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Mechanical Character Analysis of Pineapple Fibre Epoxy Composite with Nanoclay Quantity Variation

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Abstract: *Epoxy based hybrid composites are extremely wide used materials in the polymer engineering field and always have a demand for their versatile applications. Nano clay is yet another trending substance handled by many researchers due to their enhanced abrasion characteristics. This research was performed to investigate the effect of dispersing nanoclay into epoxy matrix and further coupled with pineapple fibers to fabricate a hybrid composite of excellent mechanical property. 4 layers of Pineapple fiber mats were compression moulded with epoxy nanoclay blend to obtain composite specimens of 4mm thickness. Nanoclay was added into epoxy resin at four different weight ratios (2%, 4%, 6%, and 8%) to form four different combinations of matrix materials into which pineapple fiber mats were reinforced individually at a constant weight ratio of 25%. The enhancement of mechanical and abrasion rate of the hybrid composites were matched with those of the neat Epoxy/Pineapple fiber composites that are currently being developed as alternatives for brake pads. Moisture absorption rate of the composites were analysed to ASTM D570 and Morphology was inspected using Field Emission Scanning Electron Microscope (FESEM). The results depicted optimum mechanical performance at 4 wt% nanoclay infused epoxy/pineapple fiber composite that had a tensile strength of 166.75 MPa, flexural strength of 801.15 MPa and impact strength of 148.76 kg/sq. m. The least abrasion rate was detected in the composite with 8 wt% nanoclay content, resulting in an abrasion rate of 0.1064 g/m.*

Keywords: *epoxy, pineapple leaf fiber, nanoclay, hybrid composites, abrasion resistance*

1. Introduction

Natural fiber reinforced epoxy-based materials have always been one of the key resources for the development of wear-resistance brake pads. Due to the potential benefits of nanoclay, including high frictional resistance, this experiment involves nanoclay along with epoxy to enhance its mechanical and wear properties. The engineering industry uses epoxy mainly because it is easy to handle, economical, has minimal shrinkage during curing and has excellent mechanical properties among other various thermoset plastics [1]. Reinforcement of natural fibers into epoxy matrix in composites, enhance the mechanical strength of epoxy polymer without much compromise in the overall weight and durability aspects [2].

Pineapple leaf fibers are one of the toughest among natural plant fibers. They are abundantly available at an economic cost in India and contain good tensile strength [3]. Literature survey reveals that pineapple fibers are almost ten times stronger than cotton fibers and possess high cellulose content (56% - 68%) which proves its inherent mechanical properties [4]. Pineapple leaf also has a high lignin content of 12% which makes its fibril construction sturdy and stiff. This inturn supports to improve mechanical properties when reinforced into polymers. Usually pineapple leaf fibers are used to make ropes and bags but they are sometimes woven with polyester and used in the textile industry as well. Due to their high initial modulus they are also used in industries for manufacturing conveyor belts and V-belt cords [5, 6]. Nanoclay is one recent material which provides excellent tensile, modulus, thermal,

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fire resistant and wear resistant properties [7]. Nanoclays are stacked silicates having non-metric dimensions measuring between 50 to 200 nm. Among the various classification of nanoclays, Montmorillonite (MMT) is the most commonly preferred industrial grade owing to its easy obtainability, economic-effectiveness and processing ability [8]. MMT constitutes of phyllosilicates sheets that are organized at 2:1 ratio providing two variants namely; Cloisite 30B and Cloisite 20A. Cloisite 20A is substantially economical and commercially available when compared to the former. It falls under the category of organically modified Montmorillonite (OMMT), containing antimicrobial repellant nature against microorganisms like bacteria and fungii [9]. This factor thereby indirectly supports reinforced natural fibers (in this case pineapple fibers) from bacterial and fungal attack.

Nanoclay naturally has strong interaction with resin based polymers due to its high surface area and surface reactivity. Many researchers have reported that lower nanoclay content reinforcement into epoxy resin, especially in the range of 1 to 8 wt%, had exhibited the best mechanical, thermal and tribological properties [10]. Epoxy infused nanoclay at 4 and 5wt% [11] are some of the recent studies in which nanoclay had been directly infused into epoxy resin and the mixture then being used as the matrix material. In another study, epoxy and polyester matrices were individualy reinforced with nanoclay at 5 wt% and 10 wt %. The results had shown that epoxy/nanoclay combination provided better mechanical properties than the polyester/nanoclay composites at both 5 wt% and 10 wt % [12]. Addition of upto 2 parts per hundred resin (phr) of nanoclay into epoxy matrix has proven to provide good mechanical and thermal properties [13]. Sudhagar et al. [14] performed incremental nanoclay reinforcement in epoxy resin by varying the reinforcement weight percentages at 2, 4, 6, and 8% nanoclay among which the 4 wt% reinforced nanoclay epoxy composite attained maximum ultimate tensile strength, young’s modulus, flexural properties and microhardness. Increment of nanoclay beyond 4 wt% had decreased the strength of the composites. In another study, Kumar et al. [15] had prepared epoxy composites with nanoclay weight reinforcements of 3, 5, 7, and 10%. Similar to the former literature, this research work also reported an upsurge in mechanical properties for the composites loaded with nanoclay upto 5 wt%. Beyond 5 wt%, reduction in the strength and other physical properties of the final composite was noticed.

Hybrid polymer composites pave the way for their effective utilization in industrial applications that involve mechanical and frictional shear force sliding applications. They are more capable of with-standing mechanical stress and have high rigidity along with good wear resistance. When comparing with plain polymers and mono material reinforced polymer composites, hybrids have always proven to be more effective in terms of mechanical strength [10, 14]. Achieving reduced shear rate in mechanical materials used for frictional applications is an important factor for successive operation and better service life [16, 17]. In this study, Pineapple leaf fiber is reinforced with nanoclay infused epoxy resin to form a hybrid composite that is expected to provide excellent abrasion resistance for applications related to brake pads and sports goods.

2. Materials and methods

2.1. Materials

Diglycidyl Ether Bisphenol-A (DGEBA) Epoxy of grade LY556 having a density of 1.16 g/cm^3 and a curative time of 8 h at 140°C was taken as the base resin. Triethylenetetramine Hardener- HY951 of density 0.95 g/cm^3 was used as a hardener. The materials were purchased from CIPET, Chennai, India. Pinapple (Ananas Comosus) leaf fiber mat in the form of fabric and having a thickness of 1 mm, was purchased from Go Green Products, Chennai, India. The fiber diameter and density as denoted by the supplier was 180 microns and 1.543 g/cm^3 respectively. Cloisite 20A MMT Nanoclay having a of density 1.7 g/cm^3 in the form of dry powder sieved under #500 mesh was purchased from Ultrananotech Pvt. Ltd, Bangalore, India.

2.2. Fabrication method

Epoxy resin and its hardener were combined at a ratio of 10:1 and considered to be the base solution. Using this base solution a plain Epoxy slab was fabricated using compression moulding technique. For the second test specimen containing natural pineapple leaf fiber mat as reinforcement, four layers of fiber mats were combined with the base epoxy solution by hand-layup method followed by compression moulding at 180^{o}C under a pressure of 1000 N for a time period of 4 h to fabricate a composite laminate slab having a thickness of 4 mm as standard. The four alternative layers of Pineapple mat fiber (P) and Base Epoxy resin (E) through handlay-up method was fabricated in the sequence of E/P/E/P/E/P/E/P/E. The laminated Pineapple leaf fiber epoxy composite slab was allowed to cure for a time period of 48 hours at normal room temperature post processing. The epoxy polymer slab and the fiber reinforced composite slab were finally cut to ASTM standard dimensional test specimens using Water Jet Machining (WJM) and were coded as 'E' and 'EP' respectively.

For the nanoclay constituted hybrid composite preparation, Nano clay was primarily dehydrated at a temperature of 90°C for 5 h in an induction furnace inorder to get rid of moisture content completely. This step would ensure better bonding during mixing process. The Base Epoxy resin on the other hand was also heated to 80°C inorder to bring down its viscosity [13]. This procedure ensures that the lower viscous epoxy would provide better dispersion of nanoclay homogeneously throughout the resin. This mixture was again continuously and vigorously stirred using a high intensity Ultrasonicator at 300 rpm for 30 minutes [11, 18] until it was visually ensured that there was no clogging and a smooth solution was obtained. During the ultrasonication process a curing reagent was added at a ratio of 1:10 parts of epoxy and nanoclay mixture to support better dispersion. This methodology of processing the matrix material was followed for the various reinforcement ratios of nanoclay content, ie., 2, 4, 6 and 8 wt% inorder to achieve individual variants of Epoxy/Nanoclay solutions. These nanoclay reinforced epoxy resins were considered as the matrix materials to prepare the hybrid composites by following the same procedure and processing parameters to those of the plain epoxy polymer and natural fiber reinforced composite. Initial hand-layup process, trailed by compression moulding, and then cutting the hybrid composite slabs into test specimens through WJM was followed. Test specimens were fabricated to ASTM dimensional standards that are suitable for mechanical characterization referring to ASTM D628 for tensile, ASTM D790 for flexural and ASTM D256 for impact tests [19, 20].

The hybrid composite specimens were coded as EPN1, EPN2, EPN3 and EPN4 respectively, as tabulated in Table 1.

Table 1. Test Specimens constituents and their codes

Specimen Code	Epoxy resin Base (wt%)	Pineapple Fibre (wt%)	Nanoclay Content (wt%)
E	100	0	0
EP	75	25	0
EPN1	73	25	2
EPN2	71	25	4
EPN3	69	25	6
EPN4	67	25	8

2.3. Experimentation and methodology

A Universal Testing Machine (UTM) (Model: INSTRON-3365) was used to test elasticity and bending behavior of the test specimens. Tensile test was performed to ASTM D628 and three point flexural test was performed to ASTM D790 by alternative arrangements of fixtures respectively for the test procedures. A standard and constant force of 10 kN and a head movement speed of 2 mm/min was applied for both the tensile and flexural tests until the test specimens underwent catastrophic failure. For testing the toughness of the specimens, Izod impact test was performed to ASTM D256 with hammer head force of 25 Joules. During the impact test, the specimens remained un-notched, inorder to determine the maximum cross sectional area load bearing capacity. To test the frictional shear resistance of the specimens, abrasion test was carried out on a pin-on-disc apparatus. Specimens were tested to ASTM D1044 standard to test the abrasion. The rotating drums of the equipment were set at 40 rpm over a dead load of 1 kg. Specimens were made to run over the rotatory abrasive sheet (Grade 60). Morphological images scanned from the broken surfaces of the test specimens (post mechanical characterization) were captured using an FESEM equipment (Model: ZIESS) to correlate the patterns with the mechanical results. Moisture absorption test for all the specimens was carried out to ASTM D570. Initial dry weight (W_d) and final Wet weight (W_w) of the specimens after the period of immersion were measured to determine the change in weight. These values were considered to evaluate the final amount of moisture absorbed (%WA) considering the formula shown in equation 1 [21].

$$\% WA = \left[\frac{W_w - W_d}{W_d}\right] \times 100 \quad (1)$$

3. Results and discussions

3.1. Mechanical performance

Tensile strength and modulus values of the tested specimens are graphically shown in Figure 1 and 2 respectively. The tensile strength of E was increased by 59.33% when Pineapple leaf fiber was reinforced with Epoxy ie., the EP composite showed tensile strength of 136.87 MPa while plain E had 55.66 MPa. This was due to the fortification of Pineapple fiber that had behaved as the major load bearing agent, thereby improving the tensile strength of the plain Epoxy material [22]. As for the nanoclay reinforced hybrid composites, initial addition of nanoclay at 2 wt% improved the tensile strength of EP composite marginally from 136.87 MPa to 153.6 MPa. Further increment in nanoclay content boosted the tensile strength to 166.75 MPa. Above 4 wt% load of nanoclay, the tensile strength of the EPN3 and EPN4 composites began to reduce sequentially as shown in Figure 1. The EPN2 composite depicted the best tensile of all the test specimens showing an increase in the tensile strength value by 66.62% when compared with plain Epoxy and 17.91% when compared with the EP composite. This was due to the reinforcement of the nanoclay that provided better bonding ability of the matrix with the pineapple fiber then when compared with the base epoxy resin combined with pineapple fiber.

Tensile modulus values of the test specimens in this research followed similar pattern of the tensile strength results. The addition of the pineapple natural fiber increased the modulus of the base epoxy and the addition of nanoclay further improved the tensile modulus to a maximum increase by 70.90% when compared with ‘E’ and 40.67% when compared with ‘EP’. The addition of nanoclay beyond 4 wt%, showed a decreasing pattern in the modulus values. This was due to the fact that higher nanoclay content led to agglomeration of the particulates in the EPN3 and EPN4 composies, therefore provided stress residues that initiated quicker fracture of these specimens during the test when compared with the substantial adhesion of the optimum loading of nanoclay content in the EPN2 composite.

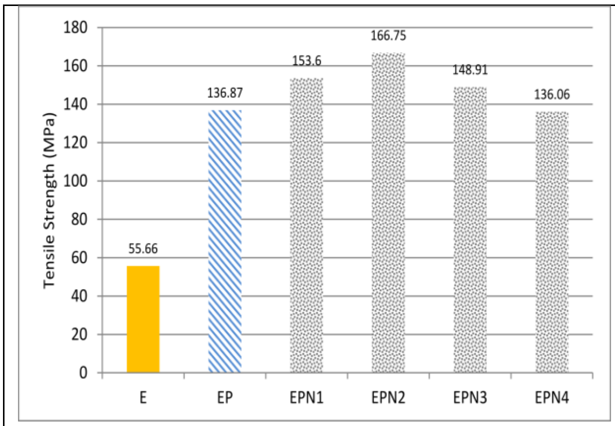

Figure 1. Tensile strength of the test specimens

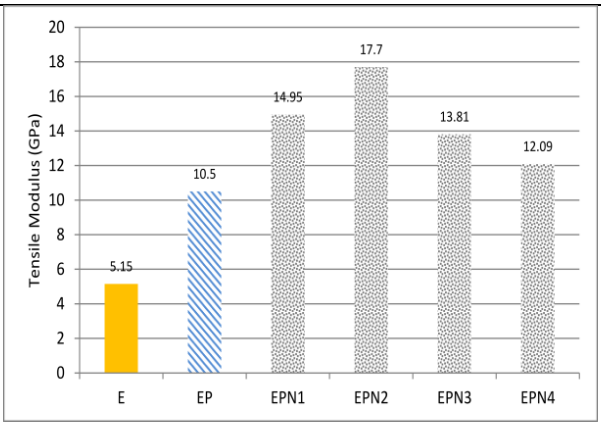

Figure 2. Tensile modulus of the test specimens

Flexural strength of E was measured to be 338.1 MPa and on reinforcement of the pineapple fiber, it improved to 458.86 MPa which was an increase by 26.31%. On inclusion of the nanoclay matrix material along with the pineapple fiber, the flexural strength further increased to 755.23 MPa. This increment of flexural strength was due to the factor of nanoclay particles been settled down into the interspatial spaces present in between the fiber mats thereby enhancing the adhesion between the matrix and fiber. The increase in flexural strength continued upto a weight loading of 4 wt% of nanoclay content beyond which the flexural strength began to decrease. This was due to the overloading of nanoclay reinforcement which had led to agglomeration and looser bonding support inbetween the matrix and fiber materials. Hence the flexural strength of EPN3 and EPN4 showed simultaneously decreasing pattern when compared with the flexural strength of EPN2 as seen in Figure 3. Figure 4 represents the values obtained from the flexural modulus analysis. The flexural modulus of the specimens followed similar trend to that of the flexural strength graph. The EPN2 composite displayed the best flexural modulus showing an increase of 58.3% compared with Base Epoxy, 37.79% on comparing with EP composite and 22.14% when compared with EPN3 Hybrid. This increase of flexural modulus for the nanoclay reinforced hybrid composites may be attributed due to the extended surface area delivered by the nanoclay particles by which adhesion between the Epoxy resin was greater [11, 23]. This factor had further led to better stiffness of the hybrid composites.

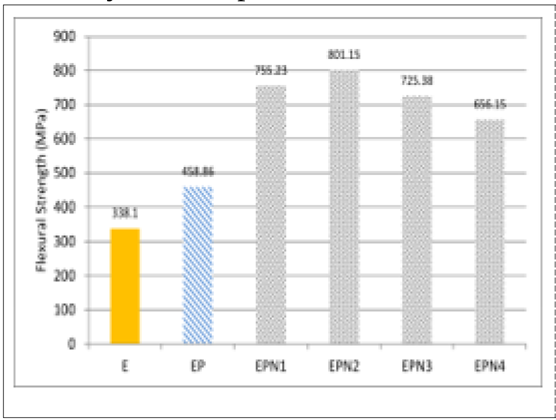

Figure 3. Flexural Strength of the test specimens

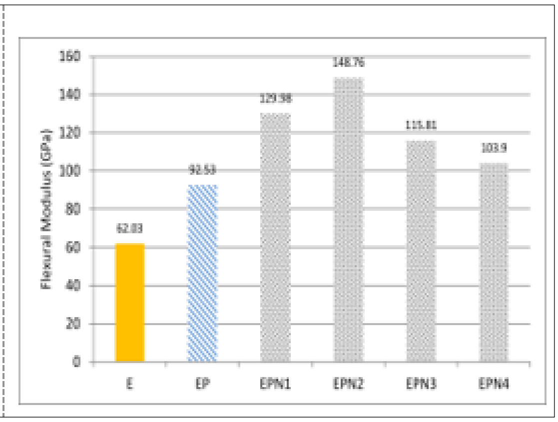

Figure 4. Flexural Modulus of the test specimens

Similarly, the properties of the hybrid composite at 6 wt% and 8 wt% of nanoclay reinforcement reduced, since the epoxy resin could possibly not homogeneously wet the inclusion of high nanoclay quantity, thereby leading to agglomeration [12, 18]. The agglomerated nanoclay particulates led to weak spots in the specimens during testing that inturn led to the initiation of sudden cracks and further propagation to quicker fracture of the EPN3 and EPN4 specimens when compared with EPN2 [23].

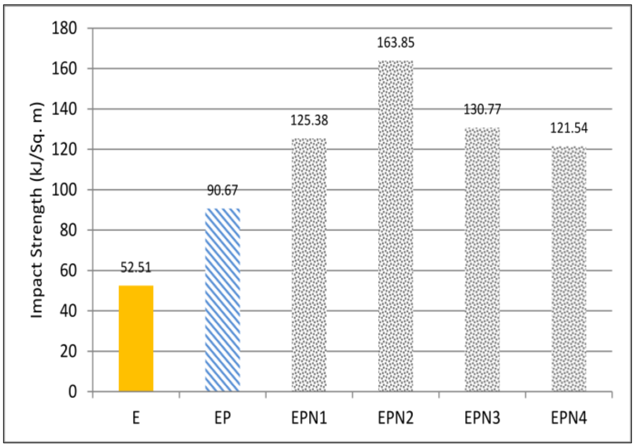

Figure 5. Impact Strength of the test specimens

Impact test represented that the nanoclay reinforced hybrid composites performed better than both the base Epoxy specimen 'E' as well as the Pineapple fiber reinforced Epoxy specimen 'EP'. As seen from Figure 5, EPN2 specimen showed the most superior impact strength among all the test specimens in the research. The impact strength of 'E' was 52.51 while reinforcement of the natural fiber ie., specimen 'EP' produced an impact strength of 90.67. This was due to the fact that the natural fiber helped in distributing the impact load transfer more evenly throughout the specimen while the plain polymer was found to be more brittle and thereby underwent sudden shattering and failure. On adding nanoclay to the 'EP' material, the impact resistance further substantially improved. The highest impact strength was found in the EPN2 composite having 4 wt% of nanoclay content. This was an increase in impact strength of 23.47% greater than EPN1. EPN2 had provided best impact resistance to the impact load due the better homogenous distribution of nanoclay within the matrix material and fibril gaps [18, 24]. For the EPN3 and EPN4 composites which had a nanoclay loading of 6 wt% and 8 wt%, the impact strength values reduced consistently by 20.18 and 25.82% respectively. This was due to the agglomeration of higher nanoclay [25] content which had led to clogging and uneven distribution of the nanoclay within the matrix material, hence providing blind spots that led to quicker fracture due to the impact load when compared to EPN2.

These increment and reduction in mechanical properties of all the test specimens were morphologically justified through the Field Emission Scanning Electron Microscopic images shown in Figure 6a, 6b, 6c, 6d, 6e and 6f. The amount of laminates seen on the surface of the fractured specimens depicts the amount of resistance that the specimen had offered during the mechanical tests. Greater number of cracks represents higher mechanical properties while lesser cracks like in the FESEM image of plain Epoxy specimen 'E' (Figure 6a) depicts lower mechanical confrontation on the force applied during analysis. Similarly for the decreasing mechanical properties, the agglomerated nanoclay particles are visible in the images.

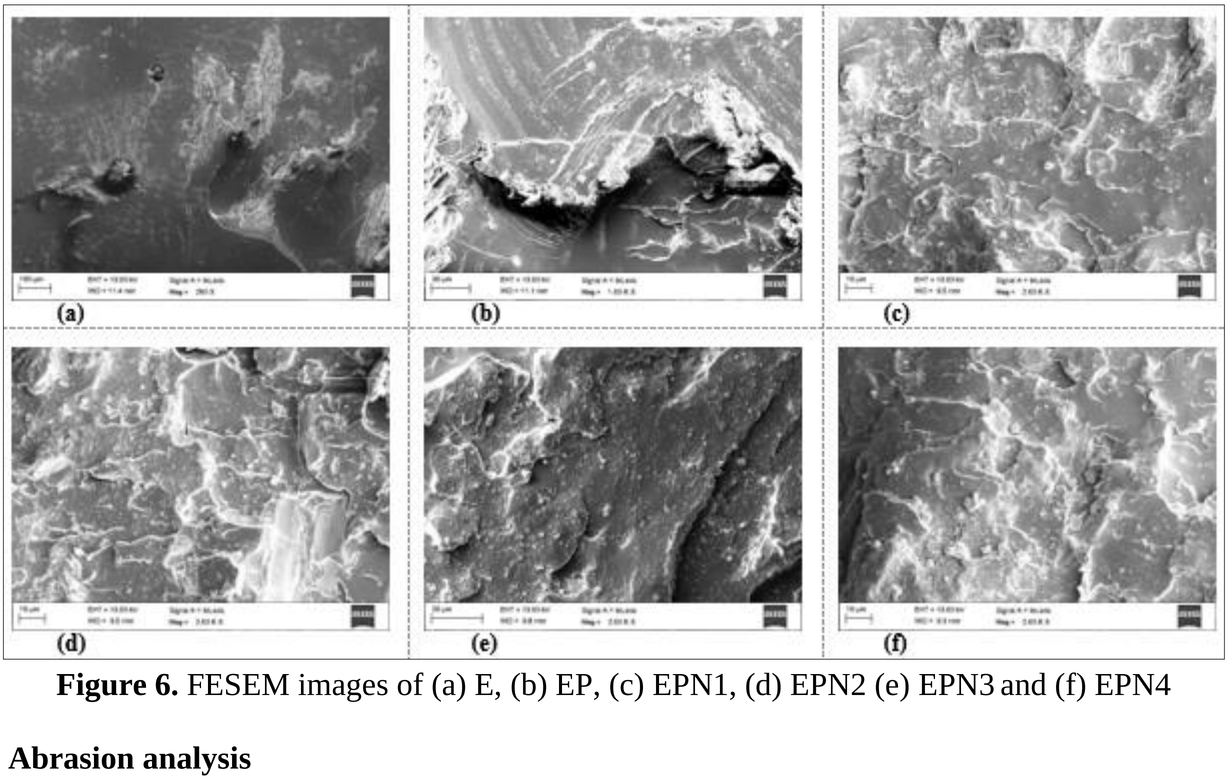

Figure 6. FESEM images of (a) E, (b) EP, (c) EPN1, (d) EPN2 (e) EPN3 and (f) EPN4

3.2. Abrasion analysis

Figure 7 graphically represents the abrasion rate of all the test specimens towards the abrasion test based on the quantity of material removed due to shear.

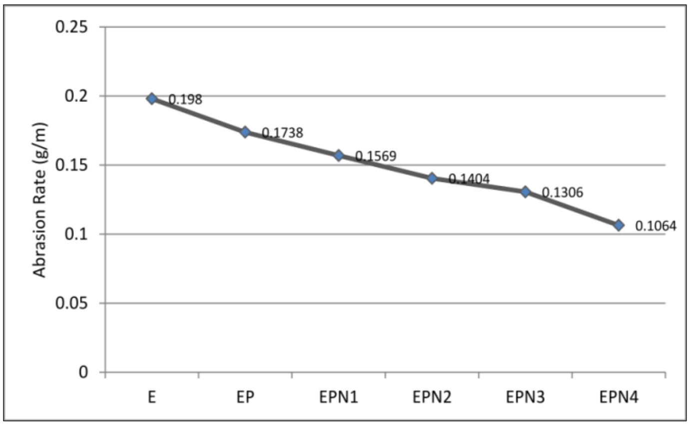

Figure 7. Abrasion rate of the Specimen

Abrasion rate of the plain Epoxy specimen 'E' was found to be the highest. On addition of the pineapple fiber, the abrasion rate of the 'E' reduced from 0.198 g/m to 0.1738 g/m for the 'EP' composite. This was due to the factor that natural fibers have the inherent tendency to the various chemical compositions present in them like cellulose, hemicellulose and lignin [26]. The high cellulose content that supports in the rigidity of the cell walls of the pineapple fiber helped the composite to withstand the shear force better during the testing process in comparison to base epoxy 'E'. Upon the introduction of nanoclay, the abrasion rate of 'EPN1' further reduced to 0.1569 g/m. Further increment in the nanoclay content led to continuous decrease in the abrasion rate of the composite [10]. EPN4 therefore showed the least abrasion rate among all the test specimens in the research work. Nanoclay by nature inherits the ability to withstand high shear force [12], this aspect justifies the obtained results in this research work.

3.3. Moisture absorption analysis

Figure 8 indicates the amount of moisture absorbed by the test specimens. The base Epoxy 'E' being a completely synthetic thermosetting plastic showed zero moisture absorption after the immersion period.

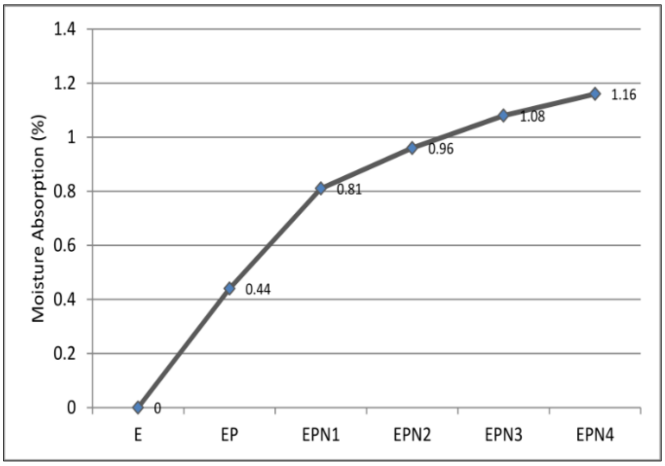

Figure 8. Percentage moisture absorption of the specimens

The addition of Pineapple fiber resulted in marginal moisture uptake from 0 to 0.44%. This was due to the reason that natural fibers possess the propensity to absorb water. All the nanoclay reinforced composites showed moderate to substantially increasing moisture uptake. From an initial increase of 0.81% for the 2 wt% nanoclay reinforced hybrid composite, the further increment in nanoclay content showed increasing trend in moisture uptake resulting with the 8 wt% nanoclay reinforced hybrid composite EPN4 having 1.16%. The large moisture uptake of EPN4 was because nanoclay is likely to absorb water content easily by nature [14].

4. Conclusions

The addition of pineapple leaf fiber to base epoxy improved the mechanical property. All the basic mechanical properties increased in general with the influence of nanoclay to formulate hybrid Epoxy/Nanoclay/Pineapple composites. The highest tensile, flexural and impact properties for the 'EPN2' hybrid resulted in an increase by 66.62, 57.79 and 67.95% respectively when compared with 'E' and an increase by 17.91, 42.72 and 44.66% respectively in contrast with 'EP'. Abrasion resistance of the nanoclay impregnated hybrids, were greater than 'E' and 'EP'. EPN2 which resulted in the best mechanical performance also provided an abrasion rate of 0.1404 g/m while EPN4 had the least abrasion rate with 0.1064 g/m. Moisture absorption of EPN2 was also reasonably low at 0.96%. Through this research it was determined that the Hybrid combination of Epoxy Pineapple leaf fiber at 25 wt% and nanoclay reinforcement at 4 wt% provided the most optimum results for frictional and shear forced based applications like brake pads and sports goods.

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