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ORIGINAL PAPER

Thermo-Mechanical and Wear Behaviour of Surface-Treated Pineapple Woven Fibre and Nano-Silica Dispersed Mahua Oil Toughened Epoxy Composite

T. Dinesh[1] · A. Kadirvel[2] · P. Hariharan[3]

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Abstract

In this present investigation effect of adding surface treated pineapple and nano-silica into mahua seed oil (*Madhuca longifolia*) toughened epoxy bio composite material was studied. The prime objective of this present investigation was to produce high toughness commercial epoxy bio composite with natural blender, fibre and filler. The bio blender (mahua) of density 0.9 g/cm^3 with 10 and 15 vol.%, pineapple natural fibre of density 1.4 g/cm^3 with 30 vol.% and nano-silica particle of 20 nm with 0.5 and 1.0 vol.% were used as reinforcements. The pineapple fibre and nano-silica particles were surface treated using APTES (3-Aminopropyltriethoxysilane) via aqueous solution method. Composites were made using hand lay-up method and evaluated for mechanical, thermal and wear in accordance with ASTM standards. The mechanical results showed that adding 30 vol.% of surface-treated pineapple fibre with 1.0 vol.% of nano-silica particle in mahua oil of 15 vol.%-epoxy bio blend gives maximum tensile, flexural and impact strength of 160 MPa, 225 MPa and 5.5 J. The TGA (Thermogravimetry analysis) and wear results explicated that adding 1.0 vol.% of nano-silica into mahua (15 vol.%)-epoxy bio blend offers highest stability and wear resistance. The SEM (Scanning electron microscopy) morphological images revealed reacted phase of pineapple fibre and nano-silica with mahua-epoxy blend. The fractograph images show striations on the failure direction, which revealed improved toughness of epoxy resin blend. These mechanically and thermally strengthened bio-composites could be used in structural, automobile and domestic applications.

Keywords PMC · Mahua oil · nano-silica particle · Mechanical properties · Thermal properties

1 Introduction

The role of polymer composites in structural, automobile and domestic sector increases dayby-day due to their light weight, higher toughness, cheaper in cost and easy processing methods [1]. Adding fibres and fillers into polymer matrix is a foreknown process about the decay in the field of materials technology [2]. These fibres and fillers are usually added as macroscopic addition into polymer matrix and improving thermal, mechanical and tribological behaviour of polymers substantially [3]. But researchers say macroscopic addition of fibres and fillers may improve thermo mechanical properties to certain level and not much higher level. In all composites the matrix phase holds larger volume than reinforcement phase, so modifying the matrix by micro-molecular level may yield substantial improvements in thermal, mechanical and wear properties of polymer matrix composite. Arun prakash et al. [4] revealed the need of toughening epoxy resin by neem seed non-edible oil and sea urchin bio ceramic/kenaf woven fibre addition to neem oil-epoxy resin blend. They concluded that adding neem into epoxy reduces the high brittleness and improves the energy absorption behaviour of epoxy composite whereas adding kenaf woven fibre and sea urchin marine bio filler increased the tensile strength, flexural strength, impact toughness, micro- hardness, thermal stability and abrasion resistance of neem-epoxy composite. Felipe et al. [5] investigated the effect of adding bio derived epoxy resin

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✉ T. Dinesh
dinesh5362@gmail.com

[1] Department of Mechanical Engineering, J.N.N Institute of Engineering, Anna University, Chennai 601102 2, India

[2] Department of Mechanical Engineering, R.M.K. Engineering College, Anna University, Chennai 601206 2, India

[3] Department of Manufacturing Engineering, College of Engineering Guindy, Chennai 601206, India

from waste vegetables. The authors highlighted the advantages of eco-friendly nature of the bio based epoxy resin. In-addition to that the inclusion of glass fibre into resin, increased the mechanical and tribological properties of bio epoxy. Nilofar et al. [6] discussed the effect of adding linseed oil addition into epoxy resin. The authors confirmed that adding linseed oil reduces the extreme brittleness of epoxy resin by breaking hard thermoset networks in polymer. The interpenetrating polymer network is the cause of improved toughness they confirmed. Julyes et al. [7, 8] examined the toughening effect of unsaturated polyester addition into epoxy resin. The authors confirmed that the addition of UP improved the ductility and energy absorption behaviour of epoxy resin but at the same time decreases the thermal stability. The authors also added iron(III) oxide of 1, 3 and 5 wt.% into UP-epoxy blend. The inclusion of iron oxide further improved the thermal stability significantly. Thus based on the previous studies very few researchers only investigated the role of non-edible oil in polymer composite technology. There is no much research studies in the domain of blending non-edible oils with synthetic resins and their respective properties. In this literature gap the present article is designed with non-edible oil blending with synthetic resins and their effects in mechanical, thermal and morphological behavior. The base matrix selected here is epoxy resin since it has very low density of 1.18 g/cm^3 and low gel time thus speed of manufacturing could be higher [9]. Mahua oil could be a bio blender since, it is cheap, large volume of availability, non-edible, simple oil extraction techniques from seeds and highly miscible in resins. Pineapple fibre is selected as primary reinforcement since on comparing with other natural fibres the pineapple fibre seems to be lower density of 1.7 g/cm^3 but superior in tensile properties. Their productivity from natural resource also considerably good compare than other natural fibres in the same classes [10]. Similarly, the nano-silica particles could be selected as secondary reinforcement since its lower density, high thermal stability, and high adhesion with chemicals and cheaper in cost too. The nano-silica production method also simpler and the rate of production is faster than other ceramics [11].

The mechanical and thermal properties of particulate epoxy composite purely relay on particle dispersion and adhesion with matrix. Hence the particle addition with good dispersion could be noteworthy process before making particulate composites with particles, whiskers, nano tubes and nano rods [12]. Arunprakash Vincent et al. [13] experimentally proved that the effect of adding surface treated MWCNTs provides improved thermo-mechanical and EMI shielding properties than as-received CNTs in epoxy matrix. Thus the role of silane surface-treatment is highly significant in polymer matrix composites for better performance. The reinforcements and fillers could be surface treated via aqueous solution method with amino-silanes since the method contains simple process flow techniques [14]. The composites could be prepared via hand layup process since hand layup requires low process parameters [15]. These mechanically toughened and thermally stabled polymer matrix composites could be used as alternate material for structural, automobile, space crafts and domestic applications where high damping and energy absorption is required.

2 Experimental procedures

2.1 Materials

The epoxy thermoset resin used in this research was liquid diglycidyl ether of bisphenal-A type epoxy resin having 195 g/mol with kinematic viscosity of 12,000 cps. The curing agent used for curing the epoxy resin was TETA having 20 cps supplied by Huntsman, India, Ltd. The surface modifier 3-Aminopropyltriethoxysilane having density 0.9 g/cm^3 a pale yellowish liquid purchased from Sigma Aldrich USA. Mahua seed nut of density 1.1 g/cm3 used as toughening element for epoxy thermoset resin. Pineapple woven mat fibre and nano-silica particle of size 20 nm was purchased from Go green industrial fibre India, pvt.ltd and Sigma Aldrich, USA respectively. Figure 1a shows the SEM image of pineapple fibre after weaving; 1(b) shows the image of nano-silica particle.

2.2 Surface-Activation of Nano-Silica Filler and Pineapple Woven Fibre

Nano-silica fillers and pineapple woven natural fibre was surface-activated via acid hydrolysis process by using 3-Aminopropyletriethoxylane. Usually acetic acid of 4 N was used to regulate the pH of ethonal-water solution for hydrolysis process. The pH was set at the range 4.5 to 5.5 to enhance better hydrolysis. Optimum quantity of silane usually 2 wt.% was used to prepare high homogeneous ethanol-water (aqueous) solution. In this process the cleavage action of ethoxy group from silane is the cause of creating Si-OH structure during hydrolysis process. The nano-silica particles and pineapple natural woven fibre was then dipped into silane solution

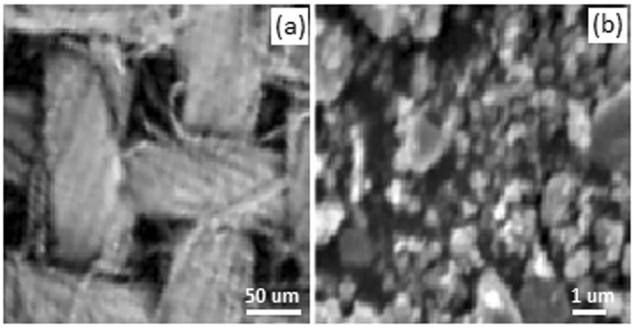


Fig. 1 SEM images of **a** Woven pineapple fibre and **b** Calcinated nano-silica particles

for about 10 min. The filler and woven fibre was then taken out and dried using a hot air oven at 110 °C to form condensed Si-O-Si configuration [16]. Figure 2 reveals the absorbance FT-IR spectrum of silane activated reinforcements (nano-silica particle). The spectrum recorded in this present study was taken by using Bruker alpha spectra machine (ATR), Germany. A peak at 3185 wave number (cm^{-1}) from Fig. 2 revealed the subsistence of NH_2 functional group on the surface of reinforcements from silane. The peak at 2925 wave number (cm^{-1}) pointed out the incidence of propyl group (C-H stretch) on particle's surface. The peak at 1410 wave number (cm^{-1}) reveals the existences of C-H bend. A peak 1028 wave number (cm^{-1}) confirms the being there of Si-O-Si constitution on particle and fibre's surface [17]. Thus the silane surface-activation process activates the surfaces of nano-silica and E-glass fibre for better adhesion and dispersion.

2.3 Composite Preparation

2.3.1 Preparation of Mahua Oil Toughened Epoxy Resin

The mahua-epoxy blend was prepared by gentle mixing 10 and 15 vol.% of mahua oil into epoxy resin in a glass container at 80 °C with uniform stirring. The stirring process was continued until a harmonized emulsion of mahua-epoxy blend has been formed. The mahua-epoxy bled was cooled further to room temperature for post processing (making of hybrid composites). Figure 3 shows the absorbance spectrum of mahua oil-epoxy blend. The strong peak at 1740 wave number (cm^{-1}) ascertain the availability of C=O bond from acetic acid. The other peaks at 2966 wave number (cm^{-1}), 1507 wave number (cm^{-1}) and 1295 wave number (cm^{-1}) explicit the existence of O-H, C-H and C-O bonds respectively [18].

2.3.2 Making of Pineapple Fibre-Reinforced Nano-Silica Particle-Dispersed Epoxy-Mahua Bio Composite

The composites were prepared via hand layup process. In this a silica rubber mould was used as a molding platform. Initially a rough coat of wax was applied on the molding plane for easy removal of composites after curing. The surface-modified nano-silica particle dispersed epoxy-mahua matrix was then poured into the mould and allowed to fill completely. Small dose of nano-silica particle of 1.0 vol.% max was utilized to prepare hybrid composites. Further addition of nano-silica particles may form agglomeration thus the dose of particles was stopped by maximum 1.0 vol.% [19]. Three layer (30 vol.%) of surface-modified pineapple fibre was laid one by one and entrapped air bubbles were removed using a cotton roller. The composites were cured at room temperature for 24 h and post cured at 48 h with temperature of 120 °C. The Table 1 shows the designation and composition of composites discussed in this present study.

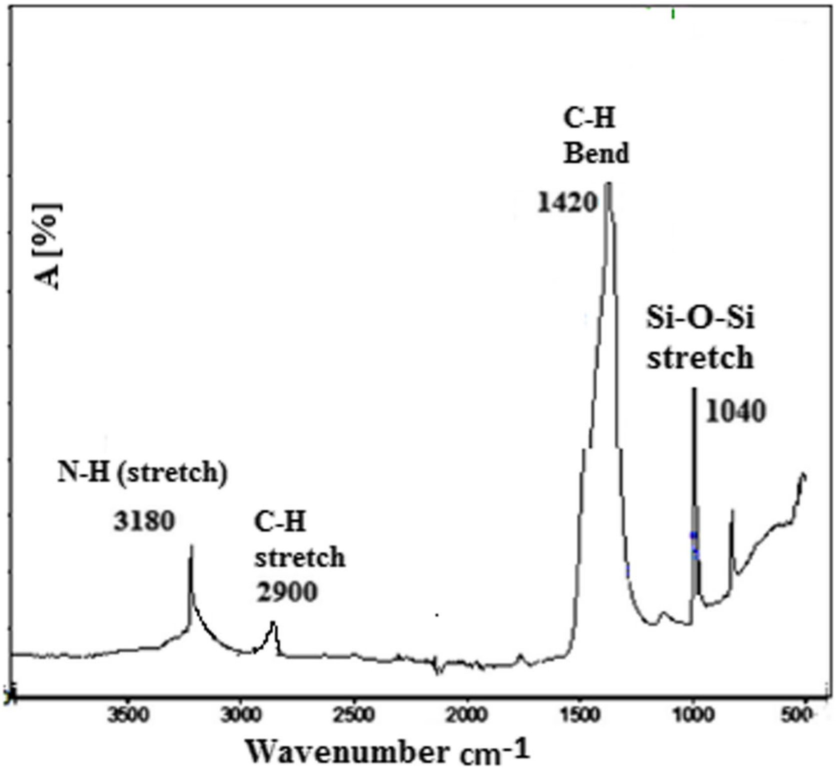


Fig. 2 Absorbance spectrum of silane surface-activated nano-silica particles

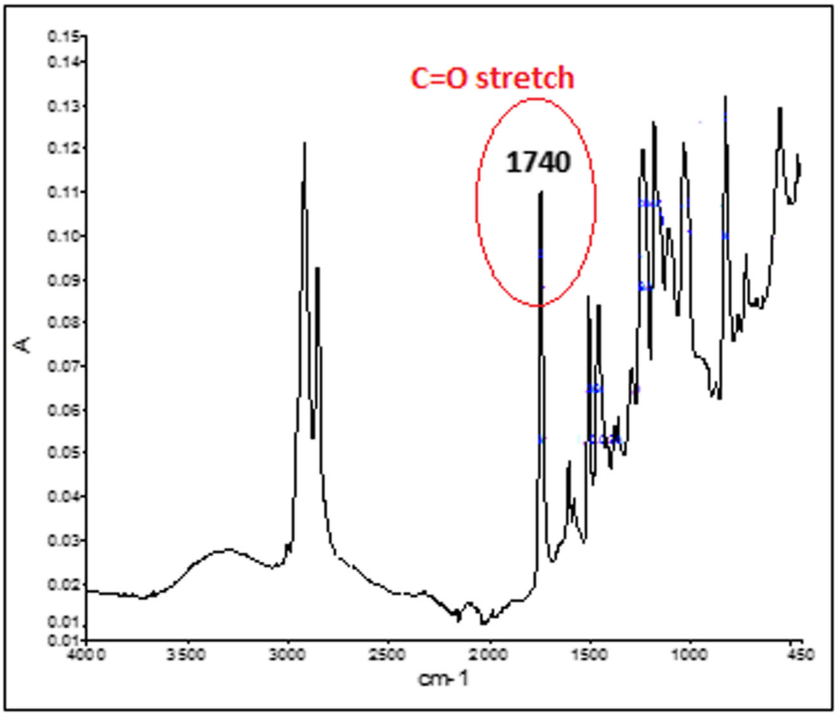


Fig. 3 FT-IR absorbance spectra of mahua-epoxy blend (mahua 15 vol.%)

2.3.3 Preparation of Test Specimen

The hand layup fabricated mahua oil toughened epoxy composites are inspected for ocular imperfections. The test samples were prepared via abrasive water jet machine (Maxiem water jets 1515, KENT, USA) in accordance with ASTM standards. Garnet size of 80 mesh; flow rate of 0.30 kg/min, working pressure of 220 MPa and nozzle diameter of 1.1 mm was set as process parameters.

2.4 Characterization

2.4.1 Mechanical Properties

Tensile and flexural strength of mahua-toughened epoxy composites were evaluated in accordance with ASTM-D 638(dog bone specimen), 3039(175X25X3mm) and 790(65X12.7X3mm) standards respectively. An INSTRON 4855, UK universal testing machine with traverse speed of 1.1 mm/s was used for testing the composites. The Impact toughness of mahua toughened epoxy composite was tested based on ASTM-D 256 (65X12.7X3mm) using a mini impact tester of loading capacity 20 J. Micro-hardness (Shore-D) of composites were ascertained by using a Durometer in accordance with ASTM-D 2240. Five equal shaped test samples were tested to compute mean of tested parameters. A typical pin-on-disc (Ducom instruments Pvt. Ltd., India) setup was used to find the wear resistance of mahua-toughened epoxy composite in harmony with ASTM standard G-99. A maximum load of 50 N and disc speed of 1000 rpm was fixed as process parameters. In all above tests a minimum of 5 identical specimens were tested to compute the average.

2.4.2 Morphology Investigation

The fractured portions of mahua toughened epoxy composite were inspected using a HITACHI thermatic Scanning electron

Table 1 Composite designation and composition

Composite designation	Epoxy (vol.%)	Mahua Oil (vol.%)	Pineapple fibre (vol.%)	Nano-silica particle (vol.%)
E	100	–	–	–
E1	90	10	–	–
E2	85	15	–	–
E3	55	15	30	–
E4	54.5	15	30	0.5
E5	54	15	30	1

microscope (S-1500, JAPAN). The scanning targeted portions are coated with gold to avoid charging.

2.4.3 Thermal Stability Behaviour

The TGA-DTA analyzer used in this present study to investigate the glass transition and decomposition temperatures of mahua toughened epoxy composite were analyzed using a NETZSCH TGA-DTA coupled thermogram with N_2 shielding gas. The composite samples were scanned from 0 to 900 °C at the heating rate of 283 K/min. The samples were hold in an alumina fire resistance crucible. Both sample and reference crucibles were heated and simultaneously the derivative of temperature plotted in a graph between mass loss and temperature.

3 Results and Discussion

3.1 Mechanical Properties

The mechanical performance of surface-modified pineapple fibre-reinforced nano-silica particle added mahua toughened epoxy composite is presented in Table 2. It is observed that the pure epoxy gives tensile strength and modulus of 65 MPa and 2.2 GPa. Similarly the flexural strength and modulus of pure epoxy accounts 103 MPa & 2.6GPa. The Izod impact toughness of 0.41 and hardness of 82 shore-D was observed for pure epoxy. But additions of 10 and 15 vol.% of mahua oil marginally decrease the tensile strength mean while increase flexural strength & modulus. A 9% and 2% improvement in flexural strength and modulus was observed for composite contain 10 vol.% of mahua oil. Similar improvements were noticed in 15 vol.% mahua oil toughened epoxy composite. The increment of 14.8% and 8% was seen for composite, which contain epoxy & mahua oil of 15 vol.%. This reduction on tensile strength and improvement on flexural strength is by the reason of increasing IPN (inter-penetrating polymer network) structure [20]. These flexible inter-penetrating polymer networks could stretch well when bending load is applied and can't bear for maximum tensile load since the tensile properties are purely depend on matrix [21]. The izod impact of mahua seed oil of 10 and 15 vol.% in epoxy gives slight decrement. It is observed that the decrement in toughness is 7.3% and 14.6% for composite category E1 & E2. This decrement is by the reason of flexible IPN formation due to the reaction of epoxy and mahua oil. It is further noted that the blending of mahua oil into epoxy resin reduces hardness in casted mahua toughened epoxy composite. The reduction of 2.3% & 4.7% was viewed for E1 and E2 composite designations. This decrement is a cause of IPN structure formation and reduced cross-linking density [22]. Thus addition of mahua oil into epoxy resin reduces the extreme brittleness by the inception of IPN structure and reduction of cross-linking density.

It is observed that the inclusion of 30 vol.% siliconized pineapple woven fabric in mahua toughened epoxy resin gives improved tensile, flexural strength and modulus. The improvement of 52%, 52%, 44%, 52% were viewed for E_3 designation composite in tensile, flexural & modulus. This positive trend is because of presence of surface-treated pineapple fibre, which consumes maximum load from epoxy matrix and reduces the griffith crack generation criterion. Similar improvements were noted in impact toughness and hardness of E_3 composite designation too. This improvement is the reason of ability of continuous natural fibre and its of load transfer from matrix [22].

The additions of 0.5 and 1.0 vol.% of nano-silica particle dispersed pineapple reinforced mahua toughened epoxy hybrid composite gives improved tensile, flexural, impact and hardness values. Maximum tensile strength and modulus of 160 MPa and 5.3 GPa was observed for composite designation E5. Similarly the E5 composite designation gives highest izod impact toughness of 5.50 joules, which is near 93% of improvement on compare to neat epoxy resin. Hardness value of 87 Shore-D was recorded for composite designation E5. This improvement is because of surface modified nano-silica particle in mahua toughened epoxy hybrid composite. The addition of particle increases the cross linking density by attracting the free OH group in epoxy resin and improved the cross-linking density [23]. The improved cross-linking density hinders the easy mobility of polymer chains, thus increased hardness was observed. Moreover the additions of

Table 2 Mechanical behaviour of mahua toughened epoxy composite

Composite designation	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Izod impact (J)	Hardness (Shore-D)
E	65 ± 1.4	2.2 ± 1.8	103 ± 1.1	2.60 ± 2.1	0.41 ± 0.1	82 ± 1
E_1	60 ± 1.2	2.1 ± 1.6	113 ± 1.1	2.65 ± 1.8	0.38 ± 0.2	80 ± 0.8
E_2	56 ± 1.2	2.0 ± 1.8	121 ± 1.2	2.82 ± 1.9	0.35 ± 0.4	78 ± 0.6
E_3	35 ± 1.3	4.6 ± 1.7	185 ± 1.3	5.51 ± 1.8	4.80 ± 0.3	79 ± 0.5
E_4	142 ± 1.2	4.9 ± 1.7	205 ± 1.2	5.80 ± 1.8	5.25 ± 0.4	84 ± 0.4
E_5	160 ± 1.3	5.3 ± 1.8	225 ± 1.1	6.21 ± 1.9	5.50 ± 0.5	87 ± 0.2

nano-silica particles occupy the molecular voids thus the mobility of polymer chains are restricted. This increment in rigidity would increase the strength of mahua-toughened epoxy resin hybrid composite. In addition with that the addition of nano-silica particles increases the bonding behavior of matrix and reinforcements, which in-turn increases the mechanical properties [24]. Thus addition of mahua oil into epoxy reduces the brittleness and improves the ductility by forming more IPN structure whereas subsequent addition of pineapple fibre greatly improved the tensile, flexural, izod and hardness further. The addition of nano-silica particles further improved all the above mentioned properties substantially.

3.2 Wear Properties

Figure 4 shows the specific wear rate of various composites fabricated. The sp. wear rate of 0.013 mm^3/Nm was noted for composite designation E. But adding 10 and 15 vol.% of mahua into pure epoxy resin marginally affects the wear resistance of epoxy resin. A reduction of 28% and 35% was noted for composite containing 10 and 15 vol.% of mahua oil. This marginal reduction is because of adding soft mahua molecules in to pure epoxy, which in-turn reduces the degree of cross-linking and affects the inter-molecular adhesion. Thus increased wear rate is observed [25]. But it is noted that the moment adding 30 vol.% of pineapple fibre the wear resistance of mahua-epoxy increases. An improvement of 23% was observed for composite, which contain 30 vol.% of pineapple fibre. This improvement is because of reduction in direct contact of epoxy molecules to explore on the abrasion plate. The reinforced pineapple fibre reduces the amount of pure epoxy expose to abrasion disc thereby decreased the wear rate [26].

It is further noted that the addition of 0.5 and 1.0 vol.% of nano-silica particle further improved the wear resistance. The improvement of 38% and 62% was observed for composite, which contain 0.5 and 1.0 vol.% of nano-silica particle. This improvement is the reason of improved micro load bearing mechanisms with in mahua-epoxy matrix by the addition of nano-silica particle. These particles reduce the coefficient of friction between composite and wear disc, which in-turn reduces the specific wear rate [27]. Figure 5 shows the COF of various composites. The COF of 0.44 and 0.4 was observed for composite designation E4 and E5. This is mere 27% and 33% of improvement.

Figure 6 shows the scanning electron microscope image of worn surfaces after wear test on nano-silica dispersed (E_5) and non-dispersed (E_2) epoxy resin composite. The wear track (Fig. 6a) explicated highly rough surface before the addition of nano-silica particles, which is due to very high COF and soft nature of mahua-epoxy molecular blend.

But in Fig. 6b the wear track appeared as almost flat surface, which indicates the improved hardness on the surface after the addition of nano-silica particles. The inclusion of nano-silica particles also present in the void space and giving considerable hardness, which gives lower COF, which in-turn reduces the wear loss [28]. It is also well-known that the dispersion of nano-silica particles played a vital role in producing average surface hardness and maintaining uniform coefficient of friction. Figure 7 shows the EDAX report of prepared nano-silica dispersed epoxy composite specimen at various places. Figure 7a–d shows the EDAX report at various places on the nano-silica dispersed mahua-epoxy composite. The strong peak reveals the presence of nano-silica particles in all four places of the composite specimen tested, which indicates uniform dispersion of nano-silica on matrix. Thus adding mahua into epoxy resin marginally affects the wear resistance of epoxy whereas additions of pineapple fibre and nano-silica particle further improved the wear resistance as greater level.

3.3 Thermal Properties

Figure 8 shows TGA thermogram of various composites used in this present study. Table 3 shows the mass loss at various

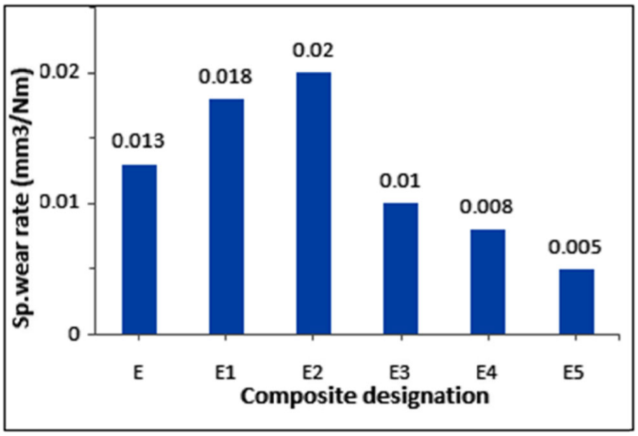


Fig. 4 Sp. wear rate of composites

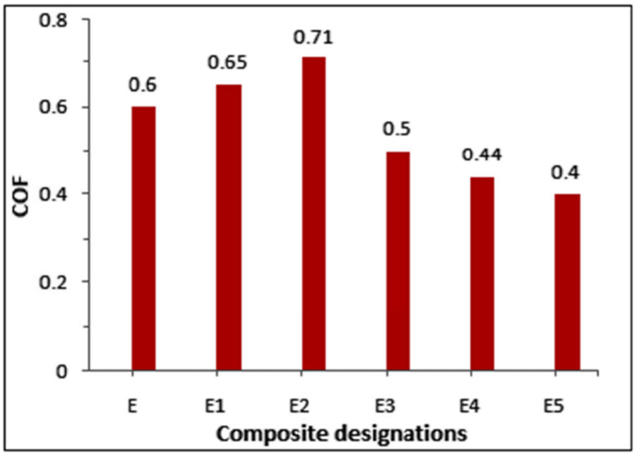


Fig. 5 Coefficient of friction of composites fabricated

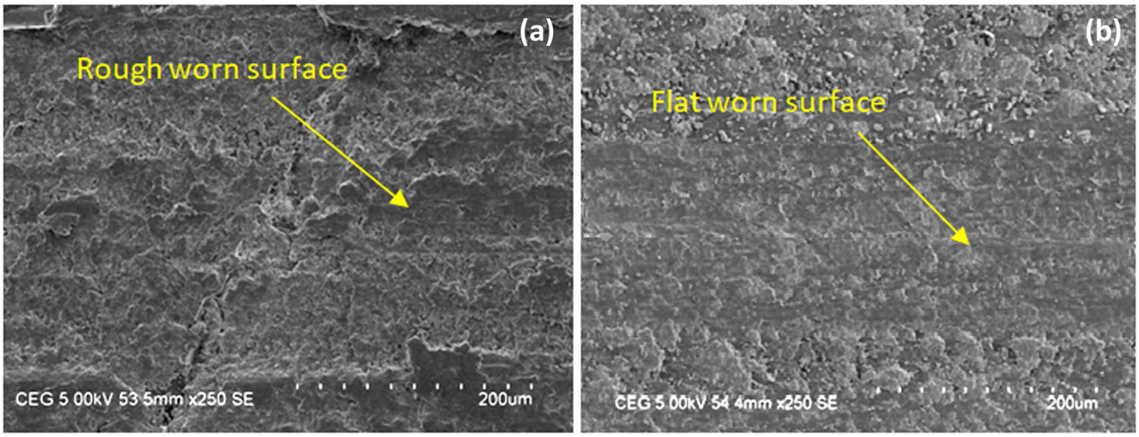
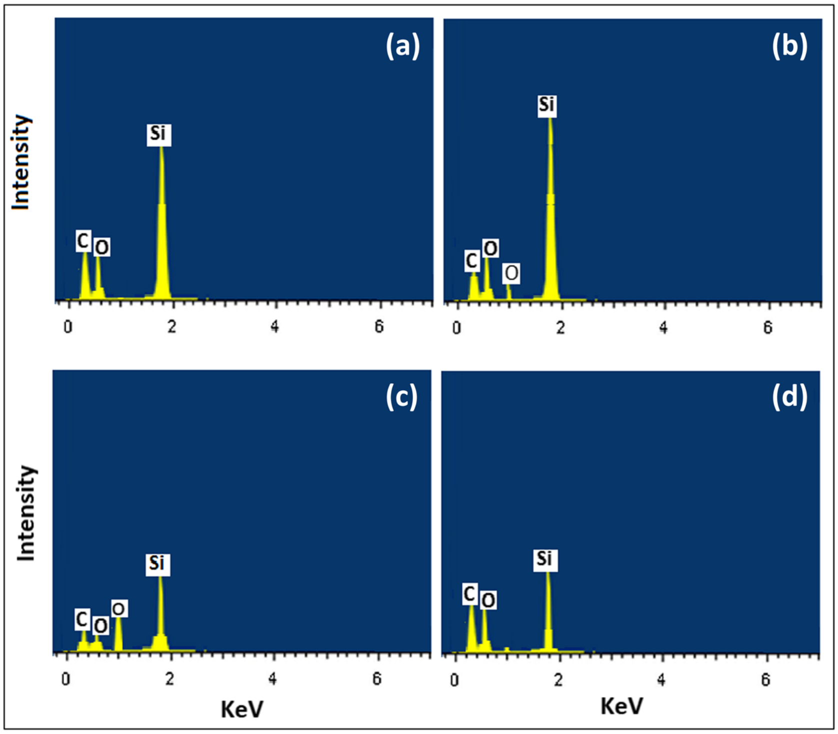


Fig. 6 SEM images of **a** worn surface of composite E_2 and **b** E_5

temperatures such as Td10, Td50, Td90 and residual mass after TGA analysis. It is observed that the pure epoxy has early, middle and end up mass decay temperatures as 290 °C, 313 °C & 420 °C respectively. But addition of 10 and 15 vol.% of mahua in epoxy slightly decreases its early, middle and end up mass stability. This is because of early evaporation of aqua molecules and ether content from mahua oil-epoxy blend [29]. It is further noted that subsequent adding surface-treated pineapple fibre in mahua-epoxy bio composite much improved the initial (310 °C), rapid (345 °C) and final (430 °C) decomposition temperatures. This improvement is by the reason of high heat capacity of pineapple fibre in mahua-epoxy bio composite. Similar progress was also noted in E_4 & E_5 composite designations. The improvement is due to the additions of either 0.5 or 1.0 vol.% of nano-silica particle in mahua-epoxy blend. The hard ceramic nano-silica particle could absorb more heat due to its high heat carrying capacity nature which in-turn improves the initial, rapid and final thermal stabilities of composite. The improvement of 16%, 24% and 8% were observed for composite designation 'E_5' in initial, middle and final decomposition stages. It is observed that compare than E_4 composite designation E_5 gives improved thermal stability in initial, rapid and final decomposition stages. This phenomenon is the reason of large

Fig. 7 **a**, **b**, **c** and **d** shows EDAX spectrum of E_5 composite specimen



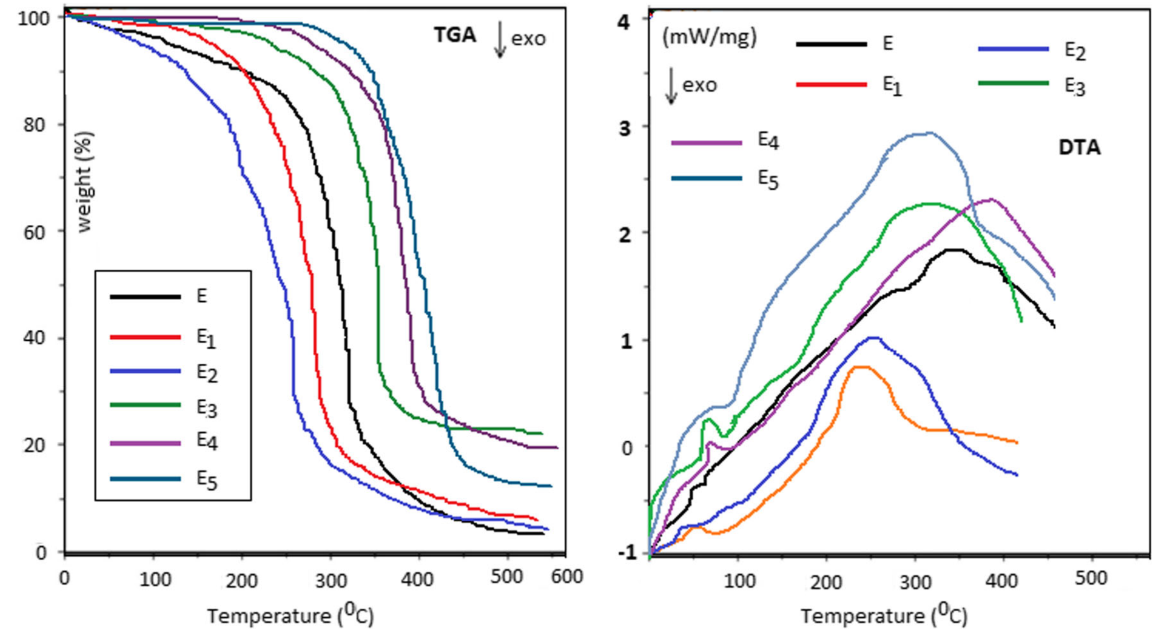


Fig. 8 TGA and DTA thermogram of composites

nano-silica particle volume in mahua-epoxy matrix and absorption of more heat. There are no issues in particle clustering since; the particles are surface-treated using an amino-silane. The silane treated particle could disperse uniformly on resin matrix and perform well. Thus the 1.0 vol.% nano-silica particle dispersed mahua-epoxy composite gives higher thermal stability than others. Similar, improvements were observed in glass transition also. Figure 8 also shows the differential temperature analysis (DTA) results of pure resin and its composites. It is observed that the pure epoxy resin gives glass transition value of 63 °C. Further addition of mahua oil of soft molecules into epoxy resin as 10 and 15 vol.% reduces the glass transition value as 56 °C and 49 °C respectively. This reduction in the glass transition temperature is the cause of formation of flexible ether group by blending mahua oil and epoxy resin [30]. The flexible IPN structure reduces the thermal stability and offers lower glass transition value. It is again noted that additions of pineapple fibre and nano-silica particles further increased the Tg values as better than mahua toughened epoxy resin. The increased glass transition value of 73 °C, 78 °C and 84 °C were noted for E_3, E_4 and E_5 composite designation respectively. This improvement is because of high specific heat of fibre and nano-silica particles [31]. Thus additions of reinforcements considerably increased the thermal stability and glass transition value.

3.4 Fractograph Analysis

Figure 9 shows the fractograph of various composite specimens evaluated in this present study. Figure 9a, b shows the dispersion morphology of nano-silica particle of volume 0.5 and 1.0. In both images there was no agglomerations found. It explicated the uniform dispersion of nano-silica particle in mahua-epoxy blend. This uniform dispersion is the result of surface-modification of particle by silane modifier [15].

Figure 9c shows the fractograph image of mahua-epoxy mixture and explicit homogeneous nature. Figure 9d shows the fractured surface of composite designation E5 under tensile test. The striations presence of striations and river marks explicated the improved toughness of mahua-epoxy composite. This improvement is the result of development of IPN flexible structures while blending. Figure 9e, f shows the

Table 3 TGA analysis of epoxy composites

Composite designation	Td_{10} (wt.%)	Td_{50} (wt.%)	Td_{90} (wt.%)	Residual (wt.%)
E	3.34	60.5	27.8	8.78
E1	4.82	58.6	24.5	12.08
E2	7.09	55.4	32.1	5.41
E3	3.18	36.9	9.24	20.7
E4	2.55	35.2	10.45	21.8
E5	2.90	41.1	8.16	17.54

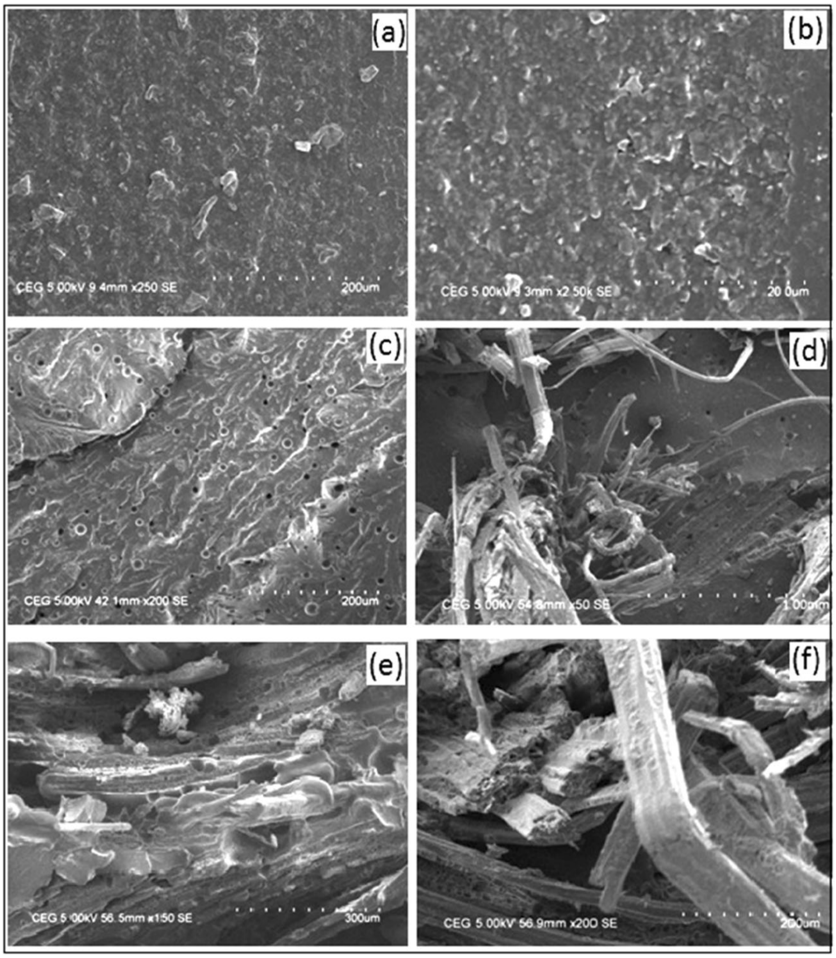


Fig. 9 SEM fractograph of mahua-epoxy hybrid composites

fractograph of ‘E_5’composite specimen under flexural and impact test. The images revealed that the reinforced pineapple fibre had improved adhesion with matrix and associate well in load sharing phenomenon. The matrix debris still available on the surface of the fibres after the test was conducted. This shows improved adhesion nature of fibre via silane-surface treatment [32, 33]. Thus silane surface-treatment improved the adhesion of fibres with matrix and makes the nano-silica particle to disperse more uniform.

4 Conclusions

The mahua blended epoxy composite has been successfully prepared by using silane surface-treated pineapple woven fibre (30 vol.%) and nano-silica particle of 0.5 and 1.0 vol.%.

a) The addition of mahua into epoxy resin improved the flexural behaviour and marginally decreases the tensile strength and impact toughness. The specific wear rate and COF was higher for 15vol. % of mahua in epoxy resin.

b) Further adding silane surface-modified pineapple fibre of 30 vol.% improved tensile, flexural, impact toughness at higher level. The wear resistance and COF also found to be lower than pure epoxy and mahua-epoxy composite.

c) The initial, middle and final thermal stability was improved greatly for composite contains 1.0 vol.% nano-silica particle in mahua-epoxy blend.

d) The fractograph results revealed that the silane-surface modified fibre gives improved adhesion with matrix and transfer the load effectively. The nano-silica particle also found to be in uniform dispersion even at higher loading percentage of 1.0.

e) Thus addition of mahua seed oil along with pineapple fibre and nano-silica particle into epoxy resin matrix improved the load bearing characteristics and thermal stability behaviour of epoxy composite. In another side consumption of natural seed oil may reduces the synthetic resin content and converting the epoxy composite as bio form.

f) These mechanically and thermally strengthened polymer matrix bio composites could be used in automobile body part manufacturing, structural engineering and domestic applications.

Compliance with Ethical Standards

Conflict of Interests Authors hereby confirmed that there are no conflicts of interests.

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