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Impact of Nanoclay on Mechanical Properties of Coccinia Indica Reinforced Polymer Composite

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ABSTRACT: One such material that may be used in practical applications where weight and energy savings are important is natural fibre composite material, which can replace traditional and synthetic materials. This paper examines Cloisite 30B's effects on the fibre of Coccinia Indica, a recently identified medicinal plant in the Cucurbitaceae family that is manually picked. The fibre reinforced composite made of chemically treated Coccinia Indica is made of epoxy resin, and a comprehensive preparation method is given. The mechanical characteristics and performance of epoxy composites reinforced with chemically treated Coccinia indica fibre were examined in this work using nano-clay in an empty composite. The tensile, flexural, impact, and compression properties of the treated Coccinia Indica fibre reinforced epoxy composites are improved by increasing the weight % of nano-clay, according to the findings of the experiments. When compared to other combinations, adding 8 weight percent of nano-clay produces the greatest results because it boosts the interfacial adhesion between the fibres and matrix.

KEYWORDS: Nano-clay, Coccinia Indica Fibre, Fibre Reinforcement Composite, Mechanical Characteristics.

I. INTRODUCTION

The whole market is rapidly shifting towards energy reduction and conservation. In today's composite world, natural fibres are all the rage. They are mostly utilised in engineering applications due to their unique qualities above regular fibres. Recent years have seen the development of ecologically friendly goods for use in the automotive, building, and industrial sectors thanks to the use of natural fibre composites rather than synthetic ones [1]. For a variety of reasons, the development of composite materials made from natural or renewable resources has accelerated recently. Plant fibre reinforced polymer composites are becoming more and more popular in many different applications due to their numerous desirable properties. Because of their favourable environmental effects, plant fibres are utilised in place of conventional fibre-reinforced polymer composites like carbon, glass fibre, and aramid [2].

However, it also has several drawbacks, including susceptibility to heat, weak transverse strength, poor adhesion to polymers, and poor water sensitivity. Numerous investigations were conducted to improve the interfacial strength by chemical treatment using substances such as silanes, anhydrides, and alkali, among others. As a result, the matrix and fibre's interfacial bonding improved [3]. Alkali treatment was applied to the fibre of the Borassus fruit at concentrations of 5%, 10%, and 15%; of these, 5% of the alkali treatment exhibits a superior mechanical characteristics [4]. An increase in alkali concentration in the solution resulted in damage to the fibre surface, which is related to a decline in the mechanical characteristics of the composites [5].

According to Barbhuiya, H et al. [6], the proper fibre length and weight percentage have a substantial impact on the properties of natural fibre composites. A small concentration of nano-clay was added to polymer composites to enhance their mechanical properties, as was noted in the review on polymer clay hybrid nanocomposites [7]. The assessment on polymer clay hybrid nanocomposites [8] states that a small quantity of nano-clay was added to polymer composites to enhance their mechanical properties. Research has been done on polymer nano-clay composites, in which polymer functions as the matrix material and nano-clay as a filler for the reinforcing particles. It was discovered that adding nano-clay enhanced the polymeric matrix's mechanical, thermal, and physical characteristics [9]. Composites break very easily because of the interstitial spaces that form between the natural fibre with a modified surface and the

polymer matrix. Since they have a larger aspect ratio, are less expensive, and are miscible with the matrix, inorganic fillers including carbon nanotubes, silica nanoparticles, and nano-clay were utilised to increase stress transfer between the filler and matrix. Due to its easy dispersion in the matrix, the mineral montmorillonite (MMT) works well as a filler for nano-clay. When compared to a normal filled polymer with micron-sized particles, a small quantity of nano-clay (5 weight percent or less) has improved stiffness and specific strength, is an effective fire retardant, and has increased barrier properties [10, 11, 12].

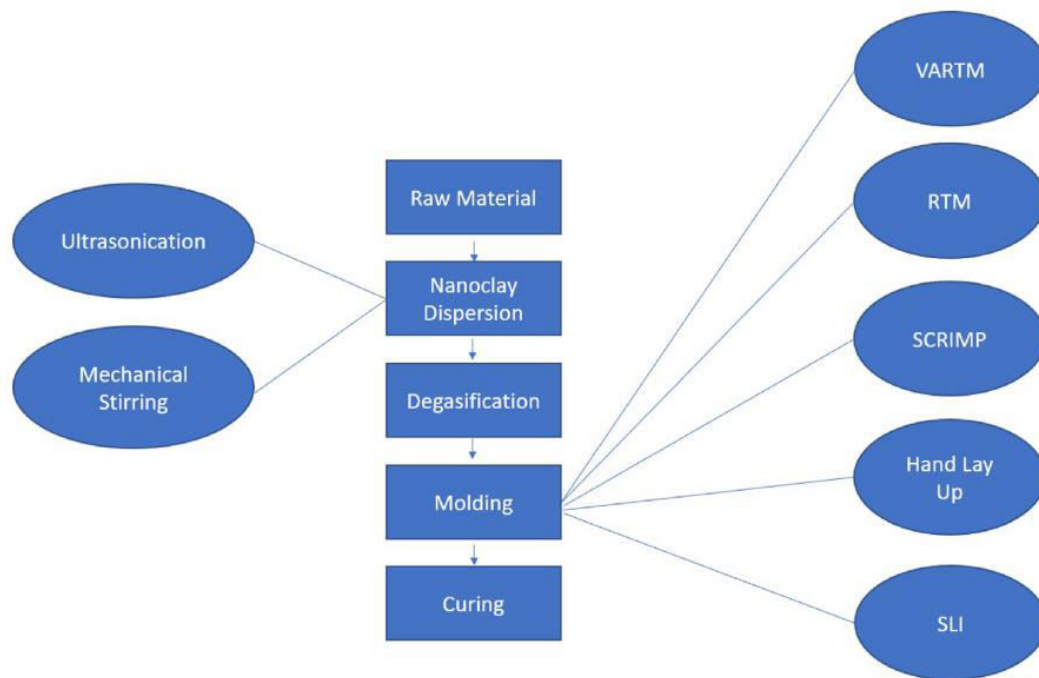


Fig. 1. Flowchart of Manufacturing of Nano-clay infused composite [13].

Free molecular mobility at the glass transition point is the reason why pure polyester has a lower storage modulus than CIFRCs, as demonstrated by the DMA test results. A reinforced composite with a 30-mm fibre length exhibits enhanced interfacial bonding, resulting in a greater storage modulus inside the glassy plateau. Longer fibres and pure polyester both have low loss moduli due to heat dissipation. The critical 30 mm fibre length is what determines which CIFRCs have the optimal modulus and damping factor. The DMA test showed that pure polyester's lower storage modulus than CIFRCs is caused by free molecular mobility at the glass transition location. CIFRCs with a critical 30mm fibre length have the optimum modulus and damping factor [14]. The study found that adding pineapple leaf fibre to base epoxy amended its mechanical properties, leading to the formation of hybrid Epoxy/Nano-clay/Pineapple composites. The 'EPN2' hybrid showed the highest flexural, tensile, and impact properties, while the nano-clay-impregnated hybrids had greater abrasion resistance. It was discovered that shear-forced and frictional applications, such as brake pads and sporting goods, were where the hybrid composite worked best [15].

B. Sharma et al. found that clay intercalation in epoxy improved with clay loadings of Agglomerates were discovered in samples containing 1 and 3 weight percent. Hardness rose when nano-clay was added, and tensile and flexural strengths increased. Durability studies showed mechanical properties degradation, but less in nano-clay-modified epoxy. Water resistance improved with glass fibre and nano-clay addition. According to Manickam et al., the mechanical characteristics of a hybrid composite with reinforcements consisting of glass fibre, abaca fibre, and epoxy matrix were enhanced by the addition of nano-clay. The composite reinforced with 4% nano-clay exhibited superior properties, demonstrating enhanced impact, flexural, and tensile strength. Compared to the EGA composite, the wear resistance was 22.1% more efficient. In the study of Chee et al., the epoxy hybrid nanocomposites with bamboo fibre mat/kenaf mat fibre reinforcement were successfully synthesised using nano-clay modification. The inclusion of OMMT, MMT, and HNT improved the composites' tensile, flexural, and impact properties. BK/E-OMMT hybrid composites, which had a good interfacial interaction between the fibres and matrix, showed the greatest mechanical performance. The use of OMMT nano-clay reduced void contents and showed strong fibre-matrix adhesion.

Ambekar et al. investigated epoxy composites reinforced with PALF and epoxy nano-clay composites reinforced with PALF. They found that adding nano-clay reduced saturation moisture uptake and diffusion coefficient, while tensile strength and modulus increased. However, after immersion, tensile strength and modulus decreased, while flexural strength increased. The reductions were lower for nano-clay composites. Rahul B et al. explores the impact of nano-clay on glass fiber reinforced epoxy composites' mechanical and thermal behavior. Results show good clay dispersion, increased hardness with minimal clay content, and higher clay loadings. Fracture toughness increases with 1% clay, and optimum clay loading is 1%. Clay loading enhances visco-elastic properties, thermal stability, and glass transition temperature.

The use of nano-clay, which is lightweight and environmentally benign, is being investigated as a filler in *Coccinia Indica* (CI) fibre for reinforcement in structural polymer composite materials. NaOH was applied to the manufactured CI fibre in order to overcome its shortcomings. The use of nano-clay enhanced the mechanical properties of the composites. The novel natural reinforcing material presented in this study has potential applications in the creation of composite materials. Within alkali-treated CIF-reinforced epoxy composites, the study examines the morphological and mechanical characteristics of nano-clay inclusion.

II. MATERIALS AND PREPARATION

The therapeutic plant, a member of the Cucurbitaceae family, was used to extract CIFs. The place is situated in the Coimbatore District of Tamil Nadu, in the southern region of India, close to the hamlet of Kanuvukarai. The fibres of the CI plant were cut off from the stem and submerged in water for a period of three weeks in order to promote microbial breakdown. The stems were immersed, cleaned in new water, and allowable to air dry for a week at room temperature. Lastly, a metal teeth brush was used to aid in the combing process to remove the fibres from the dried stems. To eliminate the surplus water from the extracted fibres, they were sun-dried for eight hours. CIF bundles were immersed for one hour at room temperature in a 5% NaOH solution in a stainless-steel tank. To get rid of the extra acid in the fibres, they were removed and carefully cleaned with distilled water. After giving the treated fibres one more wash in water containing 1% acetic acid, they were left to dry in the sun for five days. These approximately 30-millimetre-long fibres were used to prepare the CIF-reinforced epoxy composite, which was then treated with NaOH.

The CIF-reinforced epoxy composites, both filled and unfilled, were created using compression moulding and a basic manual lay-up method. The composites underwent chemical processing. Southern Clay Products Inc., a US-based company, sells commercial nano-clay called Closite 30B, with particles smaller than 13 nm. To start the process, a mechanical stirrer was used to thoroughly mix the filler material with industrial grade acetone for 30 minutes. This technique dispersed the nanoparticles throughout the acetone. Southern Clay Products Inc., a US-based company, sells commercial nano-clay called Closite 30B, with particles smaller than 13 nm. The filler material was completely mixed with industrial grade acetone for 30 minutes using a mechanical stirrer to initiate the procedure. The nanoparticles were spread throughout the acetone throughout this process. To make epoxy composites reinforced with CIFs, the parent solution of the nano-clay-acetone combination solution was coupled with the required quantity of standard Bisphenol A (LY 556) for the epoxy resin, which had an epoxy equivalent weight of 180–190 g/eq. The acetone solutions were heated to 80 °C to enhance nanoparticle wetting and lower the viscosity where they evaporated. Up until a homogenous mixture was reached, the components were continually combined using the mechanical ultrasonic. The last step involved mixing triethylenetetramine for five minutes with a mixture of 10 weight percent epoxy and 1 weight percent hardener. The composites were moulded using a steel die, which was coated with a releasing agent to facilitate composite removal. The treated CIFs and produced nano mixture were dispersed equally to the required thickness to form the composite laminates. After that, a closed mould containing the CIF-reinforced nano-mixture was treated and squeezed for three hours at 1500 psi and 80 °C in a hydraulic press. After the resulting epoxy composites reached room temperature, they were allowed to cool, which decreased the thermal residual stresses. Several weight ratios (0, 2, 4, 6, and 8 wt.%) of nano-clay were added to the resultant composites in order to assess their effects. In every experimental scenario, the specimens were formed in the same way.

III. EXPERIMENTS

KALPAK Universal Testing Machine was used to conduct compression (ASTM D3410), tensile (ASTM D3039), and three-point flexural (ASTM D790) tests on CIFs-reinforced epoxy composites with and without nano-clay particles. Samples were placed precisely along the longitudinal axis of the machine or load cell, and the force was delivered at a cross-head speed of two millimetres per minute. A circular saw was used to cut the specimens into rectangle-shaped strips. The samples fractured at the borders of their rectangular strips while being tested. In Figure 1, pictures of a few

specimens, both before and after testing, are displayed. The specimens were put into the testing apparatus, where they were compressed until they broke. Using a strain gauge with a computer interface, the specimen's deflection was measured, and its flexural strength was assessed. The specimen's compressive strength was ascertained by charting the compressive force as a function of displacement. A Pendulum Impact Tester (Izod Impact Test) was used to conduct impact testing (ASTM D256) in order to measure impact energy with an accuracy of 0.5 J. Every test used 5 specimens to reduce the possibility of equipment error, and the results were presented as averages. At a 24 °C ambient temperature and 65% relative humidity, the testing was conducted in a controlled setting.

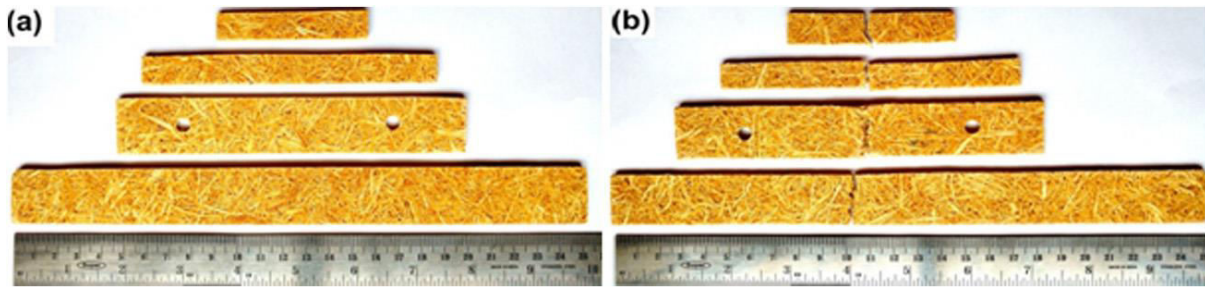


Fig. 2. Specimens a) before test and b) after tests

IV. RESULT AND DISCUSSIONS

A. Tensile Properties

Using nano-clay weight percentages ranging from 0 to 8, the tensile strength of epoxy composites reinforced with CIFs was demonstrated in this experiment. Figure 2 shows a bar graph of the tensile strength for epoxy composites reinforced with CIF and different levels of nano-clay inclusion. Epoxy composites undergo tensile testing, which reveals that the matrix serves as a conduit for load transmission between the fibres, which bear the tensile stress. Although the fibres were treated with NaOH, the moisture content was not eliminated. The result is the epoxy composites' lowest tensile strength. After adding 0, 2, 4, 6, and 8 weight percent of Cloisite 30B to the treated CIF-reinforced epoxy composites, the tensile strengths are 32.86, 34.46, 36.06, 38.66, and 39.26 N/mm². Better adherence between the fibres and matrix resulted in increased stress transfer when nano-clay was added to CIF-reinforced epoxy composites treated with NaOH as opposed to those without it. A possible explanation for this could be the removal of some weak phases from the fibre surface, including hemicellulose, lignin, wax, and other non-cellulosic plant impurities. With nano-clay, a robust cross-linking connection was created between the fibre and matrix. The maximum strength of composites (8 weight percent) varies by percentage in relation to other materials, and is 11.75 (0 weight percent), 9.67 (2 weight percent), 3.60 (4 weight percent), and 8.57 (6 weight percent), respectively.

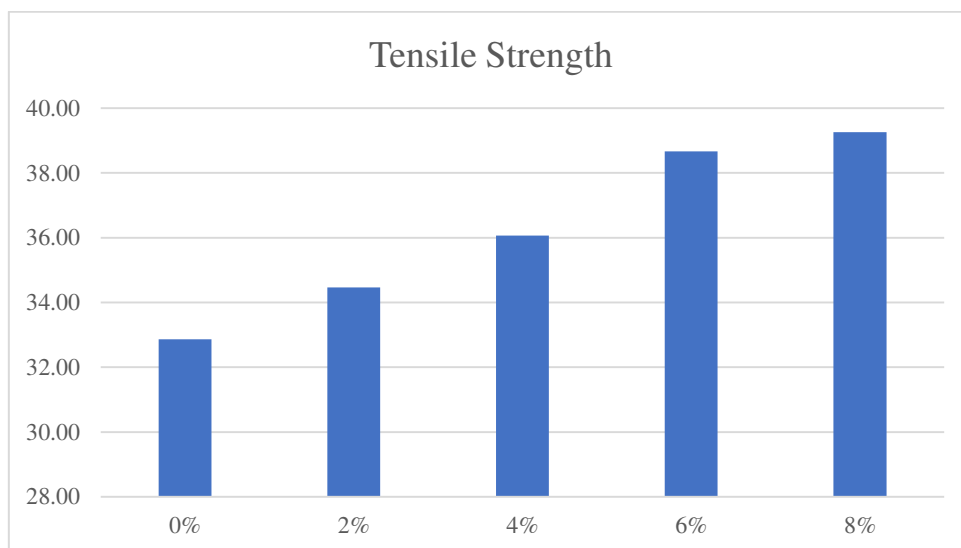


Fig. 3. Tensile Strength of Composite with and without Nano-clay

B. Flexural Properties

One crucial characteristic of structural materials is their flexural strength. In structural applications, the beam or plate must sustain a perpendicular load. In both the nano-clay and treated CIF-reinforced epoxy composites, Fig. 3 shows the flexural strength. The average value of flexural strength was determined by testing five specimens of each composition. Variable compositions have varied flexural strengths. The fibre composites treated with NaOH exhibit greater flexural strength values because a portion of the lignocellulose binder is removed from the fibre, improving adhesion within the matrix. The treated CIFs-reinforced epoxy composites have flexural strengths of 80.45, 86.21, 89.54, 92.45, and 98.67 MPa for additions of 0, 2, 4, 6, and 8 weight percent of Cloisite 30B. The fillers' maximal void filling in the matrix is what causes the maximum increase produced for a 3-weight percent addition of nano-clay relative to the neat sample. This results in a saturation value for the flexural characteristics.

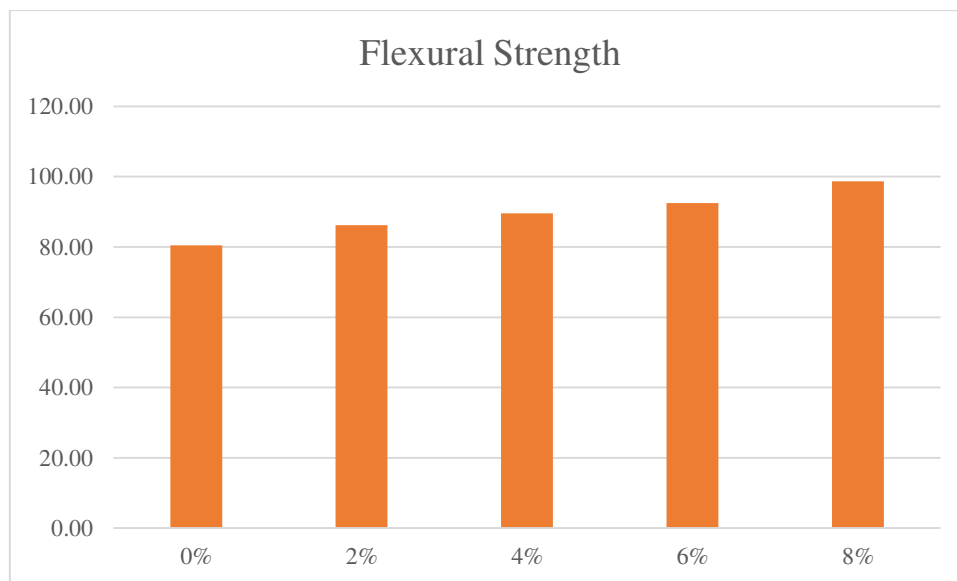


Fig. 4. Flexural Strength of Composite with and without Nano-clay

The flexural strength of the NaOH-treated CIF-reinforced empty epoxy composite was lower than that of the nano-clay filled epoxy composite. Inadequate adhesion between the fiber and matrix, coupled with increased fiber lignin, wax, and moisture content, likely contributed to this outcome. Rapid formation and propagation of fracture channels led to the shattering of the material. Filled epoxy composites generally possess higher flexural strength than unfilled composites. The addition of 8 weight percent Cloisite 30B increased the flexural strength of epoxy composites. Maximum flexural strength of composites (at 8 weight percent) varied with percentages as 13.92 (0 weight percent), 12.21 (4 weight percent), 7.63 (6 weight percent), 2.71 (6 weight percent), A higher addition of 8 weight percent of nano-clay caused a drop in the flexural strength of the treated CIFs-reinforced epoxy composite to 98.67 MPa due to the presence of more intercalated aggregate. Enhanced nano-clay filler reinforcement in the epoxy composites produced similar results. The epoxy composite reinforced with CIFs and treated with NaOH, containing 8 weight percent of nano-clay, may emerge as a strong competitor capable of replacing current structural materials.

C. Impact Properties

All materials must have impact resistance as they have to be able to absorb energy when subjected to abrupt impacts. Put another way, impact strength is a material's capacity to withstand fracture when subjected to higher applied forces and faster velocities. When the force is applied uniformly across the material, its impact resistance is increased. When specific materials are commonly employed as damping materials in structural applications subjected to impact loads. The nano-clay-filled composites and the unfilled epoxy composite are tested for impact strength. Figure 4 depicts the impact strength of epoxy composites reinforced with CIFs, both with and without nanoclay.

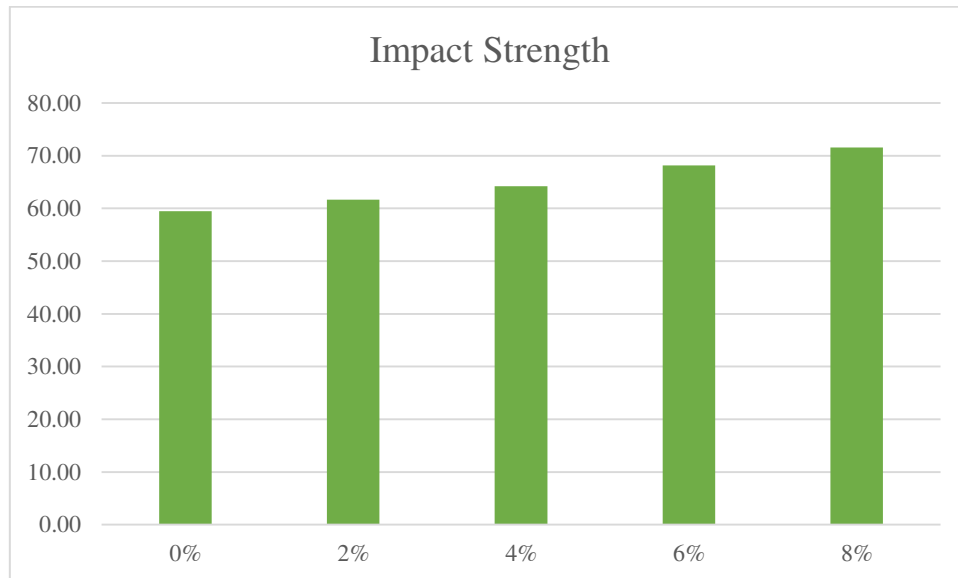


Fig. 5. Impact Strength of Composite with and without Nano-clay

A room-temperature Izod impact strength apparatus is used to measure impact strength, which is expressed in kJ/m². An average impact strength value was provided for each of the five specimens that were evaluated. The reinforced epoxy composite with unfilled treated CIFs has an impact strength of 59.44 kJ/m². This was shown to be the greatest potential gain in impact strength of nanocomposites, increasing up to 71.54 kJ/m² for 8 weight percent of nano-clay addition. This is due to the enhanced adhesion among the matrix and fibre; naturally occurring fibre in polymer composites absorbs more energy and increases the number of fracture routes at the interface. The compositions with the highest impact resistance differ from the others by the following percentages: 13.74 (0 weight percent), 8.46 (2 weight percent), 4.27 (4 weight percent), and 3.11 (6 weight percent), in that order. When 8 weight percent of nano-clay reinforcement is added, the impact strength is observed to drop to 71.54 kJ/m², making the composite more stiff.

D. Compressive Properties

When 2, 4, 6, and 8 weight percent of Cloisite 30B were added to the unfilled treated CIFs-reinforced epoxy composites, the strength values of the filled epoxy composites were 52.65, 58.45, 61.32, and 64.23 N/mm². This is in contrast to the unfilled epoxy composites, which showed a compressive strength value of 50.45 N/mm². The significant improvement in compressive strength at 3 weight percent nano-clay loading is the main result of the fibres' reinforcing action. These fibres allow the dispersed fibre phase to share stress uniformly with the continuous polymer matrix. The greatest impact resistance to all other compositions varies by percentage, with values of 20.76 (0 weight percent), 13.79 (2 weight percent), 11.84 (4 weight percent), and 5.20 (6 weight percent), in that order. The abrupt drop at higher loading (8 weight percent) suggested inadequate adhesion, which encouraged the production of microcracks at the interface and non-uniform stress transmission as a result of matrix agglomeration (Fig. 5).

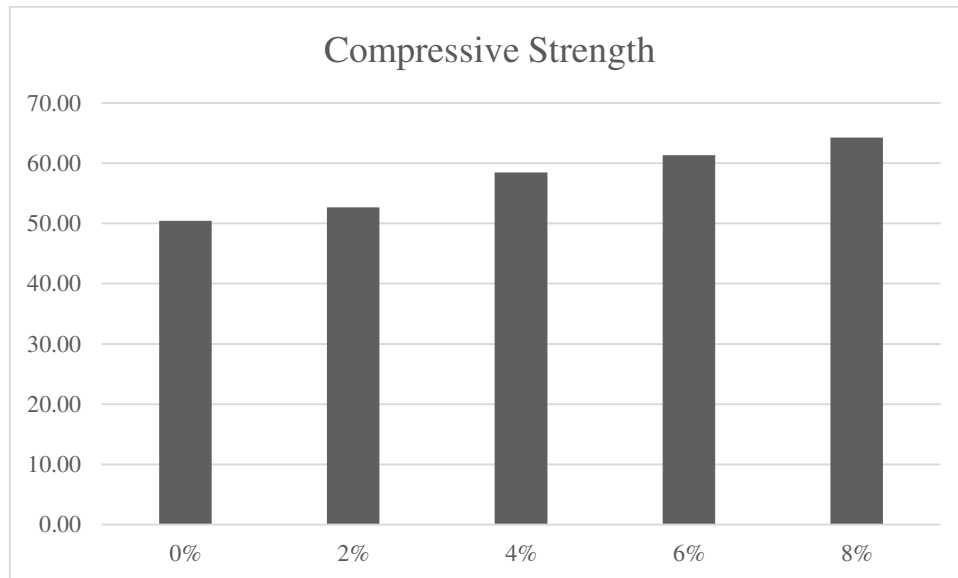


Fig. 6. Compression Strength of Composite with and without Nano-clay.

V. CONCLUSION

This work examined the effects of nano-clay on the mechanical properties of epoxy composites reinforced with alkali-treated CIFs. The tensile, flexural, impact, and compression properties of the composites were enhanced, both with and without nano-clay particles. The inclusion of nano-clay improved the matrix and fibre's interfacial adhesion while promoting the formation of microcracks at the interface and uneven stress transmission as a result of matrix agglomeration. The strength values decreased with higher loading (8 weight percent), which was apparent. Overall, the results point to the possibility that adding nano-clay particles can improve the mechanical properties of epoxy composites reinforced with CIFs that have been alkali-treated, but that adding too much weight could result in a reduction in strength. Further research could focus on optimizing the nano-clay content to achieve the desired balance between improved properties and potential drawbacks.

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