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REGULAR ARTICLE

Investigation and Performance Study of *Hibiscus sabdariffa* Bast Fiber-Reinforced HDPE Composite Enhanced by Silica Nanoparticles Derived from Agricultural Residues

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Abstract

Natural bast fiber-incorporated polymer matrix composites assures the adequate replacement of conventional material to meet their future demand such as cost-effectiveness, lightweight, specific mechanical strength and high stiffness. Natural fiber-reinforced composites face higher moisture absorption, incompatibility, de-bonding and inadequate adhesion behavior. The novelty of this research work is to enhance the adhesion behavior and limit the moisture absorption capabilities by the additions of NaOH-treated hibiscus sabdariffa bast fiber with 25wt% in High-Density Polyethylene (HDPE) matrix and hybridize with the incorporation of 0wt%, 3wt%, 5wt% and 7wt% of silica nanoparticles by compression molding technique. The silica nanoparticles were derived from agricultural rice husk ash, sugarcane ash, and paddy straw through the acid precipitation technique. The composite density, surface morphology, water absorption, flexural strength and thermal absorption were evaluated and its experimental results showed significant improvement in characteristics. The composite density has been conforming to the additions of hibiscus sabdariffa bast fiber and SiO_2 nanoparticles. The morphology studies revealed uniform particle distribution with the effectiveness of bonding quality. The composite contained 25wt% of hibiscus sabdariffa bast fiber with 7wt% SiO_2 offered high flexural strength of 124.82 MPa, a low water absorption rate of 6.01% and low mass loss at a higher temperature.

Keywords Hibiscus sabdariffa bast fiber · HDPE · Nano-silica · Compression mold · Density · Water absorption · SEM · Flexural strength · Thermal absorption

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1 Introduction

Due to their beneficial behavior, polymer matrix composites with natural fillers promise the future advanced materials for structural parts, car interiors parts, sports equipment, electronic appliances, household things, and aviation cabin parts [1–3], which includes high specific strength, lightweight, zero failure for catastrophic, high stiffness, recycling, low thermal expansion, and good chemical resistance [4, 5]. Polymer matrix plays a prominent role in adhering filler materials and sustaining structural integrity [6]. Depending on the selection of reinforcement filler material (shape, size, orientations, and distribution), treatment of filler material, matrix material, and processing-based mechanical properties are to be fixed [7–9]. Among the different polymer matrices, the high-density polyethene (HDPE) has been an excellent substitution for missed bone or bone gaps because it has good toughness and organic stability [10]. Moreover, HDPE composites were prepared with bio-ceramic fiber, enhancing mechanical strength and facilitating good wear resistance. The bio-ceramic filler materials can resist the high frictional force against an average abrasive load [11]. Silicon dioxide (SiO_2), titanium dioxide (TiO_2), and calcium carbonate ($CaCO_3$) are extensively utilized to fabricate the polymer-based composite material to obtain specific properties [12–14]. Recently, silica (SiO_2) filler has played a prominent role in polymer composite fabrication due to its enhanced physical, mechanical, and chemical properties [15].

The bio-ceramic-silica particles were extracted from biowastes such as rice husk ash [16, 17], sugarcane waste ash [18, 19], olive stone [20], pine cone [21], wheat straw [22], and coconut husk ash [23]. Recent literature reported that rice husk ash, sugarcane bagasse ash, and bamboo leaf ash waste have higher silica content than others. The chemical and thermal techniques derive the silica particle from bio-wastages [24].

Majeed et al. [25] developed a natural fiber-reinforced polymer/clay hybrid composite and studied food packaging applications' mechanical/ barrier behavior. Investigational outcome results showed increased interfacial bonding, improved mechanical strength, and reduced water absorption behavior. The glass-Caryota intra-ply fiber, SiC, and nano-clay-reinforced epoxy hybrid composites are prepared by hand layup technique for high-toughness sports components, automotive, structural and domestic appliances. The experimental outcome showed that the composite's tensile strength was increased by adding 1 Vol% SiC bonded with nano-clay in intra-ply fiber. Similarly, it offered high energy absorption capability and superior wear resistance with a lower specific wear rate of 0.024 mm^3/Nm [26]. Sidra et al. [27] fabricated the high-density polyethene (HDPE) composite by incorporating 0wt%, 20wt%, 35wt%, and 50wt% of micro-silica (25 µm and 5 µm) from sand via melt extruder associated with hot press compression molding. The 20wt% of micro-silica (25 µm) offered good toughness (810.75 ± 8.1 MPa), tensile strength (20.23 ± 3.5 MPa), ductility (29.67 ± 1.41%) and elastic Modulus of (1298.33 ± 169.8 MPa). Roselle fibers reinforced polyurethane composite hybridized with 0.5wt% to 1wt% of silica nanoparticles and studied its effect on silica content on tensile and flexural strength of a composite by response surface methodology composite design approach with 95% confidence level [28]. The recycled HDPE with rice hush ash hybrid composites was synthesized using organoclay to evaluate its thermos-mechanical properties. The experimental results showed that the composite's tensile strength was significant by the presence of rice husk ash (25wt%) [29].

The vinyl ester composites were synthesized using chemical-treated Roselle fiber and studied the effects of Alkali/ Silane-treated fiber on the chemical, surface morphological, physical, mechanical, and thermal properties of the developed composite. This investigational result provides better interfacial bonding strength between the matrix and reinforcements. It increases tensile and decreased impact strength compared to untreated fiber composite [30]. The cost-effective production fabrication and mechanical strength behavior of Hibiscus sabdariffa fibers reinforced polypropylene composite is studied [31]. The physical, mechanical, and thermal properties of Hibiscus vitifolius Plant Stalk-reinforced polymer matrix composite are studied and it reported that the tensile strength of single fiber-reinforced composite was improved. The thermal gravimetric analysis found good thermal stability up to 260 °C with a kinetic energy of 126.86 kJ/mol [32].

The effect of Hibiscus sabdariffa fiber orientations on tensile, impact and flexural strength and dynamic analysis of epoxy composite is studied. Among the various orientations, the longitudinal fiber orientations showed improved tensile (460%), impact (603%) and flexural strength (160%). Moreover, it showed higher water absorption resistance than others [33]. Epoxy composite developed with woven Hibiscus sabdariffa fiber via conventional technique and investigated its mechanical properties. The optimum result composite samples were suggested for automobile interiors, dashboards and door panels [34]. The various critical points for successful composite fabrication obtaining with enhanced properties techniques are noted from the above recent literature. Most researchers have proved that chemically treated natural fibers are offered good physical, mechanical, and thermal behavior compared to untreated fiber composite. So, the novelty of the research work is to fabricate the HDPE composite using

cost-effective hibiscus sabdariffa bast fiber. Its mechanical and thermal characteristics are enhanced by adding agricultural waste residues extracted from SiO_2 nanoparticles through compress molding.

2 Experimental Details

2.1 Extraction of SiO_2 Nanoparticles from Agricultural Residues

Generally, the SiO_2 is extracted from sugarcane bagasse ash, rice husk ash, sugarcane leaf ash, wheat straw ash, paddy straw ash, corn cob ash, fly ash, bamboo leaf ash, lantana, and sunflower [16–23]. Among the various agricultural residues, the rice husk ash, sugarcane ash, and paddy straw ash had more than 70% of silica content and were extracted using an acid precipitation technique. It is the most common and efficient technique to synthesize nano-silica particles from agricultural residues [24]. Figure 1 shows the actual silica extraction process diagram. Initially, the moisture content of selective agricultural residues is dried via a hot oven maintained at 100 °C for 1 h and kept in a sintering process at uphold the temperature of 900 °C for 6 h.

Which is helps to eliminate unwanted gases and made by successful powder ash. After the process, ash powders are dissolution and subjected to Alkali (NaOH) solution leaching assisted precipitation practice. The leaching process was made with 1 M NaOH solution to suspend the carbonaceous phase. The chemical contribution is derived in Eq. 1.

$$SiO_2 + NaOH \rightarrow Na_2SiO_3 + \text{water} \quad (1)$$

The extracted sodium silicate (Na_2SiO_3 -11 pH) has been filtered and an electrical oven dries wetness for 1 day at 100 °C. Continued that sulfuric acid (H_2SO_4) precipitation process is carried out for deriving the silica content with 7pH and involved by 1-day aging treatment followed by the drying process. The chemical reaction is derived in Eq. 2. Finally, extracted silica particles were sleeved as fine particles with 50 nm size.

$$Na_2SiO_3 + H_2SO_4 \rightarrow SiO_2 + Na_2SO_4 + \text{water} \quad (2)$$

2.2 Fabrication of *Hibiscus sabdariffa* Bast Fiber-Reinforced HDPE Composite

Before the fabrication process, the hibiscus sabdariffa bast fiber was cleaned with distilled water and dried at ambient temperature (27 °C) for 12 h and then it was treated with 2% of alkali (NaOH) solution for 4 h. This process helps to increase the physical properties of fiber, reduce the moisture absorption behavior, and increase the flexural strength of the composite. A similar approach was utilized in past decades during the fabrication of natural fiber-bonded composite and proved their enhancement of composite properties [31–33]. After the NaOH treatment, the fibers are convection naturally for 24 h. Finally, fibers are immersed in distilled water for 1 h to remove the unwanted chemicals and kept in an electrical furnace for final processing.

The High-Density Polyethylene (HDPE) material is selected as a matrix material and has good toughness, high strength, high chemical and impact resistance [10, 29]. Initially, the required quantity of HDPE, HSBF, and SiO_2 nanoparticles is weighted by digital weighing equipment and the composition details are mentioned in Table 1.

Figure 2a illustrates the actual compression molding setup and a magnified view of the die are shown in Fig. 2b. The HDPE billets are kept in a muffle furnace, preheated to 100 °C for 20 min a semisolid nature, and kept in a steel crucible with an applied temperature range of 120–140 °. Meantime, the SiO_2 is externally preheated by 200 °C to remove the moisture content. The preheated SiO_2 nanoparticles are uniformly blended with hibiscus sabdariffa bast fiber for 10 min

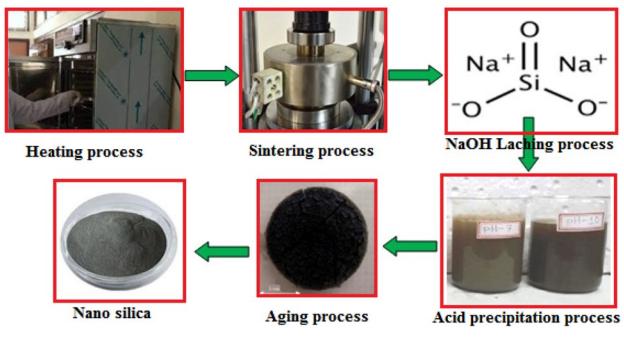

Fig. 1 Flow process diagram for silica extraction—acid precipitation

Table 1 Compositions of HDPE composite

Samples	Compositions in Wt%		
	high-density polyethylene	*Hibiscus sabdariffa* bast fiber	Silica nanoparticles
	HDPE	HSBF	SiO_2
1	100	0	0
2	75	25	0
3	72	25	3
4	70	25	5
5	68	25	7

Fig. 2 **a** Compression molding setup and **b** closed view of a die

and mixed into HDPE semi-molten pool via mechanical stirrer action of 100 rpm stir speed maintained by 15 min under 110 ° temperature.

Finally, blended matrix constitutions are poured into a compression mold die and applied pressure of 100psi (110–120 °). The molded composite sample plates (200 mm × 200 mm × 10 mm) are shown in Fig. 3 and convection naturally and machined by ASTM test standards.

2.3 Characteristics Evaluation Study details

2.3.1 Density of Composites

The effect of agricultural extracted silica loading on hibiscus sabdariffa bast fiber-reinforced HDPE composite density is tested by ASTM D792 [33] through the Archimedes principle. Before the test, the composite sample is weighed in air (W1), immersed in water, and weighed again (W2). The density of the composite is found by using Eq. 3.

$$\text{Density}(\rho) = \frac{W1}{W1 - W2} \times 1000 \tag{3}$$

2.3.2 Surface Morphology of Composites

The surface morphology of hibiscus sabdariffa bast fiber-reinforced HDPE composite with the silica presence is identified via TESCAN Scanning Electron Microscope (SEM). The fine-polished 10 mm cubic test samples are utilized for SEM examination.

2.3.3 Water Absorption Properties of Composites

Based on the ASTM D570 [30, 33], the water absorption performance of hibiscus sabdariffa bast fiber-reinforced HDPE composite with different weight percentages of SiO_2 plate (76mmX25mmX4mm) is studied. Before the test, the composite plates are dried at 50 °C temperature for 4 h via an electrical furnace and cooled by natural convection. The test plate is kept in a digital weighing balance machine weighted as (Wd). After that the plates are immersed in distilled water for 15 days and weighed every 24 h (Wt). Equation 4 finds the water absorption percentage related to time (Wat).

$$\text{Wat} = \frac{Wt - Wd}{Wd} \times 100 \tag{4}$$

2.3.4 Flexural Strength of Composites

Instran 8801Universal tensile test machine was utilized for flexural strength studies of SiO_2-incorporated hibiscus sabdariffa bast fiber-reinforced HDPE composite. According to ASTM D790 [28], the flexural strength of HDPE composite is evaluated by 2 mm/min cross-slide speed under test room conditions maintained at 25 ± 1 °C with 52 ± 5% of relative humidity.

2.3.5 Thermal Absorption of Composites

The thermal behavior of hibiscus sabdariffa bast fiber-reinforced HDPE composite containing different weight percentages of SiO_2 is analyzed by Q-series thermogravimetric

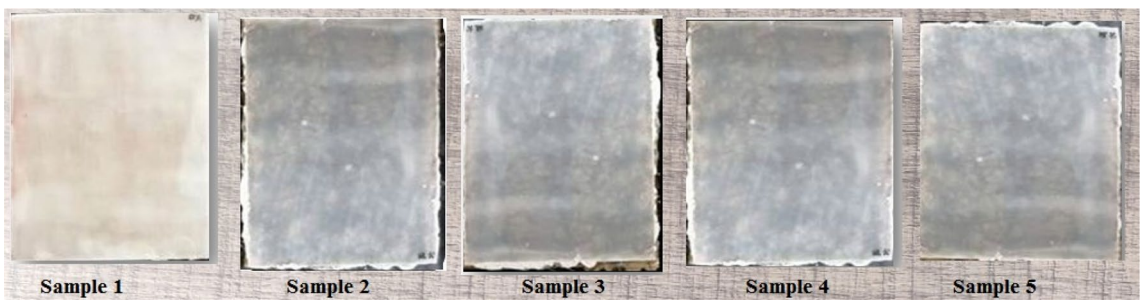

Fig. 3 Fabricated HDPE composite samples

Table 2 Density of HDPE composites

Sample	Density in g/cc		Error
	theoretical	Actual	
1	0.93	0.92	0.01
2	1.0625	1.0621	0.0004
3	1.1141	1.1138	0.0003
4	1.1485	1.1482	0.0003
5	1.1829	1.1825	0.0004

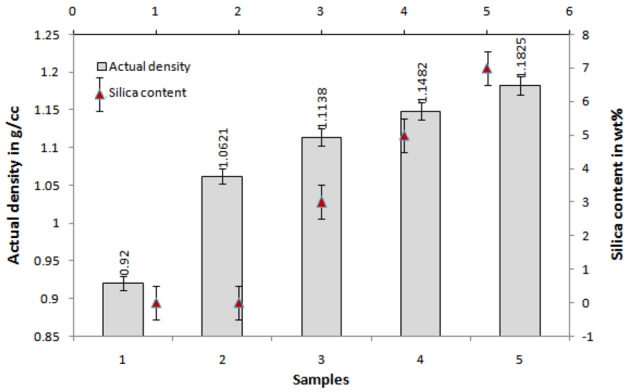

Fig. 4 Actual density of HDPE composite samples represented SiO_2 content

analyzer (TA) followed by ASTM D3850 [30]. The effect of thermal absorption on mass loss of composite is evaluated by 50–600 °C temperature with 10 °C/min heat flow rate under nitrogen nature. It helps to find the degradation of HSBF at maximum temperature [32].

3 Result and Discussion

3.1 Effect of Agricultural Residues Derived SiO_2 on the Density of HDPE Composites

Archimedes' principle measures the actual density and its theoretical density is calculated using the rule of mixture Eq. (5). However, the density of the developed composite is equal to the ratio of the mass of the composite to the volume of the composite. The theoretical and actual density with error values is specified in Table 2.

$$\rho_c V_c = V_m \rho_m + V_f \rho_f \tag{5}$$

where ρ_c, ρ_m, and ρ_f are the composite density, matrix and filler and V_c, V_m, and V_f are the composite, matrix, and filler volume.

With and without SiO_2 exposure on density variations of hibiscus sabdariffa bast fiber-reinforced HDPE composite is experimentally studied and its results are illustrated in Fig. 4. The density of sample 1 without filler material is 0.92 g/cc and the incorporation of 25wt% of HSBF found a 15.4% improvement in density. The density of samples 3, 4, and 5 gradually increases with exposure to SiO_2 content as 3wt%, 5wt%, and 7wt%. The density variation is due to the percentages of filler material presence in the polymer matrix [30]. However, the developed composite samples obey the rule of mixture theory and the actual density values show the closer value of theoretical density values. So, the compression mold synthesized HDPE composites are proven good quality, and their surface morphology (interfacial action) studies are discussed below.

3.2 Effect of Agricultural Residues Derived SiO_2 on SEM of HDPE Composites

Figure 5a–e shows the Scanning Electron Microscope observed the surface morphology of HSBF fiber-reinforced HDPE composite enhanced with different weight percentages of agricultural residues derived SiO_2 nanoparticles. Figure 5a shows the surface morphology of sample 1, which shows the smooth layer surface without the absence of filler material. The few deflection layer surfaces are noted from the surface due to the thermal variation and sudden removal of compression die after the process.

Figure 5b indicates the surface morphology of HDPE composite containing 25wt% of HSBF (sample 2). Figure 5b is the evidence of HSBF presence in the HDPE matrix. The HSBF fiber is found to have good adhesion with the HDPE matrix. It results in increased mechanical strength [28].

Figure 5c–e illustrates the HSBF-reinforced HDPE composites hybridized with varied weight percentages of SiO_2 nanoparticles. Figure 5c shows the magnified view of (sample 3) HSBF; some silica particles were deeply bonded with HSBF. The porous-free HDPE composite found that the random distribution of HSBF makes an adequate bonding with SiO_2, which results in increased mechanical and wear behavior [33].

The present research is proved the HSBF, SiO_2 nanoparticle present in HDPE matrix via density measurement and flexural strength investigation. The surface morphology of sample 4 HDPE composite is shown in Fig. 5d. The fine dispersion of silica nanoparticles is observed and denoted in Fig. 5d. The silica nanoparticles act as adequate bonding and make an interface between the HSBF and HDPE. The interaction silica leads to withstand the maximum load and resist the deflection during high sliding force.

Figure 5e represents the surface morphology of sample 5 HDPE composite containing 7wt% of SiO_2 nanoparticle. The SiO_2 nanoparticles are uniformly distributed in the HDPE matrix and show adequate interfacial bonding between the matrix and filler material.

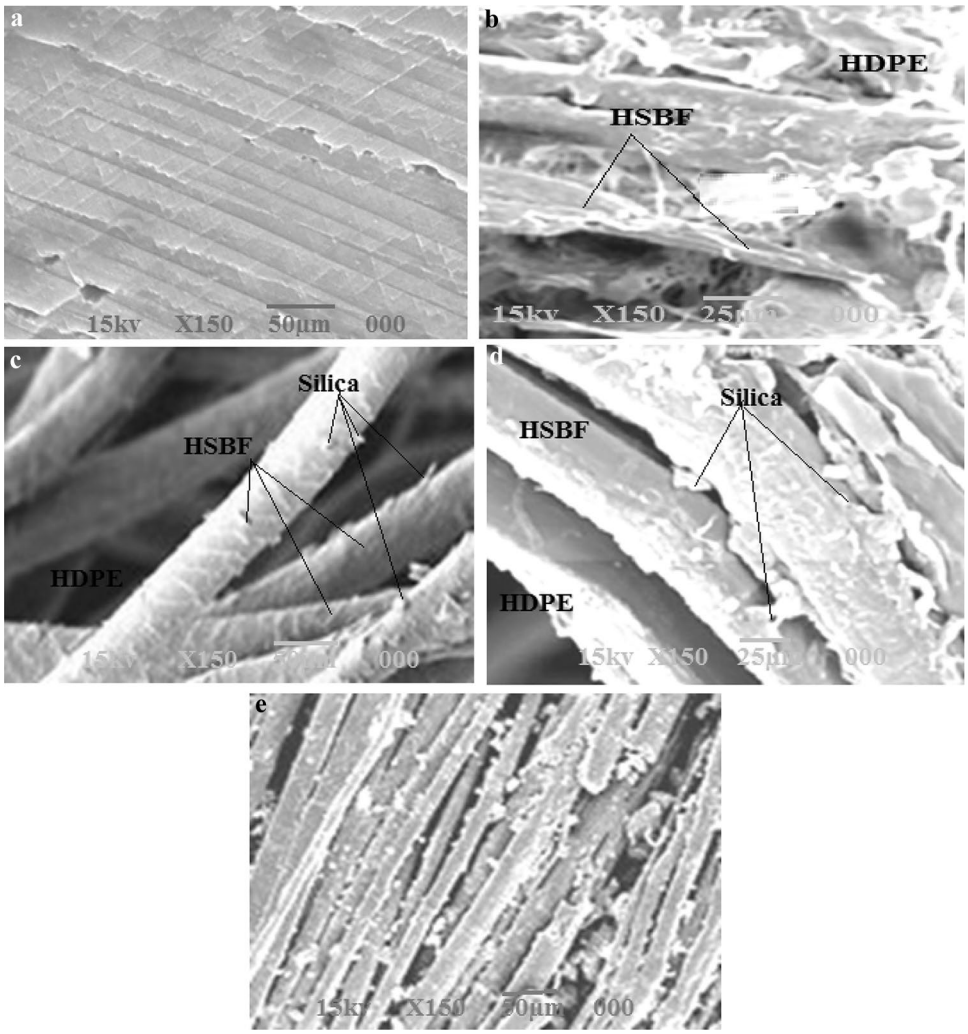

Fig. 5 **a** Surface morphology of sample 1, **b** surface morphology of sample 2, **c** surface morphology of sample 3, **d** surface morphology of sample 4, **e** surface morphology of sample 5

The light ash color particles are denoted the silica nanoparticle and block color surfaces indicate the HDPE matrix. It is proof of HSBF presence with SiO_2 nanoparticles in the HDPE matrix and the composite offers maximum flexural strength and limits the water absorption behavior, as evidenced in Sects. 3.3 and 3.4.

3.3 Effect of Agricultural Residues Derived SiO_2 on Water Absorption Percentage of HDPE Composites

Water absorption performance of HSBF-reinforced HDPE composite with and without agricultural residues derived SiO_2 nanoparticle values are plotted from 0 to 360 h at an ambient temperature is shown in Fig. 6. The water absorption percentage varies from 0.0075 to 0.01% according to the extension of the immersion period. The water absorption percentage is gradually decreased with increasing in SiO_2 nanoparticle content. All the composite samples are noted as sudden improvement in water absorption due to the capillary action [29, 30]. Figure 6 illustrates the water absorption percentage based on constant weight percentages (25wt %) of NaOH-treated HSBF and SiO_2-synthesized composite sample tested by a maximum immersion time of 360 h.

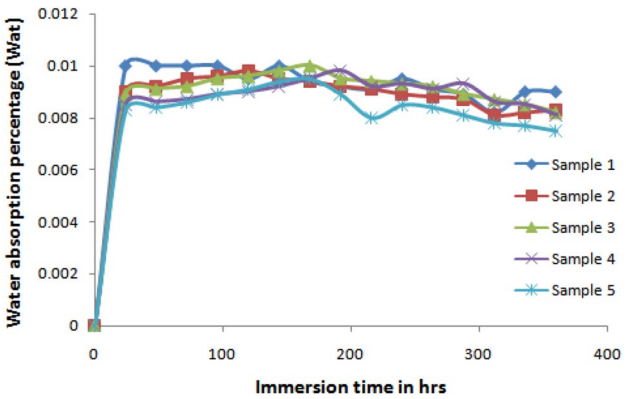

Fig. 6 Water absorption percentage based on immersion hrs

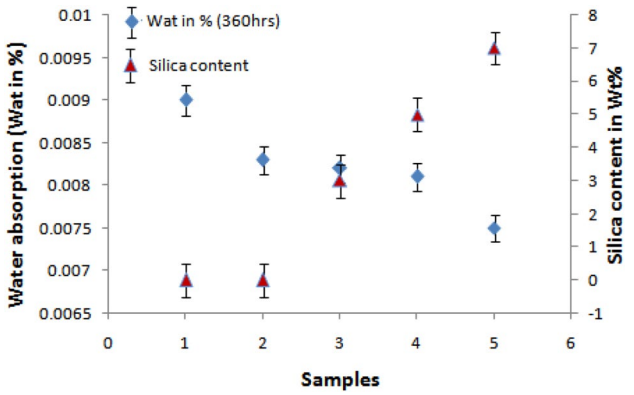

Fig. 7 Water absorption percentage based on SiO_2 content

Figure 7 shows decreased water absorption percentage on increased SiO_2 nanoparticle content. Generally, the HDPE polymer has less water absorption capacity than other polymers. The water absorption percentage of sample 1 without filler is 0.009% and the incorporation of NaOH-treated (25wt%) HSBF in HDPE matrix composite sample 2 decreased by 8.43% compared to sample 1. It was due to the presence of chemical-treated HSBF in the HDPE matrix. In past decades, chemically treated natural fiber (5wt% of NaOH)-reinforced polymer matrix composite found reduced water absorption [28]. The water absorption percentage of the composite has to vary due to the composite wall thickness [33]. Sample 3 showed a 0.0082% and further increase in SiO_2 content as 5wt% and 7wt% in HDPE/HSBF composite found reduced water absorption percentages of 0.0081% and 0.0075%, respectively. However, the water absorption percentage of HDPE composite is limited by the introduction of hibiscus sabdariffa bast fiber and increased SiO_2 content.

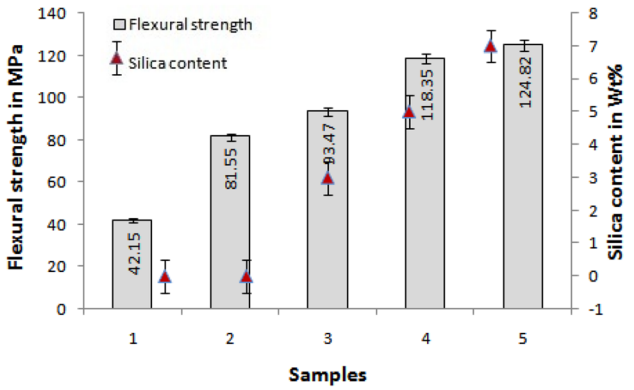

Fig. 8 Flexural strength of HDPE composite samples represented with SiO_2 content

3.4 Effect of Agricultural Residues Derived SiO2 on Flexural Strength of HDPE Composites

Figure 8 indicates the flexural strength of HSBF-bonded composites with and without SiO_2 nanoparticles developed by compression molding technique. Figure 8 shows the increased flexural strength of the composite with respect to the loading content of nano-SiO_2.

The flexural strength of sample 1 without HSBF and SiO_2 is 42.15 ± 0.85 MPa. The incorporation of 25wt% HSBF fiber found significant improvement in flexural strength in HSBF fiber HDPE composite found significant improvement in flexural strength (81.55 ± 0.91 MPa). The NaOH treatment is the prime reason for the enhancement of the flexural strength of the composite. Previously researchers reported that the chemical-treated (Alkali) natural fiber-incorporated composite found high flexural strength rather than untreated fiber composites [28]. The flexural strength of samples 3, 4, and 5 showed significant growth of 121.75%, 180%, and 196.1% compared to sample 1 without HSBF and SiO_2 nanoparticles. The composite's flexural strength was improved due to the adequate interfacial bonding between the HDPE matrix and HSBF with SiO_2 nanoparticles, as evidenced in Fig. 5c–e. This can withstand the maximum flexural load during the evaluation of the composite. The maximum flexural strength of 124.82 ± 1.01 MPa is noted by sample 5 contained a higher amount of SiO_2 content. However, the agricultural residues extracted silica content have high energy absorption capability and withstand the maximum load [15–20].

3.5 Effect of Agricultural Residues Derived SiO_2 on Thermal Absorption Behavior of HDPE Composites

The investigational outcome results during a thermogravimetric analysis of HSBF (NaOH treated)-reinforced HDPE composite enhanced by the additions of SiO_2 nanoparticles are represented in Table 3.

Table 3 Thermal absorption with degradation behavior on weight loss of composite

Sample	Weight loss % 30 °C to 220 °C	Temperature phase		Weight loss % more than 400 °C
		First degradation	Second degradation	
1	8.16	302	398	8
2	8.16	305	401	7.4
3	4.12	308	403	6.25
4	4.08	311	405	6.23
5	2.04	313	408	6.01

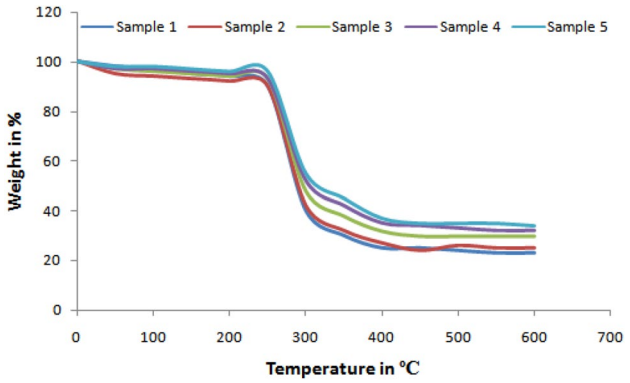

Fig. 9 Thermal absorption (weight loss) of HDPE composite (Temperature Vs weight in %)

Figure 9 shows the thermal absorption of developed HSBF-reinforced composite hybridized with different weight percentages of SiO_2 nanoparticles. Initially, all the test samples showed the zero weight loss effect and maintained their sample weight at 100%. The degradation weight loss percentage of sample 1 is 8.16% on the applied temperature range between 30 and 220 °C. At the same time, the increase in temperature of more than 220 °C showed a sudden weight loss with the first and second degradation temperatures of 302 °C and 398 °C. The HDPE composite contained 0wt% of HSBF and SiO_2 nanoparticle (sample 1) showed an 8% weight loss during the high thermal effect of more than 400 °C. However, the weight loss percentage of HDPE composite is gradually reduced with increasing the content of SiO_2.

Similarly, the weight loss percentage of samples 2, 3, 4, and 5 is noted by (8.16%, 4.12%, 4.08%, and 2.04) gradual decrement in increased content of SiO_2. The composite's reduced thermal absorption (weight loss) effect mainly depends on the compelling bonding nature of the matrix and filler material, as evidenced in Fig. 5c–e. However, the thermal characteristic of polymer matrix composite is mainly decided by the interaction quality between the matrix and reinforcement materials [30]. The sample 5 composite containing 25wt% of HSBF/HDPE/7wt% of silica nanoparticle is found to have a minimum thermal degradation effect of 6.01% weight loss at more than 400 °C.

The above Table 4 shows the present investigation results compared with past reported results. The present outcome results for sample 5 thermal weight loss are limited by 6.01% (more than 400 °C) rather than recent literature (5wt% Roselle fiber/92.5wt% Vinyl Ester) composite [28]. The flexural strength of sample 5 HDPE composite is increased 6 times and 48% as compared to 25wt% Hibiscus sabdariffa/ Polypropylene composite [31], and *Hibiscus sabdariffa* fiber-reinforced epoxy composites [33].

4 Conclusions

The extraction of silica nanoparticles from the agricultural residues via acid precipitation is made successfully and 3wt%, 5wt%, and 7wt% are utilized to enhance the performance of (25 wt%) NaOH-treated hibiscus sabdariffa bast fiber-reinforced HDPE composite. The following conclusions are made below.

- Over 80% of silica nanoparticles were derived from agricultural residues such as rice husk ash, sugarcane and paddy straw ash via the acid precipitation route successfully.
- The density of developed composite samples meets and obeys the rule of mixture theory. There is no significant deviation between the actual and theoretical density.
- The SEM image revealed adequate bonding between the matrix and reinforcement and found uniform particle distribution.
- Sample 5 contained 7wt% of SiO_2 nanoparticles, which facilitates good water absorption behavior and is limited by 0.0075% for 360 h immersion.
- The 25wt% hibiscus sabdariffa bast fiber-reinforced HDPE composite contained 7wt% of SiO_2 nanoparticle (sample 5), offered maximum flexural strength and improved by 196.13% compared to HDPE composite without filler materials.
- Thermal absorption (degradation weight loss percentage) of composite sample 5 contained higher weight percent-

Table 4 Comparison of the present research to past literature

Compositions	Water absorption percentage %	Flexural strength MPa	Thermal weight loss %	References
5wt% Roselle fiber/92.5wt% Vinyl Ester Composites	2	–	17.88	[28]
25wt% *Hibiscus sabdariffa*/Polypropylene	–	17.5	–	[31]
Hibiscus sabdariffa fiber-reinforced epoxy composites	5	83.9	–	[33]
25wt% of *Hibiscus sabdariffa* bast fiber/HDPE/7wt% SiO_2	0.0075	124.82	6.01%	Present work

ages of SiO_2, limiting weight loss and reducing 6.01% of weight loss is noted more than 400 °C temperature.

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Author Contributions All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by [RV], [RR], [SS], [GK], [P. Raja], and [MVP]. The first draft of the manuscript was written by [RV] and all authors provided language help, writing assistance and proofreading of the manuscript. All authors read and approved the final manuscript.

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Data Availability All the data required are available within the manuscript.

Declarations

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare relevant to this article's content. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Ethics Approval This is an observational study. Investigation and performance study of hibiscus sabdariffa bast fiber-reinforced HDPE composite enhanced by silica nanoparticles derived from agricultural residues, Research Ethics Committee has confirmed that no ethical approval is required.

Consent to Participate Informed consent was obtained from all individual authors included in the study.

Consent for Publication We give our consent for the publication of Novel preparation and hybridization of hibiscus sabdariffa bast fiber-reinforced HDPE composite by successful incorporation of silica nanoparticles derived from agricultural residues to be published in the Silicon Journal.

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