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Article *in* Materials Today Proceedings · January 2022

DOI: 10.1016/j.matpr.2022.01.176

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Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

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A R T I C L E I N F O

Article history:
Available online xxxx

Keywords:
Nano-filler
Kenaf fibre
Epoxy composite
Mechanical strength
Natural fibre

A B S T R A C T

Introducing nano-fillers in natural fibre polymer composite materials have attained a greater attention in recent days due to their distinct behavior in improving the mechanical characteristics of the composites with less effort. In this study, the effect of introducing nano-SiO_2 filler in kenaf fibre polymer composite on their mechanical characteristics is analyzed. The nano-fillers with five different mass fractions namely 0%, 1%, 2%, 3%, and 4% were tested in this work. The tensile, compressive and impact strengths of the composites were investigated. The results evidenced that the increment in nano-filler content proportionally improved the strength of the composite until the addition of 2% of nanofiller and then, the improvement was not impressive. The maximum enhancement of 20.61% in tensile strength, 23.71% in compressive strength, and 22.88% in impact strength was attained with 2% fraction of nanofiller in composite.

Selection and peer-review under responsibility of the scientific committee of the First International Conference on Advances in Mechanical Engineering and Material Science.

1. Introduction

Natural fibre is increasingly being used as a supporting or filling component in the manufacturing of composites, since there is a growing consciousness of the importance of using justifiable resources to switch those generated from traditional materials [1,2]. Natural fibres have a number of desired features, including cheap cost, renewable, excellent mechanical properties due to their less density, and ease of treating due to their non - abrasive character, which allows for high packing levels [3]. Further, natural fibres have risen in popularity as a reinforcing material over the last several decades owing to its eco-friendly and inexhaustible characteristics, lightweight character, and simplicity of fabrication. By and large, it is very hard to dispose of artificial polymer composites, and plastic usage has been prohibited in a number of nations [4,5]. As a result, the demand for natural fibres has expanded in a variety of industries. Hence, several researchers have employed a variety of natural fibres such as sisal, luffa, kenaf, bamboo, coir, pineapple, flax, and jute as fillers in natural fibre polymer composites [6,7].

Natural fibres are often composed of lignocellulosic biomass and have a high capacity for moisture absorption, which makes them ideal for a variety of interior applications such as upholstery, packaging, and seismic attenuators. However, natural fibres continue to lag behind synthetic fibres in terms of mechanical strength [8]. They require a variety of chemical treatments, hybridization through the use of bio and artificial fibres, and weaving in a variety of orientations in order to obtain equivalent strength to synthetic fibres [9,10]. In addition, the challenges of employing reinforcing natural fiber filler include their weak adherence to the matrix as a result of the fiber's water-absorbing character and the matrix's swampy character. As a result, a weak fiber-matrix contact is established, reducing the fiber's strengthening action and preventing force transmission between fibres and matrix material [11,12]. Natural fibre polymer matrix composites have qualities that are

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https://doi.org/10.1016/j.matpr.2022.01.176
2214-7853/
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Please cite this article as: Gujar Anantkumar Jotiram, Basanta Kumar Palai, S. Bhattacharya et al., Investigating mechanical strength of a natural fibre polymer composite using SiO_2 nano-filler, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.01.176

mostly determined by the amount of binding among the fibres and the polymer matrix material [13,14]. To address the aforementioned issues, researchers have examined many approaches for improving fibre characteristics and increasing fibre matrix interface. Chemical methods have historically been used to alter the characteristics of fibres [15,16]. Organic solvents such as silane, alkali based substances, isocyanates, and peroxides are frequently utilised, as well as polymer coupling agents.

Gowda et al. [17] examined the thermophysical nature of diverse natural fibres, including silk, husks, grasses, and coir, fortified with polymeric composites, and concluded that the amalgamation of natural fibre improved the thermo - physical properties properties of the polymer matrix by 11%. Sheng et al. [18] discovered that increasing the packing density linearly enhances flexural strength upto 8% for 0.4 fibre proportion. Cai et al. [19] observed that fibres processed with 5.0% of sodium hydroxide (NaOH) demonstrated optimal tensile stress and elastic modulus values when compared to unprocessed fibres, as well as increased interlaminar shear capacity when used in conjunction with an epoxy resin. The introduction of particulate or powder form of filler materials to matrices was yet another approach for improving the qualities of natural fibre reinforced composites, and it has shown to be an alternate option for improving the characteristics of natural fibre composite materials [20]. The proper choice of matrix, fillers, and reinforcing agents can result in a composite with comparable or even superior qualities than traditional composite alloys. The use of particle filler materials with polymers is becoming more useful in commercial and industrial applications [21,22]. Fillers are added to polymers to increase the process capability, rigidity, and resilience of polymer composite [23]. In order to tackle polymer constraints such as poor rigidity, as well as to employ them in a spectrum of uses, inorganic nano-sized particle shaped fillers such as silica, alumina, carbon, titania and fly ash particles are frequently mixed with the matrices for generating polymer nanocomposites [24,25].

According to Ozdemir et al. [26], combining nano-lead oxide with the artificial elastomeric EPDM polymer improves the thermophysical characteristics of polymeric composites. As per findings of Nikmatin et al. [27], the use of rattan fillings at a weight of 5.0% increases the outer texture and toughness of composite materials more than artificial fibres. Kushwaha et al. [28] produced polymer nanocomposites reinforced bamboo fibres with carbon nano tubes (CNT) using a straightforward manual method. They observed a 6.67 percent increase improvement in tensile behaviour and a 5.8 percent enhancement in flexural values, while simultaneously decreasing water uptake by 5.1 percent.

Hosseini et al. [29] employed around 5% of Nano-SiO_2 particles as the nano-fillers to generate high dense polymer composites with the reinforcement of sugarcane fibre, and observed a 72 percent improvement in mechanical properties in the polymer composites comparing to the composites without nano-fillers. Hence, by altering the matrix with nano-SiO_2 filler, it is possible to enhance the characteristics of natural/synthetic fibre composite materials. In the present study, the objective is framed to experimentally investigate the tensile and compressive strength of the kenaf fibre reinforced epoxy composite at various loading level of nano-SiO_2 filler. The composite plates were fabricated using the compression molding machine.

2. Materials and methods

2.1. Materials used

From an environmental standpoint, kenaf fibre is an appealing option for composite reinforcement since it is a fast-growing crop that matures in half year to a height of around 5 m [30]. Additional advantage of producing kenaf is its great capacity to fix co2 from the atmosphere [31]. The hybrid kenaf/banana strengthened composite exhibited the greatest gain in mechanical strength owing to the absence of pressure at the composite interface [32]. The impact of alkaline treatment on the strength properties of linear kenaf fibre in polymer matrix demonstrates that the strength of the alkaline processed composite is 16 percent more compared to the unprocessed polymer composite. The kenaf fibres were rinsed with the water in a bucket and then sun - dried for a couple of days to eradicate any waxy or tannin materials. Following that, the fibre was chopped and formed into mats. The prepared kenaf fibre is hydrophilic in nature, and hence, it was processed with 5% sodium hydroxide to remove moisture and other foreign matters from the fibre. The nano-SiO_2 particles of size 100 nm were procured from the local chemical suppliers. Further, epoxy and hardener were supplied by CF Composites, New Delhi.

2.2. Preparation of Kenaf/epoxy nano-composites (KENC)

Initially, the epoxy was thoroughly mixed with the nano-SiO_2 fillers in five loading levels namely, 0%, 1%, 2%, 3%, and 4% of nano-SiO_2 in epoxy using a stirrer. The loading levels of nano-Sio2 were chosen based on the previous literature. Each time, the epoxy with each loading level was carefully synthesized to avoid the agglomeration of the nanoparticles in the solution. The stirring was sustained for atleast 60 min and further sonicated for another 60 min using the ultra sonicator as shown in Fig. 1. The epoxy and hardener were mixed at the ratio of 1:0.3 for better curing. Then, the composite plates, each of size 25 cm × 25 cm × 0.3 cm were produced after laying-up the fibre and nano-loaded epoxy in alternative layers with the aid of a compression moulding machine as illustrated in Fig. 2. During the preparation, the mold pressure was maintained at 1 MPa with a curing temperature of 50 °C. The sample plates with the 0%, 1%, 2%, 3%, and 4% of nano-SiO2 fillers were labeled as KENC0, KENC1, KENC2, KENC3, and KENC4, respectively.

2.3. Testing of the composites

It was planned to conduct the tensile test, compressive test and impact to characterize the mechanical qualities of the prepared composite plates. For this purpose, the composite plates were cut into required dimensions as per the standards for different testing. For an instance, the tensile test samples were trimmed into the size of 25 cm × 2.5 cm × 0.3 cm following ASTM D3039, the compressive test samples were prepared with the dimension of 1.0 cm × 1.0 cm × 0.3 cm following ASTM D695 and impact test samples were 6.35 cm × 1.25 cm × 0.3 cm in accordance with

Fig. 1. Ultrasonication of epoxy with nano-filler.

Fig. 2. Compression molding machine used for composite fabrication.

ASTM D256-Type A standard. The tensile and compression tests were accompanied with a universal testing machine and the Charpy impact test was carried-out on an impact testing machine. For each tests, there were around five samples were tested to ensure the uniformity of the results.

3. Results and discussion

The scanning electron images (SEM) of the KENC0 (composite without nano-filler) and KENC4 (composite with 4.0 fraction of nano-filler) are presented in Fig. 3 for understanding the infusion of nano-fillers in kenaf/epoxy composite material. It could be comprehended that the presence of voids were large in the composite, which doesn't contain any nano-fillers (Fig. 3a). But, the voids were not significant in the composites with the nano-inclusions (Fig. 3b). Further, the agglomeration of the nano-fillers can be seen at the higher level loading of nano-SiO2 within the composite matrix.

3.1. Tensile strength

The effect of nano-SiO_2 content on the tensile strength of the kenaf/epoxy composites are illustrated in Fig. 4. The tensile strength of the composite without nanoparticles was recorded as 42.65 MPa. The tensile strength of the kenaf/epoxy nano-composites was 46.37 MPa, 51.44 MPa, 48.78 MPa, and 45.88 MPa, respectively with 1%, 2%, 3%, and 4% presence of nano-fillers in composite. The percentage improvement of tensile strength of composite was 8.72%, 20.61%, 14.37%, and 7.57%, respectively. It can be vividly understood that the tensile strength was enhanced until 2.0% fraction of nano-SiO_2 and further increment in nano-filler content didn't yield the positive effect. The nanoparticles helped to reduce the pores and improved the tensile characteristics at their lower volume content.

3.2. Compressive strength

Fig. 5 illustrates the variation of compressive strength of the kenaf/epoxy composite with the increase in nano-SiO_2 content. The compressive strength of the composite without nanoparticles was recorded as 44.32 MPa. The compressive strength of the kenaf/epoxy nano-composites was 47.46 MPa, 54.83 MPa, 51.44 MPa, and 48.08 MPa, respectively with 1%, 2%, 3%, and 4% presence of nano-fillers in composite. The percentage improvement of compressive strength of composite was 7.08%, 23.71%, 16.06%, and 8.48%, respectively. Similar to the tensile strength, the maximum compressive strength was observed for the composite with the 2% fraction of nano-SiO_2 fillers, which can be accredited to the agglomeration of nanoparticles at the higher mass content.

3.3. Impact strength

The impact strength of the samples with the different mass of nano-filler is plotted in the Fig. 6. The impact strength of the composite without nanoparticles was recorded as 11.8 J. The compressive strength of the kenaf/epoxy nano-composites was 12.9 J, 14.5 J, 13.6 J, and 13.2 J, respectively with 1%, 2%, 3%, and 4% presence of nano-fillers in composite. The percentage improvement of compressive strength of composite was 9.32%, 22.88%, 15.25%, and 11.86%, respectively. It is once again proved that the optimum nano-SiO_2 content was 2%, when it is combined with the kenaf/epoxy composite.

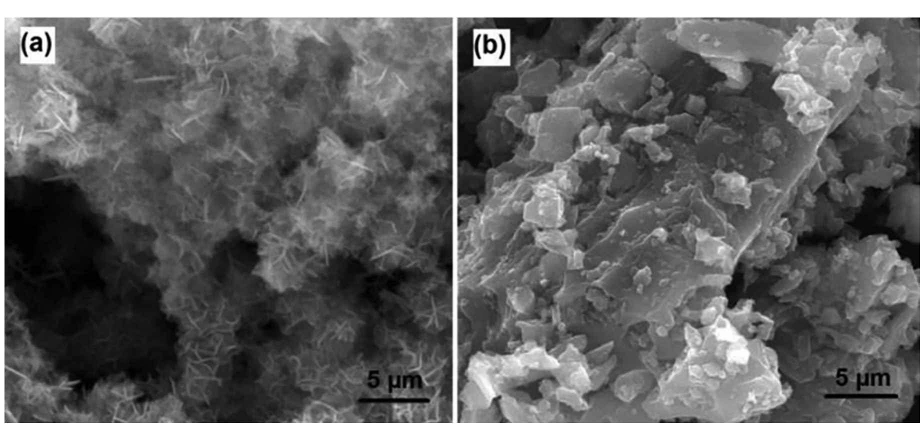

Fig. 3. SEM images of (a) KENC0 (b) KENC4.

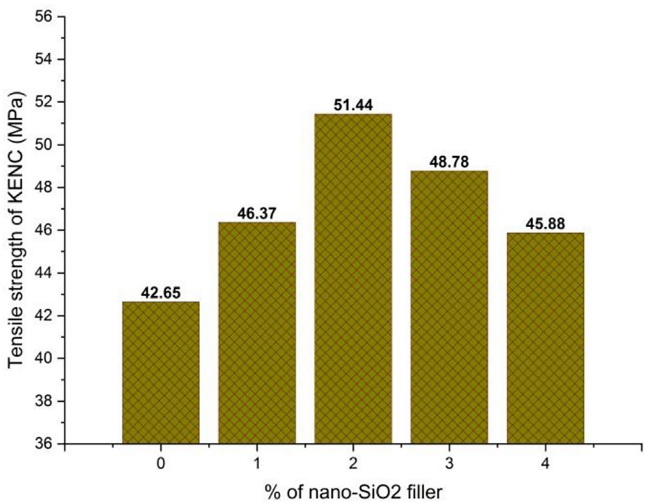

Fig. 4. Tensile strength of the KENC with the increase in nano-filler content.

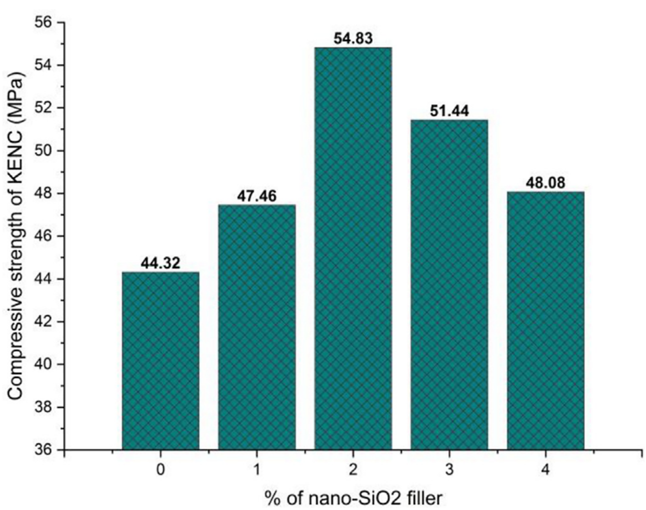

Fig. 5. Compressive strength of the KENC with the increase in nano-filler content.

The nano-dispersion was not sustained its uniformity, when the quantity of reinforcement was improved beyond 2% in the composite. Hence, in all sort of mechanical tests, the optimum fraction of nano-SiO_2 filler was found to be 2.0% for getting maximum benefit out of it.

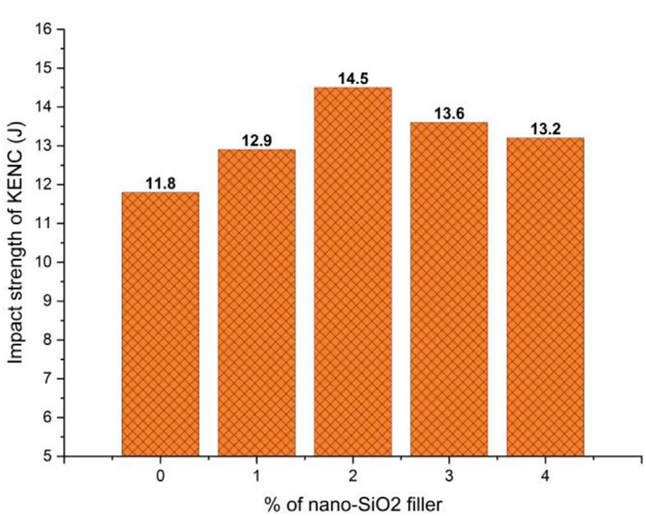

Fig. 6. Impact strength of the KENC with the increase in nano-filler content.

4. Conclusions

The effect of disbanding nano-SiO_2 fillers on the mechanical characteristics of kenaf fibre epoxy composite is investigated. The mass fraction of nano-filler was chosen as 0%, 1%, 2%, 3%, and 4% in composite. The conclusions are presented as follows.

- The maximum tensile strength was observed with 2% nano-filler in composite, which was 20.61% higher than the ordinary composite.
- Similarly, the nano-SiO2 fillers of 2% mass in composite enhanced the compressive and impact strengths by 23.71% and 22.88%, respectively.
- Altogether, it was observed that the 2% fraction of nano-SiO2 filler is the optimum content in the kenaf fibre epoxy composite.

CRediT authorship contribution statement

Gujar Anantkumar Jotiram: Supervision, Writing – review & editing. **Basanta Kumar Palai:** Data curation, Writing – review & editing. **Sumanta Bhattacharya:** Writing – review & editing. **S Aravinth:** Investigation, Writing – review & editing. **G. Gnanakumar:** Writing – review & editing. **Ram Subbiah:** Validation, Writing – original draft. **Makendran Chandrakasu:** Conceptualization, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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