Experimental Study of Mechanical and Thermal Properties of Nano-Carbon Areca Fiber Powder Reinforced Epoxy Composites

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Abstract

In this research work, a sustainable experimental development of Nano-Carbon Areca Fiber Powder (NCAFP) reinforced epoxy composites and its mechanical and thermal properties have been presented. Experimental results showed optimum mechanical strength with low thermal conductivity of 15% NCAFP reinforced epoxy composite can become alternative engineering materials.

Key Words: Mechanical Strength, Thermal Conductivity, Nano-Carbon materials, Fractography.

1. Introduction

The bio-inspired natural materials such as bone, wood, and shells were utilised for the technological development of humanity in its early stages. As antiquity advanced, these materials were slowly replaced by synthetic materials to improve performance. Today, scientists and engineers explored distinctive qualities of natural materials as lightweight with desired mechanical properties can be engineered [1-3]. The Modern civilization have a challenging issue of developing novel and propelled innovative techniques to utilize solid natural agro waste materials in polymers composites. Recently, a broader applications of cellulose has been proposed at the Nano-structure level for developing various biocompatible products and variety of commercial cellulose derivatives [4, 5].

Nano-technology is the advanced solution for many challenging problems such as energy conversion, energy storage, and material science [6, 7]. In composite materials field, nanoparticles are dispersed in a matrix material such as metals, ceramics, or polymers to enhance their mechanical, chemical and thermo-physical properties [8, 9]. Polymer nanocomposite materials found their applications in essential fields such as the aviation and automotive industries [10, 11]. There are many techniques accepted to produce polymer Nano-composites. All techniques aimed to develop nanocomposite materials with uniform or random dispersion and without aggregations. Melt-mixing, mixing, in-situ polymerization, electrospinning, and selective laser sintering techniques are the most commonly used techniques to produce polymer nanocomposite [12, 13]. Also, sonication with high frequencies plays the same role for mixing techniques [14]. In-situ polymerization provides fabrication of nanocomposites that are thermodynamically stable [15]. Electrospinning represents an effective method which is suitable for producing porous structures. In addition, fabrication of nanocomposites via selective laser sintering has obvious benefits to overcome the problem of aggregation. The working principles of each technique, includes some advantages and disadvantages also [16, 17].

In this research work an experimental developed of different weight percentage NCAFP reinforced epoxy composites and its factual mechanical and thermal properties were discussed. In future, the analytical prediction models for density, mechanical strength and thermal conductivity of NCAFP reinforced epoxy composites can be explored.

2. Experimental Setup

1.1. Materials and Methods

The Areca fiber was burned into closed furnace at 300^0C to develop Nano-Carbon Areca Fiber Powder (NCAFP). The epoxy resin (LY 556) and the proportionate hardener (HY-917) were mixed to form neat epoxy matrix. The synthesized NCAFP was randomly dispersed into epoxy matrix in different ratio as 5%, 10%, 15%, 20% and 25% by weight percentage to develop sample laminate sheets separately using casting method. A mold consists of base of glass and sides of wood having size dimensions 300 mm × 160 mm × 6 mm was utilised for casting the NCAFP composite sheets. The mold release sheet was kept over glass plate for quick and easy removal of the NCAFP composite sheet.

The NCAFP by weight percentage (i.e. 5, 10, 15, 20 and 25 weight %), was mixed with the matrix material consisting of epoxy resin and hardener in the ratio of 5:4. The formation of air bubbles was minimized by curing at room temperature for 24 hours in vacuum chamber. Then after, the cured laminate was cut into desired size for various mechanical tests.

These sample laminate sheets were machined as per ASTM D638-03 shown in figure 1. Five identical samples of each set of weight percentage of NCAFP reinforced epoxy composite were machined to validate reproducibility of measured data. The tensile strength of the developed samples was measured by INSTRON 1195 testing machine. The density and thermal properties of these developed NCAFP composite samples was estimated by LSA 1000 (Linseis Germany). The surface morphology of fractured NCAFP composite samples were analysed by scanning electron microscopy (JEOL EDS System) of ACMS Laboratory at Indian Institute of Technology, Kanpur.

Figure 1. Developed NCAFP composite sample as per ASTM D638-03.

3. Results and Discussion

The density and thermal conductivity of these developed different weight percentage NCAFP composite samples were experimentally obtained by LSA 1000 (Linseis Germany) as shown in figure 2 and 3.

The figure 2 illustrates that a merest increase in density of developed different weight percentage NCAFP composite samples as compared to neat epoxy composite. The figure 3 reports the gradual reduction in thermal conductivity and become steady in further loading of NCAFP in the epoxy matrix. The experimental percentage error in measuring density, thermal conductivity and tensile strength is less than five percent (PE > 5%).

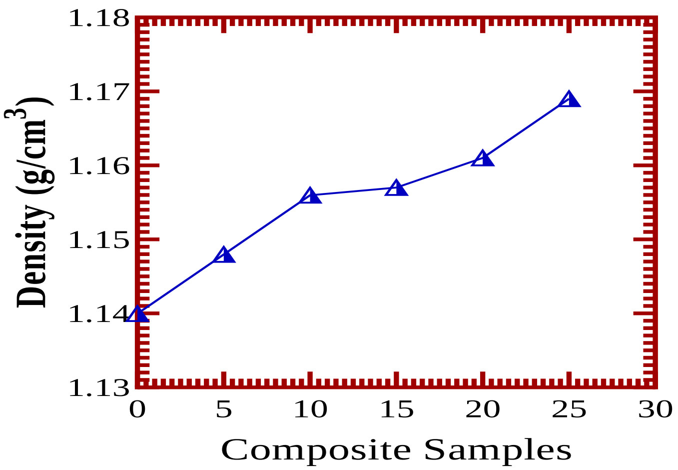

Figure 2. Plots of density versus composite samples

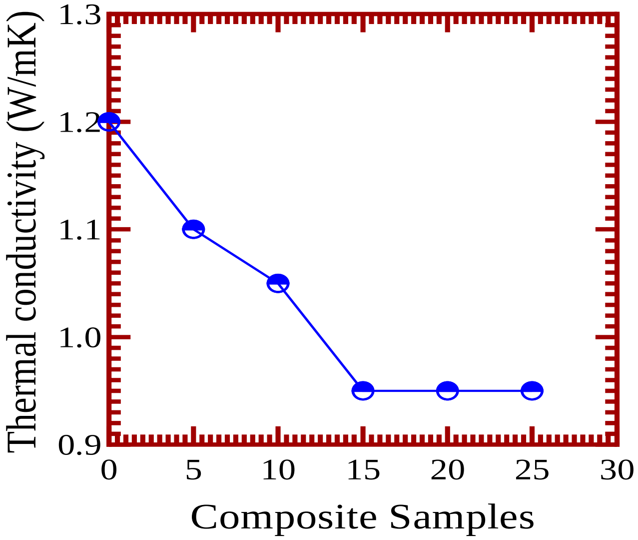

Figure 3. Plots of thermal conductivity versus composite samples

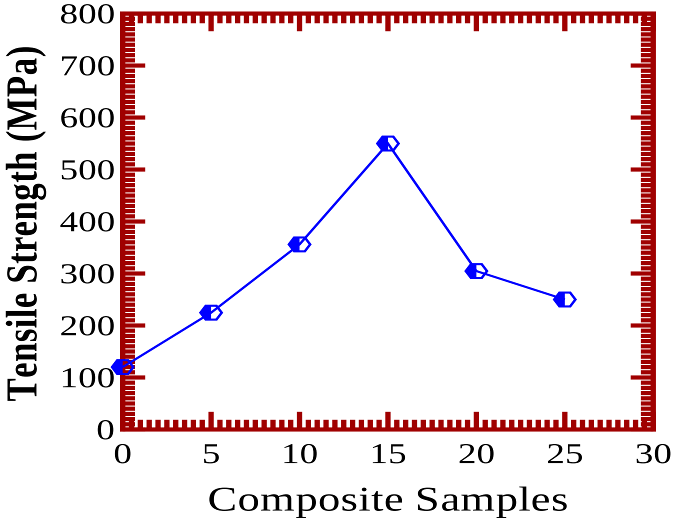

Figure 4. Plots of tensile strength versus composite samples

The figure 4 displays experimentally obtained tensile strength of developed different weight percentage NCAFP composite samples. An enormous increase in tensile strength is noticed in developed different weight percentage NCAFP composite samples which become optimum for 15 % NCAFP composite sample. Further, higher loading of NCAFP in epoxy polymer matrix causes substantial decrease in NCAFP composite samples as shown in figure 4.

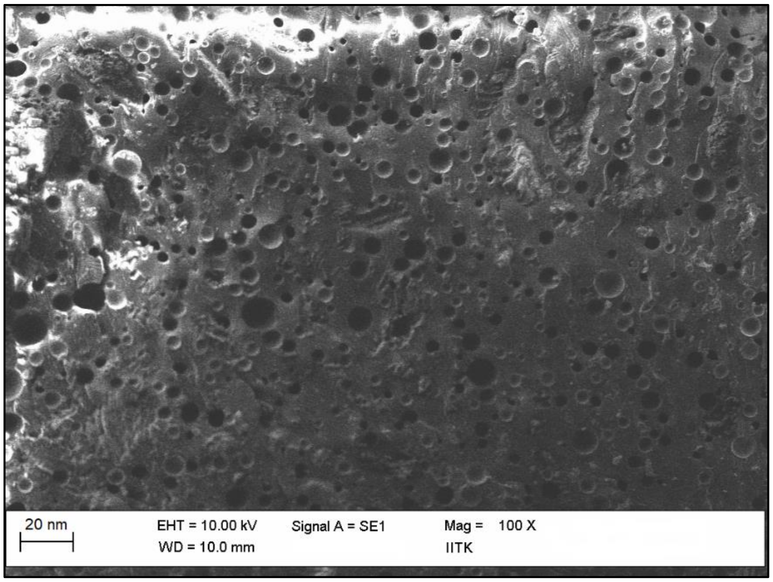

Figure 5. Fractographic SEM images of 15% NCAFP composite sample.

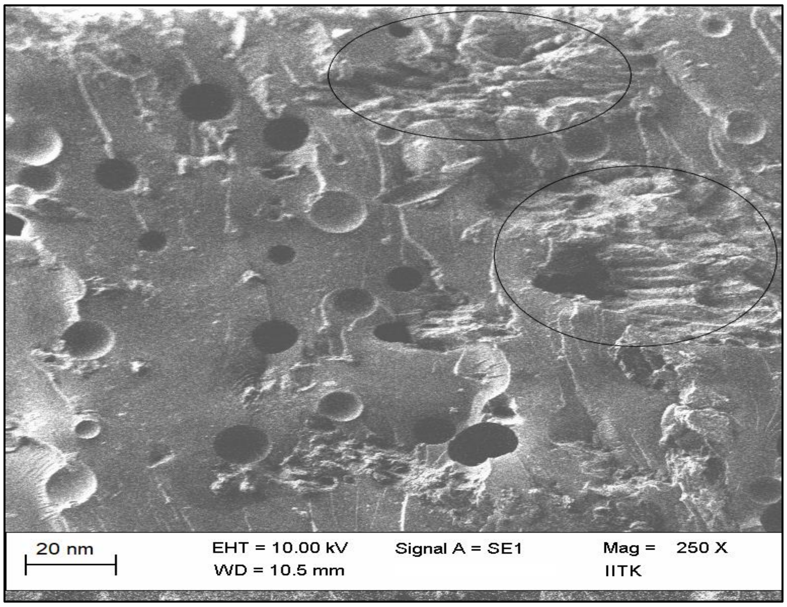

Figure 6. Fractographic SEM images of 20% NCAFP composite sample.

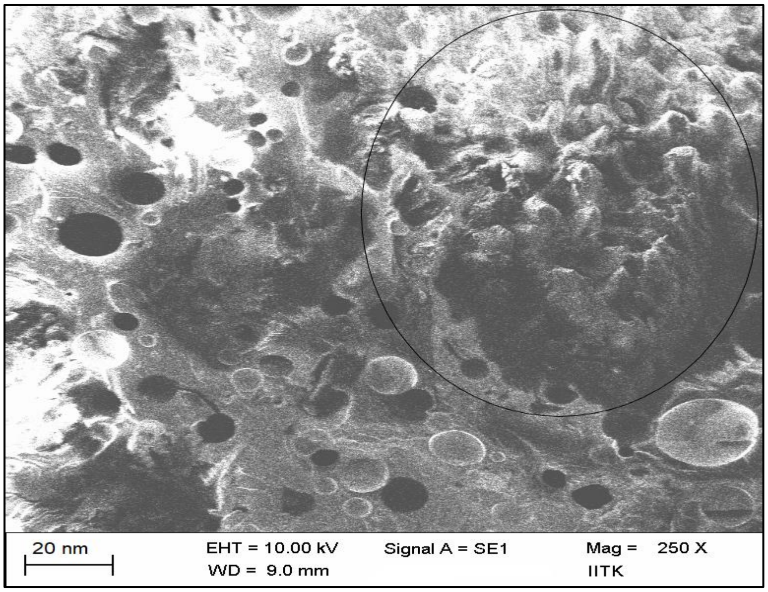

Figure 7. Fractographic SEM images of 25% NCAFP composite sample.

In the tensile test experiment the samples were fractured by INSTRON 1195 testing machine to obtain tensile strength. Now, these fractured sample surface was analyzed by scanning electron microscope imaging technique to probe the reason behind the optimum tensile strength.

The figure 4, 5 and 6 illustrates SEM images of fractured 15%, 20%, 25 % NCAFP composite samples respectively. Surface analysis of these fractured NCAFP composite samples describes that there is minimal agglomeration of NCAFP particles in the epoxy matrix up to 15% NCAFP composite samples (figure 5) with least voids and porosity which causes an enormous increase in tensile strength having good interfacial bonding between epoxy matrix and NCAFP.

Higher loading of NCAFP in epoxy matrix greater than 15% produces agglomeration of NCAFP particles in the epoxy matrix which causes a decrease in tensile strength having low interfacial bonding between epoxy matrix. The localized agglomeration area can be noticed in the figure 6 and 7 shown by black circles.

4. Conclusion

In this research work an experimental developed different weight percentage NCAFP reinforced epoxy composites and its mechanical and thermal properties were discussed. The overall discussion leads to conclude that the optimum tensile strength 550 MPa [Figure 4] with thermal conductivity 0.95 W/mK [Figure 3] of developed 15% NCAFP reinforced epoxy composite were obtained experimentally. Absence of localized agglomeration, porosity and voids in SEM image [Figure 5] provide the justification for optimum tensile strength of 15% NCAFP composite. Consequently, the developed 15% NCAFP reinforced epoxy composites can be used in microelectronics packaging, aeronautics and automobile engineering due to its lightweight (low density), optimum mechanical strength and low thermal conductivity.

In future, the analytical prediction models for density, mechanical strength and thermal conductivity of NCAFP reinforced epoxy composites can be explored.

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