Thermal and wear properties of sansevieria trifasciata green fiber–carbon fiber polymer hybrid composite

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Abstract

The composites of the recent era have replaced the conventional materials which are widely used in the aerospace industry and safety applications. These application areas require high strength and tough structural materials. Hybridization of natural and synthetic fibers reduces cost, weight, and environmental effects caused by synthetic fiber composites without compromising its strength. In the present study Sansevieria Trifasciata Fiber (S.T.F) and Carbon Fiber (cf) reinforced hybrid composite materials were developed and subjected to wear analysis, Thermo Gravimetric Analysis (T.G.A), Differential Thermo Gravimetric (DTG) analysis, Scanning Electron Microscope (S.E.M.) for micro structure. The hybrid composites were prepared through the manual hand layup process with different percentages of S.T.F. and cf T.G.A test was performed on the 63.5 × 12.7 × 3 mm³ samples. 30% S.T.F. and 70% cf hybrid epoxy composites under TGA reveals to have the content of 30.9% fiber loss, 67.8% resin loss and 2.2% ash content. 40% STF and 60% CF hybrid composite reveal to have 11.9% fiber loss, 87.2% resin loss and 1% ash content. Similarly 30% STF and 70% CF hybrid composite have the content of 25.8% fiber loss, 72.7% resin loss and 1.5% ash content. Specific wear index of approximately 0.0028062 mm³/N-m was recorded for a sample of 40% STF and 60% CF and the minimum specific wear rate is 0.0010964 mm³/N-m, recorded for a sample of 30% STF and 70% CF at 15 N. TGA contour confirmed that the fiber was solid below 250 ºC with the highest cellulose decomposition temperature of 375 ºC. DTG confirmed that the crystallization temperature of the fiber was found to be 480.5 ºC and the decomposition of lignin was found to be 810 ºC temperature.

1. Introduction

Sansevieria Trifasciata is known as a snake plant which produce large amounts of oxygen and absorbs carbon dioxide. These are naturally and widely available in the tropical regions. The cross-sectional area of carbon fibers used in preparation of hybrid composite is 5 to 10 micrometers. Carbon fibers [1] mixed with carbon and graphite fibers are used in high surface temperature applications. The 21st century saw a boom in the use of various forms of fibers for textiles, automobiles, space, and several structural applications (Koronis et al 2011; Summer scales et al 2010; La Mantia and Morreale 2011). Overall performance of man-made fibers such as carbon and glass fibers widely used in automobile and space applications. It is confronted with asking for situations which in the reality depends on oil. The decreasing petroleum resources combined with fluctuating costs of crude oil, disposal worries, and also toxins with synthetics has mooted the options for relieving from these factors (Koronis et al 2011) as well as Ignited the search for alternate natural fibre as well as an international waking up in the direction of using degradable and also sustainable modern technologies [2]. International awakening to the use of sustainable and degradable technologies started using fibers together with flax, kenaf, hemp and number of natural fibers for the cause of the production of fibrous compounds [3] in structural applications. Mainly through the European vehicle
manufacturers and from the European legislation 2000/53/EC, encouraged vehicle manufacturers use recyclable components and are biodegradable. At least five specimens were prepared for every test and for each composite; an average value of the test results was determined [4]. Carbon fibers and Sansevieria Trifasciata reinforced with Polymeric compounds have been shown to improve mechanical properties [5] such as tensile, impact, flexural strength and also Improves resistance to wear at high temperatures. The composites have improved wear [6] and friction properties and mechanical properties such as tensile [7], impact, stiffness and flexural properties due to the hybridization [8] of synthetic materials and natural fibers.

2. Preparation of hybrid compositematerial

Raiyah et al, Studied sansevieria trifasciata fibers [9] and carbon mat fibers reinforced in an unsaturated polymer matrix based primarily on a fully hybrid composite. The advantage of using [10] sansevieria trifasciata fiber proved to be worthy compared to ordinary carbon fiber reinforced composite. In this study, the hybrid composite material the STF, extracted from leaves of Sansevieria Trifasciata plant, which were of different lengths as shown in figure 1. Carbon fiber (CF) is in the sheet form extracted from Go green products, Chennai. Carbon fiber specification including HS 12 K in the 0 °C direction and the 90 °C direction. The thickness of the carbon fiber was 0.45 mm according to ASTM D 1777 and the width was 1005 mm according to ASTM D 3776. The weight of the carbon fiber was 419 g mm$^{-2}$ according to ASTM D 3801, and the diameter of the filament were 7 μm. The tensile strength of carbon fiber is 3450 Mpa. Carbon Fiber Reinforced Polymer is an extremely strong and are lightweight. The composite material may also contain other fibers, such as aramid, Kevlar, twaron, aluminum or glass fibers. CF allows better shielding on the basis of weight of a single coat of paint and allows shielding the interior of an aircraft.

They are made of carbon fiber fabric and polymeric resin and are manufactured using modern technologies. Carbon fiber supports the world’s most advanced [11] applications including: A350 XWB, JSF, F18 E/F, A380, Eurofighter Typhoon, A400M, Boeing 787, and GENX Engines. Epoxy and curing materials reinforced with CF and STF Epoxy of LY 556 Monomers and hardener HY951. The hybrid composite laminates were made with 8 layers, as shown in figure 2. Table 1 containing randomly oriented carbon fibers and sansevieria trifasciata fibers

Table 1. Epoxy and Hardener properties.

| Property          | Specification | Unit   | Epoxy-LY 556 | Hardener-HY 951 |
|-------------------|---------------|--------|--------------|-----------------|
| Viscosity at 25 °C| ISO 12058     | MPa.s  | 10,000–12,000| 10–20           |
| Density           | ISO 1675      | gm/cc  | 1.15–1.20    | 0.97–0.99       |
| Flash point       | ISO 2719      | °C     | 200          | 180             |

Figure 1. Sansevieria Trifasciata Fiber preparation process & Carbon Fiber.

Figure 2. Hybrid composite specimen preparation process, specimens and fractographic analysis.
in the polymer matrix. The thickness of the hybrid composite laminate was 3 mm. The laminates were subjected to a wear test and thermal gravimetric analysis according to ASTM standards and the selected sample sizes were $63 \times 12 \times 3$ mm$^3$ for wear and $63.5 \times 12.7 \times 3$ mm$^3$ for thermal gravimetric analysis. SEM was used to observe the samples subjected to wear tests for the microstructure of the hybrid composite samples. The microstructure shows breakdown and damaged structure of the analyzed samples. Figure 15 shows an image of a microstructure with a resolution of 100 $\mu$m in the fracture part of the wear specimen (table 2).

### 3. Wear test

Structures were exposed to atmospheric moisture because most of the polymers degradable with moisture. The specimen was emerged in water at agreed upon conditions, often at room temperature for 24 h or until equilibrium.

### 4. Thermo-gravimetric analysis

Thermo Gravimetric Analysis (TGA) is a method of thermal analysis in which the mass of a sample is measured. Over time with the temperature changes, which helps to analyse the percentage of resin, fiber and ash at different temperatures. The TGA test was performed in accordance with ASTM standards and the samples with a size of $63.5 \times 12.7 \times 3$ mm$^3$ were used. This test was performed in the temperature range of 0 °C to 1000 °C using a thermogravimetric analyser, model TGDTA6200 from Hitachi.

### 5. Scanning electron microscope

After the wear test, the surfaces of the hybrid composite samples are plated with gold and then the faces are identified using a Scanning Electron Microscope (SEM) as shown in figure 3. SEM scans a high-energy electron beam on the surface of the samples. The SEM shots are repeated as they reproduce the electron of single pixel. The microstructure shows damage and damage structure of the analysed samples.

### 6. Results and discussion

The eight samples for each of the combination of hybrid composite were taken and are subjected to tests according to ASTM characterization standards. The difference in the percentages of hybrid composites consists of carbon fibers with 100%, 90%, 80%, 70%, and 60% and with the percentages for Sansevieria Trifasciata Fiber
as 0%, 10%, 20%, 30%, and 40%, respectively. The highest wear resistance was obtained for 30% S.T.F. and 70% cf hybrid composite. Thermogravimetric analysis revealed to have content of 30.9% of fiber, 67.8% of resin and 2.2% of ash for 40% of STF and 60% of CF.A content of 11.9% of fiber, 87.2% resin and 1% ash for 30% STF and 70% CF hybrid composite. A content of 25.8% fiber, 72.7% resin and 1.5% ash for 20% STF and 80% cf The maximum specific wear rate was approximately 0.0028062 mm$^3$/Nm$^{-1}$ recorded for the 40% STF and 60% CF sample, and the minimum specific wear rate was 0.0010964 mm$^3$/Nm$^{-1}$ recorded for the 30% sample. STF and 70% CF at 15 N. TGA contour confirmed that the fiber was solid below 250 °C with a maximum cellulose [16] decomposition temperature of 375 °C. DTG confirmed that the crystallization temperature of the fibers reached 480.5 °C and the decomposition temperature of the lignin as 810 °C. Wear test results and the thermal gravimetric analysis of the hybrid composite material was discussed for Epoxy hybrid composites by monitoring and mentioning the percentage of STF and remainder is the percentage of CF for the total fiber content.

### 6.1. Wear test results

Pin on disc wear test used for wear testing and friction, tabulated the data of frictional force and Coefficient of friction, wear volume, Specific Wear Rate compared to Sliding Distance by applying the normal load of 5 N, 10 N, 15 N at the speed of 700 rpm and 500 rpm.

Figure 4 shows a specific wear rate compared to the sliding distance by applying a normal load of 5 N, 10 N, 15 N at constant speed of 700 rpm. It was observed that the maximum rate of specific wear is 0.0010414 mm$^3$/N-m was observed for the sample of 20% STF and 80% CF at a sliding distance of 328.523 m and the minimum specific wear rate was observed was 0.00040086 mm$^3$/Nm$^{-1}$ for a sample of 40% STF and 60% CF at 549.81 m of sliding distance. Furthermore, at a load of 15 N, a wear rate of 0.00007831 mm$^3$/N-m$^{-1}$ was recorded for epoxy 30% STF and 70% CF at a sliding distance of 443.214 m. As the STF content increases, the specific wear rate also increases.

Figure 5 shows Specific Wear Rate compared to Sliding Distance by applying the normal load of 5 N, 10 N, 15 N for the Speed of 500RPM. The maximum specific wear rate of 0.0028062mm$^3$/N-min was observed for 40%STF and 60% CF Epoxy sample at 392.7 m Sliding Distance and minimum specific wear rate of 0.001011258mm$^3$/N-min was recorded for 30%STF and 70% CF sample at 267.52 m Sliding Distance and 0.0010964mm$^3$/N-m wear rate recorded for the 20% STF and 80% CF sample at 148.27 m sliding distance at 15 N.

Figure 6 shows the degree of wear in relation to the sliding distance. The maximum degree of wear was observed for 40% STF and 60% CF epoxy hybrid composite and a minimum wear rate was observed for 30% STF with 70% CF Epoxy hybrid composite at 15 N with 549.8 m at a constant speed of 700 RPM.

Figure 7 shows the degree of wear relative to the sliding distance. The maximum wear was observed for 40% STF with 60% CF and the minimum wear for 30% STF with 70% CF at 15 N with a sliding distance of 392.7 m. Figure 8 shows a coefficient of friction against sliding distance at a normal load of 15 N at a speed of 700 rpm. The maximum coefficient of friction was recorded as 0.75 for 40% STF – 60% CF, 0.38 for 30% STF – 70% CF, and 0.38 for 20% STF – 80% CF As the content of STF increases, the coefficient of friction is increases.

Figure 9 shows the coefficient of friction against the sliding distance at normal load of 15 N and at a constant speed of 500 rpm. The maximum friction coefficient 0.75 was recorded for 40% STF with 60% CF Epoxy hybrid composite, 0.27 for 30% STF with 70% CF Epoxy hybrid composite and 0.35 for 20% STF with 80% CF Epoxy hybrid composite. As the content of STF increases, the coefficient of friction is increases.
Figures 8 and 9 shows all the samples with a high degree of wear and the friction coefficient decreases with the sliding distance. The advantages of low coefficient of friction was producing less noise at work, extended service life, and increase in the operating efficiency.

Figure 10 shows the specific wear rate for different loads of 5 N, 10 N and 15 N at a constant speed of 700 RPM with respect to all combinations of Epoxy hybrid composite. The maximum specific wear index was
approximately $0.0010414 \text{ mm}^3 \text{ Nm}^{-1}$, reported for hybrid composite with 20% STF and 80% CF, and the minimum specific wear index was $0.00007831 \text{ mm}^3 \text{ Nm}^{-1}$, reported for the hybrid composite of STF 30% and 70% CF at 15 N.

Figure 11 shows the rate of specific wear at different loads of 5 N, 10 N and 15 N at a speed of 500 RPM with respect to all combinations of research study of Epoxy hybrid composite. The maximum specific wear index was approximately $0.0028062 \text{ mm}^3 \text{ N-m}^{-1}$, recorded for a 40% STF and 60% CF hybrid composite and the minimum specific wear rate is $0.0010964 \text{ mm}^3 \text{ N-m}^{-1}$, recorded for a 30% STF and 70% CF hybrid composite at 15 N.
6.2. Thermal Gravimetric Analysis (TGA)

The Thermo Gravimetric Analysis (TGA) is a method of thermal analysis [19] in which the mass of a sample [20] is measured over time as the temperature changes which helps in analyzing percentages of resin, fibre and ash contents at different temperatures of these composites. TGA test was carried out a per the ASTM standards for the specimens of size 63.5 × 12.7 × 3 mm³. This test was performed over the temperature range 0 °C to 1000 °C using Thermal Gravimetric Analyzer- model TGDTA6200 of Hitachi.

Figure 12 shows the Thermal Gravimetric Analysis for 40% STF and 60% CF, which shows the contents of 30.9% fiber loss, 67.8% Resin loss and 2.2% ash content.

Figure 13 shows the Thermal Gravimetric Analysis for 30% STF and 70% CF, which shows the contents of 11.9% fiber loss, 87.2% Resin loss and 1% ash content.

Figure 14 shows the Thermal Gravimetric Analysis for 20% STF and 80% CF, which shows the contents of 25.8% fiber loss, 72.7% Resin loss and 1.5% ash content.

6.3. Scanning Electron Microscope (SEM) analysis results

Figure 15 shows an image of a microstructure with a resolution of 100 μm in the fracture part of the tested composite sample. With Epoxy resin and hardener without sansevieria trifasciata represents good wetting of epoxy resin with carbon fiber, and the same there is a trend even for STF and epoxy. Strong binding with comparable density was observed.
Figure 13. Thermal gravimetric analysis at 30% STF – 70% cf.

Figure 14. Thermal Gravimetric Analysis at 20% STF – 80% cf.

Figure 15. SEM images of Carbon fiber with epoxy and hardener without STF.
Figure 16 displays the image with a resolution of 100 μm of the fracture part of the tensile test sample of 10% STF and 90% Carbon fibers with hybrid epoxy resin polymer composite [21] form a strong bond for better, denser crystals. Micro structure in the image below, consisting of 20% STF and 80% CF it forms a compressed crystalline microstructure.

Figure 17 shows an image with a resolution of 100 μm in the fracture part of a tensile test sample with 30% STF and 70% CF with epoxy resin and hardener. With this hybrid [22] composite, it forms a denser and more crystalline microstructure.

On the other hand, the following image, consisting of 40% STF and 60% CF, shows a clear view of the carbon fibers and, well adhered to the epoxy resin [20] form, forms a better and better compressed crystalline microstructure. Fiber breaking and pulling is observed during wear [23] and this is evident in the SEM.

Hybridization of the polymer with sisal/glass resulted in properties [24] intermediate between the pure glass fibre and pure sisal properties. Jarukumjorn et al, investigated hybrid compositions of glass and sisal of PP matrix. Khanam et al, Investigating sisal/carbon hybrid composites reinforced in a polyester matrix. The tensile, flexural and chemical properties of the hybrid compound significantly improved compared to non-hybridized compounds. The alkaline treatment of sisal fiber has increased in wetting and tends Improve in the mechanical and chemical resistance properties [25] of the hybrid compound. Hybrid composites were chemically resistant to all chemicals except for CCL4. The snowboards are made from hemp fibers based on NFC. Hemp-fiberglass hybrid compounds are also evaluated for various sports items. R Potluri etc have developed Flax/Hybrid carbon composites and are also used to develop golf clubs and fishing rods. Compound based on coconut fiber the materials are used for the production of sports and helmets. Eco-board is designed with hemp fiber and a bio-based resin and the composite material developed can be used for the above applications. It is also in close agreement with these researchers which also make the CF/STF Epoxy composites as versatile to these applications, which are economical and due to natural fiber bio degradable compared to pure CF composites.
7. Conclusion

- In this research work, properties such as the wear test and thermogravimetric analysis have been observed for the developed Hybrid composite of Sansevieria Trifasciata and Carbon Fiber.
- The hybrid composite of 30% Sansevieria Trifasciata fibers and 70% carbon fibers shows a good resistance to wear.
- Hybrid composite polymeric materials can replace existing automotive and aeronautical application materials
- STF, which is a natural fiber used in hybrid composites, reduces the cost of the composite.
- The scanning electron microscope shows the good wetting of fibres in hybrid composite materials.
- Thermogravimetric analysis reveals the content of 30.9% fiber, 67.8% resin and 2.2% ash for 40%
- STF and 60% CF Epoxy hybrid composite.
- The content of 11.9% fiber, 87.2% resin and 1% ash for 30% STF and 70% CF Epoxy hybrid composite,
- The content of 25.8% fiber, 72.7% resin and 1.5% ash for 20% of STF and 80% of CF Epoxy hybrid composite.
- The maximum rate of specific wear was approximately 0.0028062 mm³/N-m, recorded for a sample of 40% STF and 60% CF Epoxy hybrid composite and the minimum specific wear index is 0.0010964 mm³/N-m, recorded for a sample of 30% STF and 70%CF CF Epoxy hybrid composite at 15 N.
- Fracture and fiber pull out was observed during wear is evident from SEM.
- From the thermal analysis [26] it can be concluded that the beginning and end temperature of degradation for epoxy composites with sansevieria trifasciata fibers are 250 °C and 375 °C, respectively. The more degradable temperature of the epoxy is accelerated by the addition of carbon fiber.
- The pre dominant effect of the load and the sliding distance is evident from the wear test.
- In addition these cracks segments of Scanning electron microscope images show a good bond between the fibers and the epoxy resins.
- SEM photographs show that fiber break and pull out take place proximity to the fracture surface.
- Due to advantages of hybridization the thermal, wear resistance the hybrid composite of STF/CF can be used to produce parts of, airplanes and automobiles.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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