact test are shown in Table 3.

3.4 Effect of granite nano-filler on damping properties

Testing the vibration (damping ratio) properties of four different kinds of laminates is used to determine their vibration properties. The laminates' vibration (damping ratio) properties are listed in Table 4. The addition of granite fillers to the composite reduces the damping ratio. As a result, the amplitude vs. time graph for the 2% filler laminate.

The damping ratios of composite materials are shown in Table 4 indicating that increasing wt. % of the granite-nano-filler on the silk-sisal hybrid composite increases the damping factor. This is due to granite-nano-filler properly dispersion with resin and closely packed with silk-sisal fibre mat, which leads to an increase in the damping characteristics of hybrid composite. In addition to that, granite itself has inherent properties of higher damping factor (Kumar et al., 2015).

Table 4 Damping ratios of composite materials

Compositions	*Sample 1*	*Sample 2*	*Sample 3*	*Average*
No filling	0.368	0.031	0.037	0.145
2% filling	0.039	0.034	0.025	0.032
4% filling	0.025	0.034	0.040	0.033
6% filling	0.057	0.033	0.028	0.039

4 Conclusions

The woven hybrid mats of silk and sisal fibre were successfully reinforced with epoxy resin using a simple hand lay-up technique with granite nano-fillers of 2%, 4%, and 6% volume percentages, respectively. This paper presents the following findings.

- Mechanical testing like tensile, flexural, and impact strength. In tensile behaviour was observed that maximum stress occurs in a 6% filling composite of about 0.0252 GPa. In flexural strength, the maximum stress occurred in a 4% filling composite of about 112.86 MPa in impact strength, the maximum impact is in a 2% filling of about 0.83 J.
- In addition, a vibration study was carried out, the result infers that the maximum damping ratio at no filling composite is about 0.145.
- Given the results presented, silk-sisal reinforced granite nano-filler can be recommended as a potential to enhance the tensile and flexural strength and significant effect on damping.

5 Future scope

Silk-sisal reinforced hybrid composites were created using the manual layering approach with granite nano-fillers. The following suggestions are given to advance the research and better comprehend the impact of silk-sisal.

- Rigorous research work is going to be included focusing on water absorption and biodegradable studies.
- Simulation analysis will be performed to the understanding of effect replacing the automobile bumper.

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