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HYBRID POLYESTER COMPOSITES REINFORCED WITH SUNN HEMP AND FLAX FIBRES: SHORE D HARDNESS AND DIMENSIONAL STABILITY ANALYSIS

Summary

Fibres are incorporated into polymeric matrix materials such as polyesters and epoxies to enhance the overall mechanical properties and open up a new range of applications in engineering. Natural fibres are recognized as alternatives to synthetic fibres due to their properties of being environmentally friendly, renewable, and lightweight. The aim of this paper is to experimentally determine the Shore D hardness and dimensional stability of polyester composites reinforced with sunn hemp and flax fibres. The water, oil, and acid absorption tests conducted on this composite (10 days) showed the maximum water, oil, and acid absorption levels of 13.4 %, 5.7 %, and 5.5 %, respectively.

Key words: *Hybrid natural fibres, Polymer matrix composites, Shore D hardness, Dimensional stability analysis*

1. Introduction

In recent decades, polymer matrix composites have been considered an emerging trend in the field of natural fibre-reinforced polymer composites due to their high strength-to-weight ratio, biodegradability, wide-range availability, and affordable cost. Natural fibre-reinforced composites are used in engineering applications such as the automotive industry (e.g., car dashboards), aerospace industry (e.g., engine blades and wings), and sports equipment (e.g., hockey sticks). Natural fibres have high specific strength and low density, so they can be used as reinforcements in composites with either polyester or polypropylene to get a better result in thermal properties [1]. Bio-composites can be obtained from coir, banana, sisal, and jute and can be used as reinforcements for automotive interiors and false ceilings, due to their observed mechanical properties [2]. Polymer composite materials have superior corrosive resistance and high strength and are preferably used in automotive and aerospace industries and for sports equipment where a better strength-to-weight ratio and a low coefficient of thermal expansion are required [3]. The factors to be considered for using natural fibres are mechanical stiffness, redundancy in density, and enhancement in the existing mechanical strength. The bonding between fibres and the matrix is vital for the strength and overall performance of the composite material; the fibres provide the strength and stiffness, whereas the matrix holds the fibres in place and distributes the stress to the fibres [4]. The hybrid sisal-pineapple fibre was fabricated; the improvement in mechanical and tribological properties of the hybrid fibre composites was achieved by adding 40-50% of hybrid sisal-pineapple fibre [5]. The hybrid sisal-roselle fibre can be used for various automobile parts such as car side panels and dashboards because of its good insulating characteristics [6]. The Shore D hardness values of Cyperus pangorei-polyester composites were studied by varying the fibre length. The use of nanoparticles with the reinforcement reduces the influence of the friction coefficient on hardness behaviour and dimensional stability of stem-based natural fibres, namely sunn hemp (Crotalaria juncea) fibres and flax (Linum usitatissimum) fibres in combination with polyester resin, by varying the fibre length and orientation angle, i.e., the random, angular, and multiaxial orientation of polyester composites reinforced with sun hemp and flax fibres. The mechanical behaviour of the polymer matrix composites was enhanced by reinforcing them with various natural and hybrid natural fibres, such as abaca [8], bamboo [9], kenaf [10], agave [11], Typha angustifolia [12], golden cane [13], Rumex acetosella [14], jute-banana [15], jute-bamboo [16], sisal-caryota [17], and hemp-banana [18]. In the listed studies, it is noted that mechanical properties are improved, e.g., tensile, flexural, impact and hardness values increase when polymer composites are reinforced with various natural and hybrid natural fibres. In addition to this, several studies are focused on the tribological and hardness properties of polymer composites reinforced with natural and hybrid natural fibres, such as areca [19], cotton [20], Nettle-Bauhinia vahlii [21], jute-carbon [22], Prosopis juliflora, abutilon indicum, and tapsi fibres [23]. The wear performance of the hybrid epoxy composites reinforced with optiva and vahlii fibres predominantly depends on the fibre content, sliding velocity, sliding distance, and normal load. The hybridization of fibres enhances mechanical properties and reduces the slide wear rate; it is recommended to use this process in lightweight applications, such as door panels, insulation boards, tennis rackets, etc. [24]. The mechanical and wear properties are enhanced when peanut oilcake is added as a filler to hybrid epoxy composites reinforced with pineapple and flax fibres; this epoxy composite can be used for brake pads [5]. The water absorption test was conducted on hybrid polypropylene composites reinforced with banana and coir fibres for 24 hrs, 48 hrs, and 72 hrs; it was observed that a longer time of soaking increases the water absorption percentage of the composite specimen [24]. The water absorption behaviour of hybrid phenol formaldehyde composites reinforced with calotropis gigantea and palmyra fibres was observed for 5 days. The results revealed that a rise in the fibre volume increases the percentage of water absorption; however, the composite specimen attains equilibrium, and no weight percentage increase is noted after 120 hours [25]. In response to the increased demand for fibrous materials, researchers have developed an environmentally friendly material. There is some relevant literature on polymer composites with agricultural residue and fibre, but little research is being conducted to promote the commercial production of these new materials and provide excellent economic returns to farmers. This study should be encouraged to stimulate the commercial production of these novel materials and provide good economic returns to farmers. Research on flax fibres has been extensively conducted, but sunn hemp fibre has barely been discussed. To the best of our knowledge, the hybridization of hemp and flax fibre has been less addressed.

The aim of this research is to examine the hardness behaviour and dimensional stability of stem-based natural fibres, namely sunn hemp (Crotalaria juncea) fibres and flax (Linum usitatissimum) fibres in combination with polyester resin, by varying the fibre length and orientation angle, i.e., the random, angular, and multiaxial orientation of polyester composites reinforced with sun hemp and flax fibres. The photographic images of sunn hemp fibres and flax fibres are shown in Figs. 1 and 2.

Fig. 1 Sunn hemp fibres.

Fig. 2 Flax fibres.

2. Materials Preparation

2.1 Sunn hemp (Crotalaria juncea) Fibre

Sunn hemp is a shrub that grows to a height of 1.5 to 3 meters. It is sometimes called Madras hemp. This plant is widely accessible in India, Bangladesh, and Brazil. Sunn hemp generally grows in temperatures ranging from 28 to 35°C. The stems are cylindrical, with a diameter ranging from around 1.5 to 2.5 cm. The fibres are extracted by a technique known as water retting, in which the plant stems are submerged in water. During the steeping, bundles of fibres are put in water in a single layer to allow for better absorption. After extraction, the fibres are thoroughly cleaned in water and dried in the sun before being retted. The proper washing process bonds the finer components of fibres into large layers, resulting in a more uniform appearance. Towards the lower ends, the fibres are twisted and linked together. Sunn hemp is beneficial in enhancing soil qualities by reducing soil erosion, conserving water, and recycling nutrients from the plants that grow in it. The major constituents of sunn hemp fibre are crystalline cellulose (64.2 to 70.5 %), hemicellulose (16.99 to 23.79 %), lignin (5.68 to 7.96 %), pectin (1.37 to 1.64 %), and fats and waxes (0.52 to 0.73 %) [26].

2.2 Flax (Linum usitatissimum) Fibre

Flax is a 30-50 cm tall perennial plant, also known as linseed. The temperature range of 21-30°C is the most suitable range for flax plant growth. This plant is widely accessible in southern India, Canada, Argentina, and France. It is good for pH levels ranging from 6.6 to 7.6. Flax fibre is more durable and has a higher strength-to-weight ratio than cotton fibre. The flax fibre was extracted by water retting in the extraction process that took around 3-5 days. The major constituents of flax fibre are crystalline cellulose (64.57 to 75.38 %), hemicellulose (12.97 to 26.07 %), lignin (4.78 to 7.44 %), pectin (0.45 to 3.23 %), and fats and waxes (0.83 to 1.9 %) [26].

2.3 Fabrication of Composite Plates

A hydraulic-based compression moulding machine (closed mould) of 30 tons was utilized to make plates of polyester composites reinforced with sunn and flax fibres. Compression moulding is a closed-mould method that uses high pressure. When the sunn hemp and flax fibres are placed in the lower mould, it is possible to create a variety of composite goods. The compression moulding machine is capable of both product manufacturing and curing at the same time. The die is made of mild steel. As a result of high pressure exerted by the upper mould and a high temperature, the excess resin comes out via the orifice provided in the lower mould. Hence, it is necessary to cover the die plates with a clear wax applied on a transparent sheet to prevent the composite plate from adhering to the mould during the preparation phase. The sunn hemp and flax fibres were prepared by varying fibre lengths (15 mm, 30 mm, and 50 mm), fibre orientation angles (0°, 45°, and 90°), and multiaxial fibre orientation (biaxial and triaxial). Compared to sunn hemp-polyester composites, the tensile strength values of polyester composites reinforced with sunn hemp and flax fibres were increased by 13.8 % in the random orientation and a fibre length of 50 mm. In the 0° angular orientation and triaxial orientation of polymer composites reinforced with sunn and flax fibres, the tensile strength values were increased by 23.4 % and 21 %, respectively. The fibre length and fibre orientation angle play a vital role in enhancing the tensile, flexural, and impact properties of polymer composites reinforced with sunn and flax fibres. The thermosetting polyester resin of G-0051 grade was used. Initially, a catalyst and an accelerating agent in the proper proportions are required for polyester resin. The catalyst is methyl ethyl ketone peroxide (MEKP), which is used for the chemical reaction resulting in the resin hardening and increased temperature required for curing. Specifically, cobalt octoate, a purple liquid with low toxicity and little odour, was used as an accelerator. The use of cobalt octoate helps to speed up the reaction between resin and the catalyst. To make use of 300 g of polyester resin, 4.5 ml of catalyst and 1.5 ml of the accelerator are mixed. The catalyst and the accelerator are blended in a 3:1 ratio. With the polyester resin accounting for 70% of the overall weight of the composite plate, the sunn hemp fibre and the flax fibre account for 15% each. The hybrid fibres (sunn hemp and flax) were chopped into lengths of 15 mm, 30 mm, and 50 mm. A bunch of each length of hybrid fibres was placed on the die plate in the steel frame. Then, the fibres of around 30 strands were tied together in a frame made up of steel rods with dimensions of 300 mm x 300 mm at multiple angle orientations, i.e., 0°, 45°, and 90°, biaxial and triaxial. To compress the hybrid fibres and the resin mixture, they were kept at a temperature of 76°C and a pressure of 2.6 MPa for 20-25 minutes. Composite plates were manufactured by preserving them at an average room temperature of 30°C and relative humidity between 45-55 %. Subsequently, the samples were cut from composite plates in precise dimensions to perform hardness tests on properties of the composites. The weight proportion of hybrid fibres in the composite is around 30% (± 2%). The photographic images of various plates before and after fabrication are shown in Fig. 3 and Fig. 4, respectively.

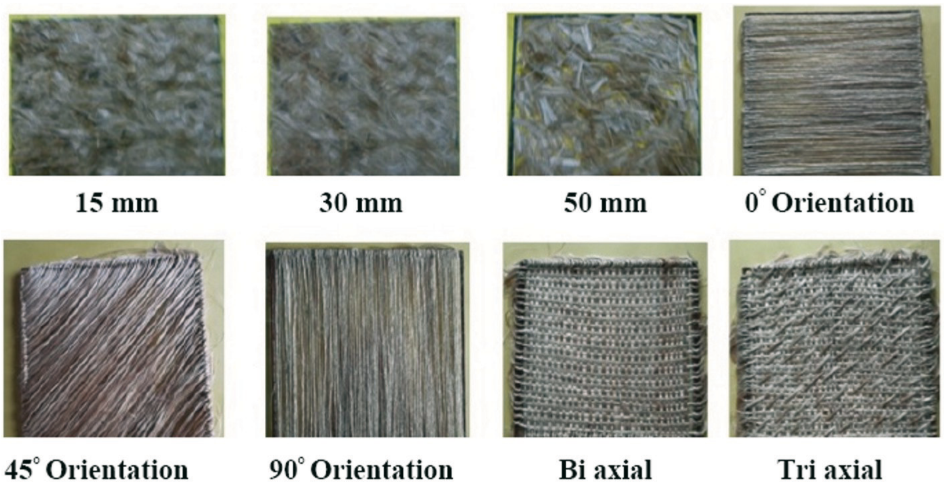

Fig. 3 Photosgraphic images of various plates before fabrication.

3. Mechanical Behaviour Testing and Dimensional Stability Analysis

3.1 Shore D Hardness Test

The Shore D (Durometer) hardness test was used to measure the hardness of the hybrid polymer composites reinforced with sunn and flax fibres. Hardness testing involves the evaluation of the resistance of a material to permanent distortion; the testing is performed by the penetration of a harder substance into the tested material. The hardness test is used to assess the qualities of a material, its strength, ductility, and resistance. The hardness test can be done using any of the following testers: the Shore, Brinell, Vickers, and Knoop. Here, the Shore D hardness tester is used. The Shore D hardness test measures the material's resistance to needle penetration under a defined spring force. For each sample, the average hardness value was measured. The analogue Shore D (Durometer) hardness tester determines the hardness value of polyester composite reinforced with sunn hemp and flax fibres. The hardness of the polymer composites reinforced with sunn and flax fibres was tested on a total of eight samples, and indentations were done in three different positions following the ASTM D 2240 standard.

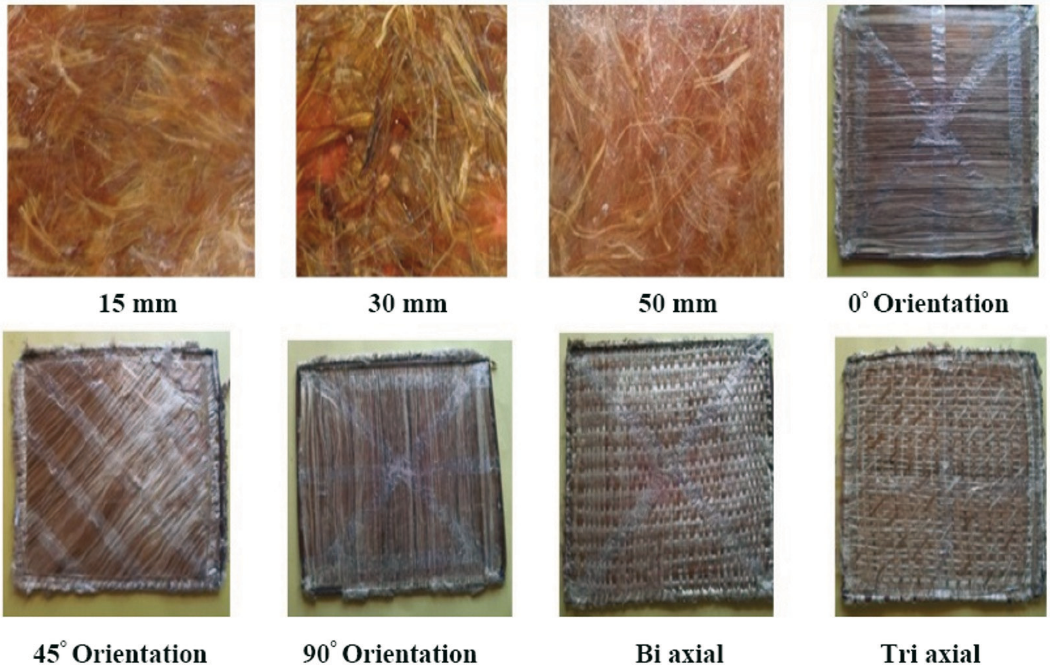

Fig. 4 Photos of various plates after fabrication.

3.2 Dimensional Stability Studies on Polymer Composites Reinforced with Sunn and Flax

An experimental study on water absorption, oil absorption, and acid absorption showed that absorption can disrupt hydrogen bonds among segments of the polymers and cause swelling of the polymer. The water absorption increases the diffusion coefficient of water within the polymer. Testing of the water absorption behaviour of composite samples was performed using the ASTM D 570 standard, with the sample dimensions of 76.2 x 25.4 x 3 mm. Samples of each type of composition were taken and dried in an oven for 24 hours at a temperature of 60°C. Then, the samples were submerged in distilled water at room temperature for about 1-10 days. The same procedure was followed in the oil and acid absorption test, but the sample dimensions were 10 x 5 x 3 mm as per the ASTM D 543 standard. Crude oil was taken for the oil absorption test, and the acetic acid was taken for the acid absorption test. Weight differences between dried and submerged samples were measured at regular intervals using high-precision weight balance. Water absorption of polyester composites reinforced with sunn hemp and flax fibres is to be computed using equation (1).

$$WA(t) = [(W_t - W_0)/ W_0] \times 100 \tag{1}$$

The term WA (t) is the water absorption (%) at time t, W_0 is the weight measured after oven drying, and W_t is the weight of the sample at a given immersion time t. The photographic images of samples of polyester composite reinforced with sunn hemp and flax fibres immersed in water, oil, and acid (1st day) at room temperature are shown in Figs. 5, 6, and 7, respectively. Moisture absorption in the samples occurs by surface concentration and diffusion process due to the polymer resin. During the oil and chemical absorption, there is a chance of a breakdown in hydrogen bonds between polyester fragments. The tested plates of polyester composite reinforced with sunn and flax may swell or gain weight due to the absorption of water, oil, and chemical agent. Dimensional stability behaviour in terms of water absorption, oil absorption and acid absorption is studied on composite samples to determine the withstanding capacity of the material under hazardous environmental conditions.

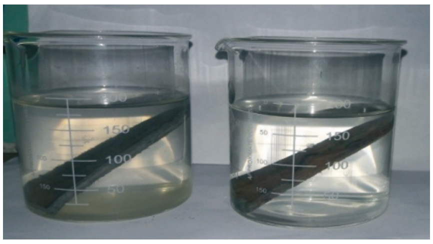

Fig. 5 Photographic image of water absorption test with samples of polyester composite reinforced with sunn and flax fibres.

Fig. 6 Photographic image of oil absorption test with samples of polyester composite reinforced with sunn and flax fibres.

Fig. 7 Photographic image of acid absorption test with samples of polyester composite reinforced with sunn and flax fibres.

4. Results and Discussion

The Shore D hardness test results, water absorption, oil absorption, and acid absorption test results have been evaluated; each sample was tested five times, and the standard deviation values for the triaxial orientation of the polymer composites reinforced with sunn and flax fibres are better than those for the biaxial, random orientation (15 mm, 30 mm, and 50 mm) and angular orientation (0°, 45°, and 90°). The experimental results for Shore D hardness, water absorption, oil absorption, and acid absorption of hybrid polymer composites reinforced with sunn and flax are given in Table 1; Figure 8 gives a comparison of Shore D values for various hybrid fibre composites. The maximum value of Shore D hardness is 75.1.

Table 1 Experimental values of Shore D hardness, water absorption, oil absorption, and acid absorption

Fibre Types	Shore D Hardness (Unit)	Water absorption (%) (At the end of day 10)	Oil absorption (%) (At the end of day 10)	Acid absorption (%) (At the end of day 10)
15mm	62.1 ± 0.4	13.8 ± 0.7	6.0 ± 0.8	5.9 ± 0.7
30mm	63.1± 0.5	13.7 ± 0.6	5.9 ± 0.7	5.8 ± 0.7
50mm	64.4 ± 0.4	13.5 ± 0.7	5.7 ± 0.8	5.7 ± 0.6
0°	67.6 ± 0.7	13.4 ± 0.6	5.5 ± 0.8	5.4 ± 0.7
45°	69.2 ± 0.6	13.2 ± 0.6	5.3 ± 0.9	5.3 ± 0.6
90°	69.5 ± 0.7	12.9 ± 0.9	5.2 ± 0.8	5.0 ± 0.8
Biaxial	71.8 ± 0.9	12.8 ± 0.8	5.0 ± 0.8	4.9 ± 0.7
Triaxial	75.1 ± 1.0	12.6 ± 0.8	4.8 ± 0.9	4.7 ± 0.8

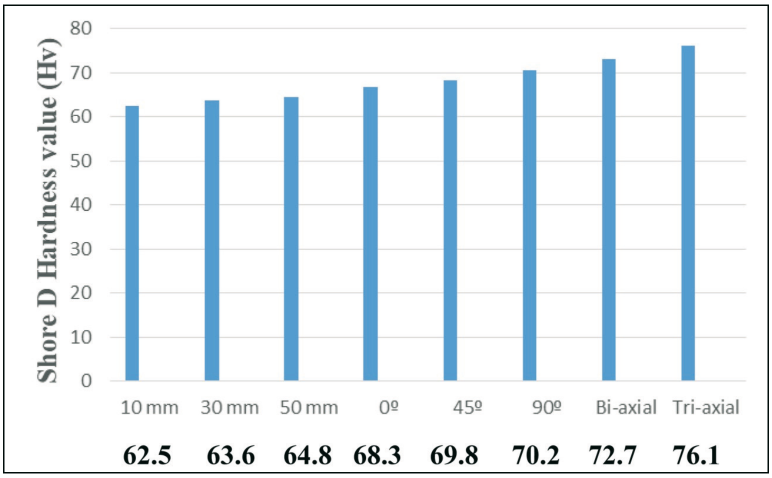

Fig. 8 Comparison of Shore D hardness values of various hybrid fibre composites.

4.1 Water Absorption Analysis of Polymer Composites Reinforced with Sunn and Flax

The water absorption behaviour of polymer composites reinforced with sunn and flax was determined by immersing samples of the material in distilled water for 10 days. The water intake in the polymer composites reinforced with sunn and flax samples was measured consecutively for 10 days by the difference in weight before immersion in the water and after it. At the end of day 1, the polymer composites reinforced with sunn and flax sample absorbed about 10.3 % of water. At the end of day 5, water absorption increases by up to 2 %. At the end of day 10, water absorption attained a peak value of 13.41 % due to the hygroscopic nature of fibres and consecutive immersion in distilled water. The graph for the water absorption behaviour of polymer composites reinforced with sunn and flax is shown in Fig. 9.

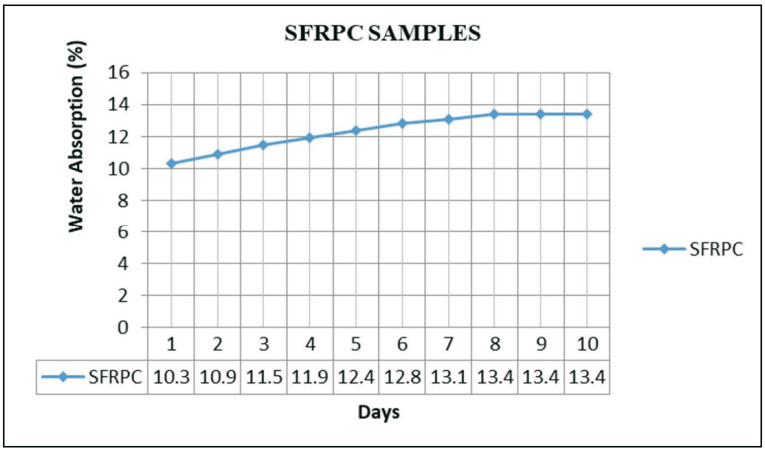

Fig. 9 Water absorption graph (SFRPC = Sunn and Flax-Reinforced Polymer Composite).

4.2 Oil Absorption Analysis of Polymer Composites Reinforced with Sunn and Flax

The thickness swelling behaviour of the polymer composites reinforced with sunn and flax sample was tested by immersing it in crude oil for 10 days. The oil absorption of the sample was measured consecutively for 10 days by the difference in thickness before immersion in the crude oil and after it. At the end of day 1, oil absorption of the polymer composites reinforced with sunn and flax sample was observed to be 4.2%. At the end of day 5, the swelling increased by up to 0.72%. At the end of day 10, a peak oil absorption value of 5.7% was observed. The graph of the oil absorption behaviour of polymer composites reinforced with sunn and flax is shown in Fig. 10.

4.3 Acid Absorption Analysis of Polymer Composites Reinforced with Sunn and Flax

The acid absorption behaviour of the polymer composites reinforced with sunn and flax sample was tested by immersing it in hydrochloric acid (HCl) for 10 days. The acid absorption of the sample was measured consecutively for 10 days by the difference in weight before immersion in HCl and after it. When exposed to HCl, the bond between fibres and matrix breaks. At the end of day 1, the polymer composites reinforced with sunn and flax sample exhibited a 4.1 % weight loss. It was also observed that the weight loss increased gradually in the upcoming days. At the end of day 5, the weight loss increased by up to 0.9 %. At the end of day 10, a peak weight loss value of 5.5 % was observed. The graph of the acid absorption behaviour of polymer composites reinforced with sunn and flax is shown in Fig. 11.

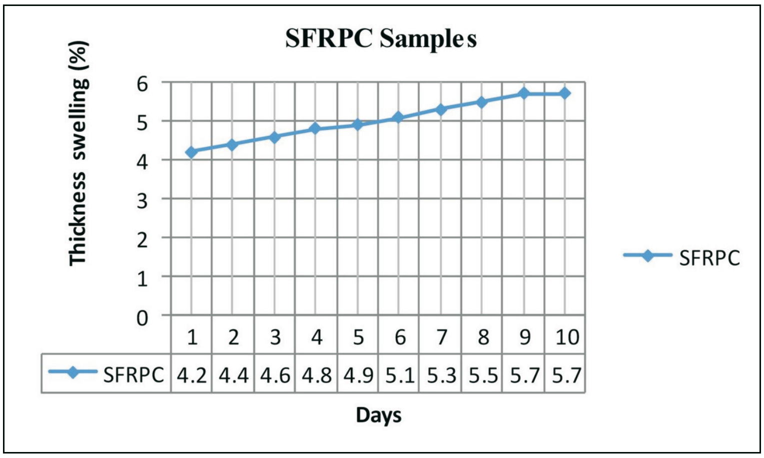

Fig. 10 Oil absorption graph (SFRPC = Sunn and Flax-Reinforced Polymer Composite).

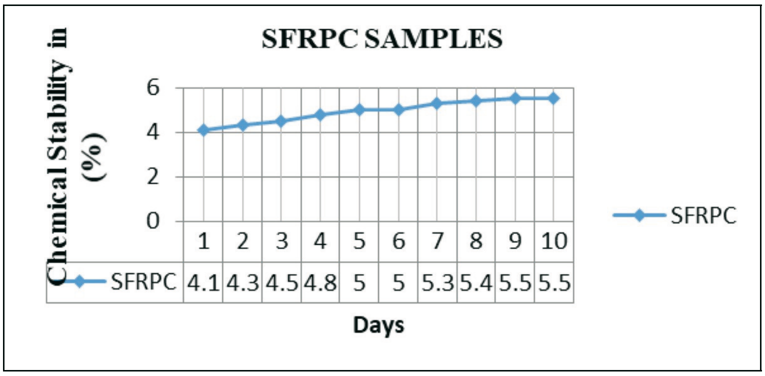

Fig. 11 Acid absorption graph (SFRPC = Sunn and Flax-Reinforced Polymer Composite).

Figures 9, 10, and 11 show that maximum values of water absorption, oil absorption, and acid absorption are 13.4 %, 5.7 %, and 5.5 %, respectively.

5. Conclusion

In this study, the Shore D hardness and dimensional stability of polymer composites reinforced with sunn and flax were tested. The following conclusions are drawn based on the test results:

- The maximum Shore D hardness value of the polymer composites reinforced with sunn and flax sample was 76.1. It was measured for the Shore D unit in triaxial orientation. The minimum hardness value was 62.5, measured for the Shore D unit in 10 mm random fibre orientation of polymer composites reinforced with sunn and flax.

- The other intermediate samples showed hardness values ranging from 62.6 to 76.0 Shore D unit. However, the composite's shore D hardness value increased by 14.6% compared with polyester composites reinforced with individual flax fibre and sunn hemp fibre.
- The dimensional stability results of polymer composites reinforced with sunn and flax showed the maximum water absorption, oil absorption and acid absorption of 13.4 %, 5.7 %, and 5.5 %, respectively.

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