# Performance Evaluation of Mechanical Properties of nano-silica-based wild date palm tree fiber reinforced polyester composite material

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**Abstract:**

The problems associated with natural fiber waste management and the disadvantages of synthetic fibers have conditioned the use of natural fibers as reinforcement in composites. The incorporation of the same type of reinforcing fibers does not necessarily lead to the production of composites that meet exceptional quality standards, especially in terms of dynamic mechanical properties. Several studies have shown excellent properties of natural fiber-reinforced hybrid composites. Therefore, the aim of this article is to discuss research related to natural fiber-reinforced hybrid composites, with an emphasis on dynamic mechanical properties.

**Keywords: Nano SiO2, PMC, NFC, Wild date palm**

## 1. Introduction

Throughout history, mankind has used composite materials to achieve combinations of properties that individual materials could not achieve. The Bible explains that straw and clay are mixed to make stronger bricks. Concrete is a mixture of cement paste, sand, and gravel. Today, poured concrete is almost always reinforced with steel bars. Other examples of composites include steel-belted tires, gravel-mixed asphalt for roads, alternate-grain plywood, and fiberglass-reinforced polyesters used in furniture, boats, and sporting goods. Composite materials offer a combination of properties not otherwise available. Although the concept of "composite material" is not a human invention. Wood is a natural composite material made up of polymer species such as cellulosic fibers with excellent strength and rigidity over the resinous matrix of another polymer, the lignin polysaccharide.

In composites, the materials are combined on a macroscopic scale, allowing them to make better use of their strengths while minimizing to some extent the effects of imperfections. This optimization process relieves designers of the limitations associated with traditional material selection and fabrication. You can use stronger and lighter materials with properties that can be adjusted to meet your specific design needs. Because even complex shapes can be easily manufactured, a complete rethinking of established designs from a composites perspective often leads to better and more cost-effective solutions.

The properties that can be improved by forming components are:

- Strength
- Stiffness
- Corrosion resistance
- Wear resistance
- Biodegradability
- Attractiveness
- Weight
- Fatigue life
- Temperature-dependent behavior
- Thermal insulation
- Thermal conductivity
- Acoustical insulation

Not all of the above symptoms can be improved at the same time, but many of them can be improved. Composites have been around for a long time. The Israelites used straw to strengthen mud bricks. Fiber-reinforced plastic composites have a high stiffness-to-weight ratio. This is why composites are so popular in aircraft and spacecraft. These materials are also frequently used in the automotive industry for weight-sensitive functions.

## 2. Literature Review

**History of nano-particles**

**18th Century**

- Nanoparticles of gold and silver were used in Lycurgus cups of glass structure that changed color from green to red when the flow of light is changed to different side.
- Silver nanoparticles to achieve yellow light and gold particles to get red color from stained glass windows was another illustration of nanoparticles back in time.
- Nano sized particles of copper and silver proved success in getting red and gold burnishing outcome which was used by Deruta ceramicists.

**19th Century**

- Joseph Niepce in 1827, became first individual to use silver nanoparticles for lightsensitivity in photography.
- Louis amended Joseph's project and minimize the exposure time, in 1839.
- Michael Faraday, with no intensions, while working on metallic colloids with special electronic and optical properties in 1856, took spot in the types of nanoparticles.

**20th Century**

- To get the probable size of nanoparticles for a specific quantity of light scattered, Mie theory was given by German physicist Gustav in 1908.
- Development of electron microscope in 1933, proved crucial in expansion of methods to empower the groundwork at nanoscale.
- Semiconductor industries took a niche at the nanotechnology after commencement of microelectronics. Investigation is under progress to prepare chips to hold huge amount of nanoscale transistors.
- Reacting octadecyl trichlorosilane or OTS with glass surface, the work of Jacob Sagiv initiated the building of three-dimensional nanoscale structures layer by layer.
- The ability to control nanoparticles became possible because of the scanning tunnelling microscope which was invented by Gred Binning and Heinrich Rohrer in 1981.
- The discovery of quantum dots, which later contributed to the analysis of quantum confinement effect, was founded by Dr. Louis Brus and his team in early 1980s, where they uncovered that nano-sized crystal semiconductor materials made from similar substance showed surprisingly different colors.
- New form of carbon named nanotubes were invented by Sumio Lijima in 1991, which later helped in unearthing of single walled nanotubes with 1-2nm diameter which has improved conductivity than copper and heat dissipation than diamond. Also became the strongest material known.
- Chad mirkin discovered Dip-Pen nanolithography in 1999, which helped in writing with nanometer dimensions and precision of the surface.

**Recent studies on Natural Fiber Reinforced Polymer composites**

- **Ramesh Kumar et.al.,** have done an attempt to study the water absorption behaviour of banana/glass fibre composite. They came to the conclusion that water absorption capacity is better in banana fibre than kenaf/glass fibre composites [23].
- **Naheed Saba et.al.,** represented knowledge about the varied classes of natural fibres, nanofiller, cellulosic fibre based composite, nanocomposite, and natural fibre/nanofiller-based hybrid composite whereby specifying their application as well. Incorporation of nano particles in place of reinforcement of composite showed a higher possibility [24].
- **Ashish Thakur et.al. has done** an attempt to prepare a completely new composite material with Bamboo fibre reinforced in the epoxy resin, varying percentage of CNT and examining the mechanical characteristics of the prepared composite specimens. The composite samples were prepared and their grain size and grain boundary was analysed using Atomic Force Microscope (AFM). Tests like Tensile, Flexural and Impact Strength of the Bamboo fibre & CNT reinforced polymer composites were studied by conducting tests on the INSTRON-3382 machine at CIPET, Bhopal, Madhya Pradesh. Hybrid composites of bamboo + epoxy dispersed with 1%, 2%, and 3% CNT have been successfully

prepared using hand lay-up technique. Tensile strength of the specimens increased with increasing % of CNT in hybrid composite. Material became brittle with increasing % of CNT in epoxy + bamboo specimen. Increment in the number of grains and average grain size were also observed. [25]

- **Ashish Kumar et.al. have done an** study to enhance the mechanical properties of natural fibre composite mixed with glass fibre. Sisal fibre was mixed with glass fibre reinforces epoxy composites. Hand lay-up method was used. Tests like Tensile, flexural & impact test were performed on the specimens. This paper concluded the upgradation of the mechanical properties to larger extent along with increasing the moisture resisting capacity. Tensile strength of epoxy failed to improve by the reinforcing of sisal fibre while tensile modulus, flexural properties and impact properties were found to be improved.[26]

- **Sofiene Helaili et.al.** did fabrication of Alfa Fibre (composite material). Matrix – Epoxy Resin, Reinforcement – natural Alfa fibre. Moulding technique is used to judge the structural application. Here, flexural modulus increased in a linear way as fibre content increases. When we compare epoxies modulus of elasticity, we can conclude that Alfa Fibre gave superior stiffness to the composite and moreover better elongation before failure was observed.[27]

- **S.V. Joshi et.al.,** in their paper compared the difference in life cycle of glass fibre and natural fibre composites, and also studied driving factors of their environment performance. NFRC were found to be superior to the GFRC in most cases.[28]

- **Kumar.S et.al.,** did an up-to date review of natural fibre and resin type is made. It is concluded that green composites are good alternative being pollution free.[29]

- **Ankit et.al.,** has made profound realisation that production technique used in the manufacturing of composite effects its mechanical properties namely flexural, tensile and impact strength.[30]

- **Kishore Kumar Mahato et. al.** has comprehensively studied thermal and mechanical properties of glass fiber in the form of woven mats embedded with $Al_2O_3$. Hand lay-up method combined with hot press was used. Two laminates were formed to study the composites. Many mechanical properties, thermal properties and physical properties tests are conducted. Tests like SEM (scanning electronic microscope), flexural strength, etc. are performed at appropriate temperatures. The aim of the experiment is to enhance the mechanical characteristic, thermal characteristic and physical characteristics, by mixing nano $Al_2O_3$ in the different Wt% in the composite material and in hybrid composite material [31].

- **Dan M. Constantinescu et. al.** mixed pure epoxy with the nano silica particles. Both unfunctionalized and functionalized nano silica particles were added into pure epoxy. The three different Wt% of nano silica was added are 0.1, 0.3 and 0.5 Wt%. They cannot obtain a conclusive remark from the monotonic static testing and tensile testing at the room temperature which lead to the enhancement of mechanical properties.

For the enhancement of the mechanical characteristic, sonication method was used in which fumed silica is mixed. As a result, smaller clusters are formed by gradually breaking up of larger aggregates [32].

- **Tian Fuqiang et. al.** underwent comprehensive study of dielectric properties as well as space charge of epoxy resin with addition of nano fillers like $SiO_2$-$Al_2O_3$ at different temperatures. They also carried out the study of electrical conductivity variation between 19-199 C.in order to study nano particle dispersion SEM was used.[33].

- **Yalin Zhu et. al.**, had supercooling and poor thermal conductivity as major challenges. Nano encapsulated phase change material was used in their study with nano $SiO_2$. Which removed use of supercooling. Hydrolysis and polycondensation of self-assemble graphene in mini emulsion and alkoxy saline's is used for manufacturing of NePCMs. Better thermal stability as well as thermal reliability were observed here [34].

- **Xiangyu Li et. al.** has carried out experiment using spray coating method in which it uses forming acetone solution made up with epoxy, mesoporous SiO2 and benzoxazine. Here they were able to generate a super hydrophobic surface which can bear almost 1.9 gm abrasion under load of 1.5KPa, thus resulting in improved adhesive, mechanical and chemical properties [35].

- **Zhenyu pi et. al.** in his study found out that if a multiplayer film of nano $SiO_2$ was coated on cement composites i.e., with steel fibers it leads to filler material reacting with $Ca(OH)_2$ which leads to hydration of cement, this makes denser microstructure at fiber matrix interface, leading to improved mechanical properties at the interface [36].

- **Gang li et. al.** work was primarily based on enhancement of thermal as well as mechanical properties by underfill adhesive of $SiO_2$ nanoparticles. Here various oregano silanes were used in the study out of which best was observed by methacrylic terminated silane.[37].

- **Ismail sarac et. al.** used various nano fillers such as $Al_2O_3$, nano $TiO_2$ and nano $SiO_2$ powders and formed a lap joint in epoxy adhesive. The lap joint was investigated tin shear load with lengths eg. 20mm, 25mm, 30mm, 50mm, and 70mm. the conclusion derived from that was when nano fillers are added in epoxy adhesive it leads to elongation of the joint [38].

- **Ayman matta et. al.** gave a thorough study about panels which are having coating of hydrophobic silica particles. It results in improved surface morphology, chemical structure and thermal stability. Also, here better corrosion resistance could be seen [39].

- **Junsongfu et.al.** used layer by layer assembly method to manufacture carbon fiber reinforced epoxy composite, where graphene oxide/ silica was used (GO/SiO2). This led to improvement in mechanical interlocking as well as roughness and surface energy of fiber.

- **M. Rajaei et. al.** achieved 87% reduction in heat released by epoxy composite which is based upon ammonium polyphosphate. Here two nano clays i.e., Layered Double Hydroxide (LDH) Halloysite nano tube (HNT) were used for comparison [40].

- **Jun bian et. al.** found out that because of "heterogeneous nucleation effect improvement in melting and thermal properties" was observed for polypropylene nano composites having nano SiO2 and graphene oxide manufactured by melt blending technique. When properties were compared with polypropylene embedded with only nano $SiO_2$ it was observed that enhanced mechanical and thermal properties were observed [41].

- **K. Viswanath Allamraju et. al.** used hand lay-up method for the fabrication and the development of hybrid composites. They made two type of hybrid composite. First one is nano jute fiber composite and the other one is nano jute glass fiber epoxy composite. ASTM standards were used for the preparation of the samples. The two main mechanical properties are tested are tensile strength and the compressive strength. On the basis of these properties' comparison is made between two composites, out of which nano jute fiber composite is the best one in terms ofself-healing [39]. The specification like lighter in weight and enhanced mechanical properties are founded in fiber reinforced polymer (FRP) composites, therefore, they are used in various applications. Abrasive wear components like rollers, gear, bearings, etc. shows inadequate wear resistance. Therefore, **Santi Swarup Mohanty et. al.** enhanced the wear characteristic in the area of structural and abrasive wear of polymer matrix composites. They performed the tests on the sample made up ofglass/carbon fiber reinforced polymer hybrid composite. Box-Behnken design analysis was used for the evaluation. By obtaining Response Surface Methodology (RSM) a mathematical model was developed, which aids in deciding minimum specific wear rate of polymer hybrid composite. As a result, model results satisfy the experimental results [45].

- **Pankaj Charan Jena et. al.** investigated vibration signature analysis on the particulate's polymer composite damaged area. The polymer composite was consisting of polyester matrix with silicon carbide in the powered form. Different Wt% of SiC was used in ratio varies as 10%, 15%, 20%, 25% and 30%. Both FEM and analytical method were conducted to get the vibration signature. Vibration Signature means to get the value of mode shape and natural frequency. The boundary condition that was applied to calculate the natural frequency was clamped free condition. As a result, with the change in different wt% of SiC, the frequencies also change. [49]

- **Anisha Christy et. al.** fabricated the polymer matrix composite by using the hand lay-upmethod. They mixed the nano SiO2 particles of different wt% into epoxy resin. Acetone was added in the mixture for proper bonding of matrix with nano fillers. Along with the microstructural (SEM) tests, they also tested the flexural characteristic and tensile characteristic. As a result, there is an enhancement in the properties up to 3 wt% of the nano SiO2 particles incorporated with epoxy resin. Also, for the proper bonding between the epoxy resin and the nano SiO2 particles, ultrasonic vibration bath was conducted at specific rpm [45].

- **Sushil Kumar Singh et. al.** performs the experiment in which they enhanced the flexural properties and the tensile properties of the composite. The composite incorporates epoxy with different wt% of nano $SiO_2$ filler up to 8 wt%. ultrasonication process were conducted for the proper dispersion of SiO2 in the epoxy. Results, reveals that the polymer matrix composite containing nano SiO2 in 4wt% shows excellent enhancement in the flexural properties andtensile properties. Above 4 wt% of nano SiO2 with epoxy, the mechanical properties decreases due to long curing time [16].

- **Gazala ruhi et. al.** achieved very good thermal stability of polymer composite for epoxy coating embedded with polypyrole $SiO_2$ composite by performing tests like TEM and SEM through TGA analysis. Homogeneous dispersion is shown by $SiO_2$ particles in polypyrole matrix. Resistance to corrosion also got improved through Salt spray test [46].

- **B. Ramezanzadeh et. al**. took Cerium Nitrate and 3-amino propyltriethoxysilane (APTES) embedded with Aluminium nano particles. The mechanical properties got enhanced up to great extent. By treating APTES with aluminium nanoparticles, improvement of the interaction and dispersion properties were seen. Along with that, various mechanical properties also got improved specially tensile strength due to presence of Silane treated nanoparticles [47].

- **G. Seshanandan et. al.** used hand lay-up method to manufacture jute- glass FRP. Here mechanical characteristics were investigated for fiber reinforced plastics which are mixed with titanium oxide nano particles and jute- glass fiber. The results observed were great mechanical, properties such as tensile, shear and flexural [48].

## 3. Experimental Details

### 3.1 Equipment's required:

The machine and equipment's required for the fabrication of polymer hybrid composite is as listed below:

- Weighing machine
- Borosil glass beaker
- Magnetic stirrer
- Ultrasonic bath
- Mechanical stirrer
- Mild steel plate die
- Mild steel shoulder die
- Universal testing machine

Raw materials required:

- Nano silica particles in powdered form

- Polyester resins
- Wild date palm fiber in the form of woven mat
- Hardener (methyl ethyl ketone peroxide)

### 3.2 Work Plan

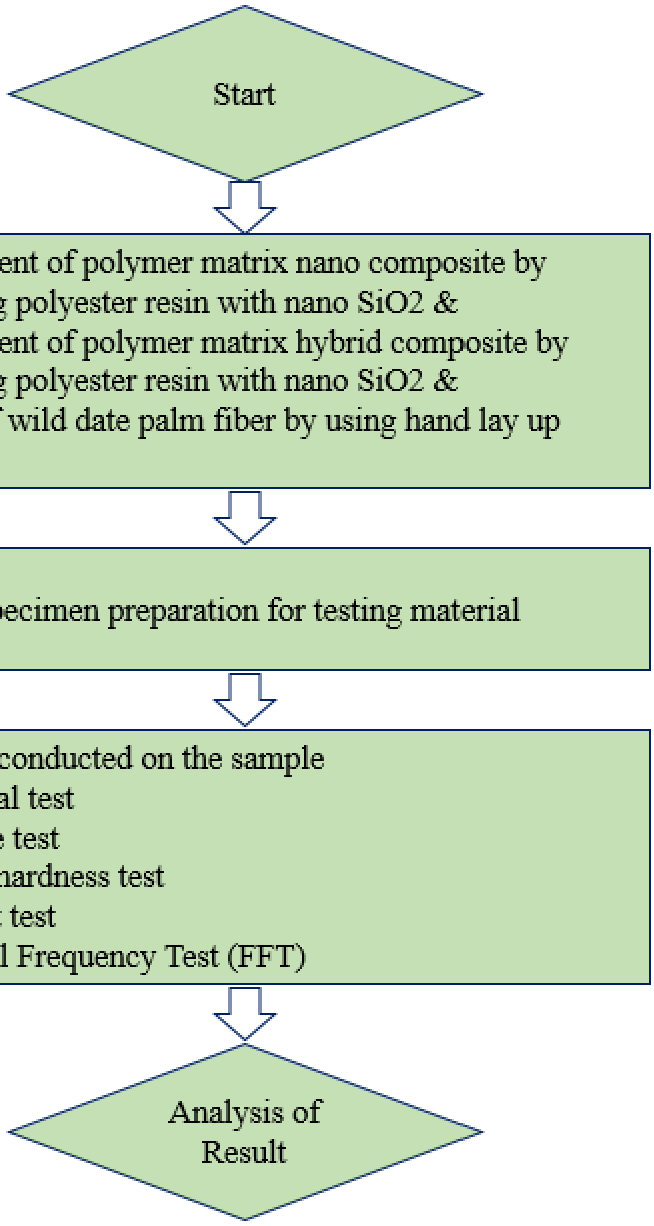


**Figure 3.1 Work plan**

**3.3 Flow Chart for the Preparation of Polymer Matrix Nano Composites**

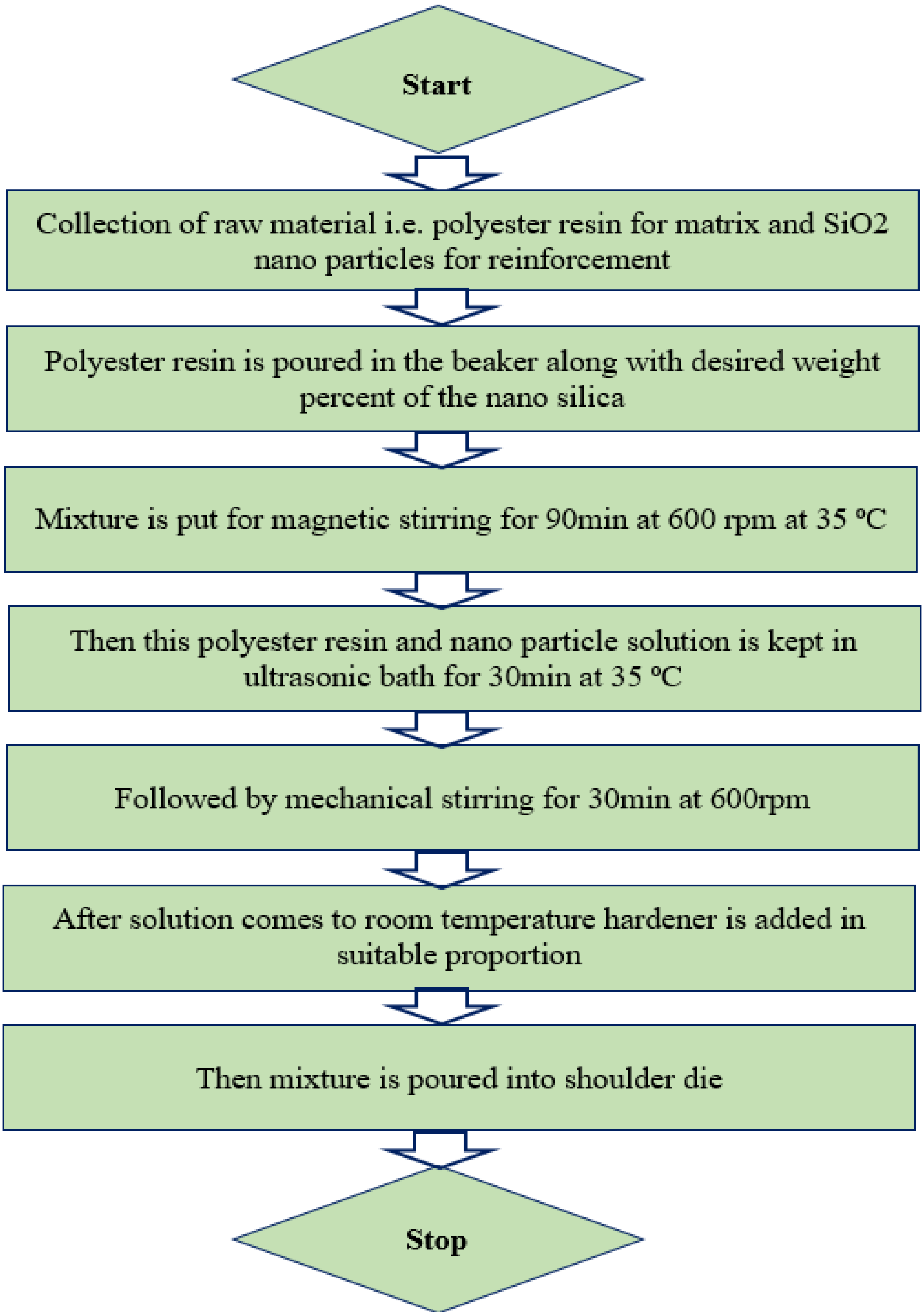


**Figure 4.2 Steps involved in preparation of polymer matrix nano composite**

### 3.4 Flow Chart for the Preparation of Polymer Matrix Hybrid Nano Composites

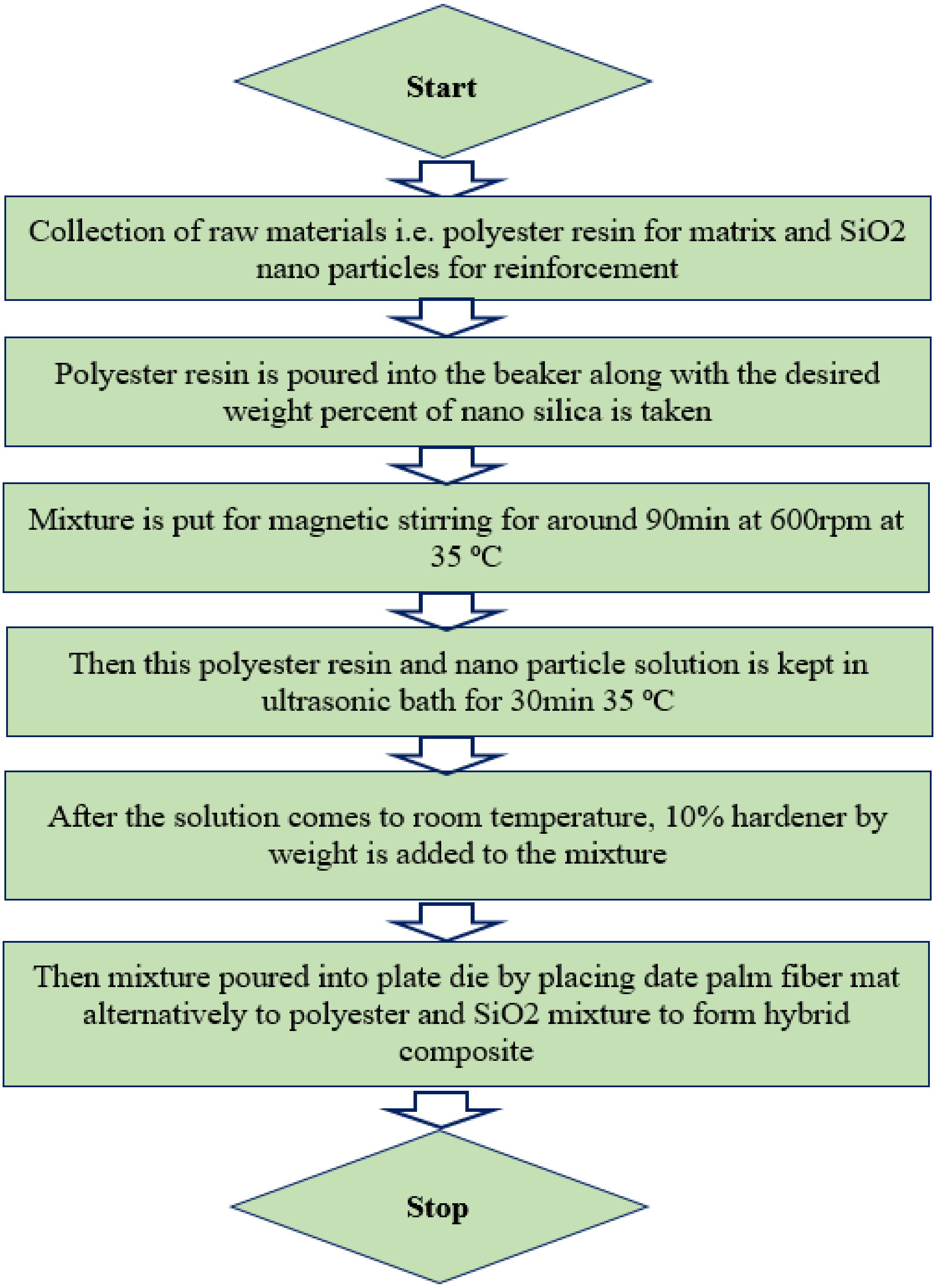


**Figure 4.3 Steps involved in preparation of polymer matrix hybrid nano composite**

## 4. Results and Discussion

### 4.1 Tensile Test Observations

Following graphs below depicts the load vs. extension plots of various composition variations as well as orientations. It could be seen clearly over here is each and every change in wt% of $SiO_2$ as well as orientation of fiber leads to comprehensive changes in ultimate load as well as extension.

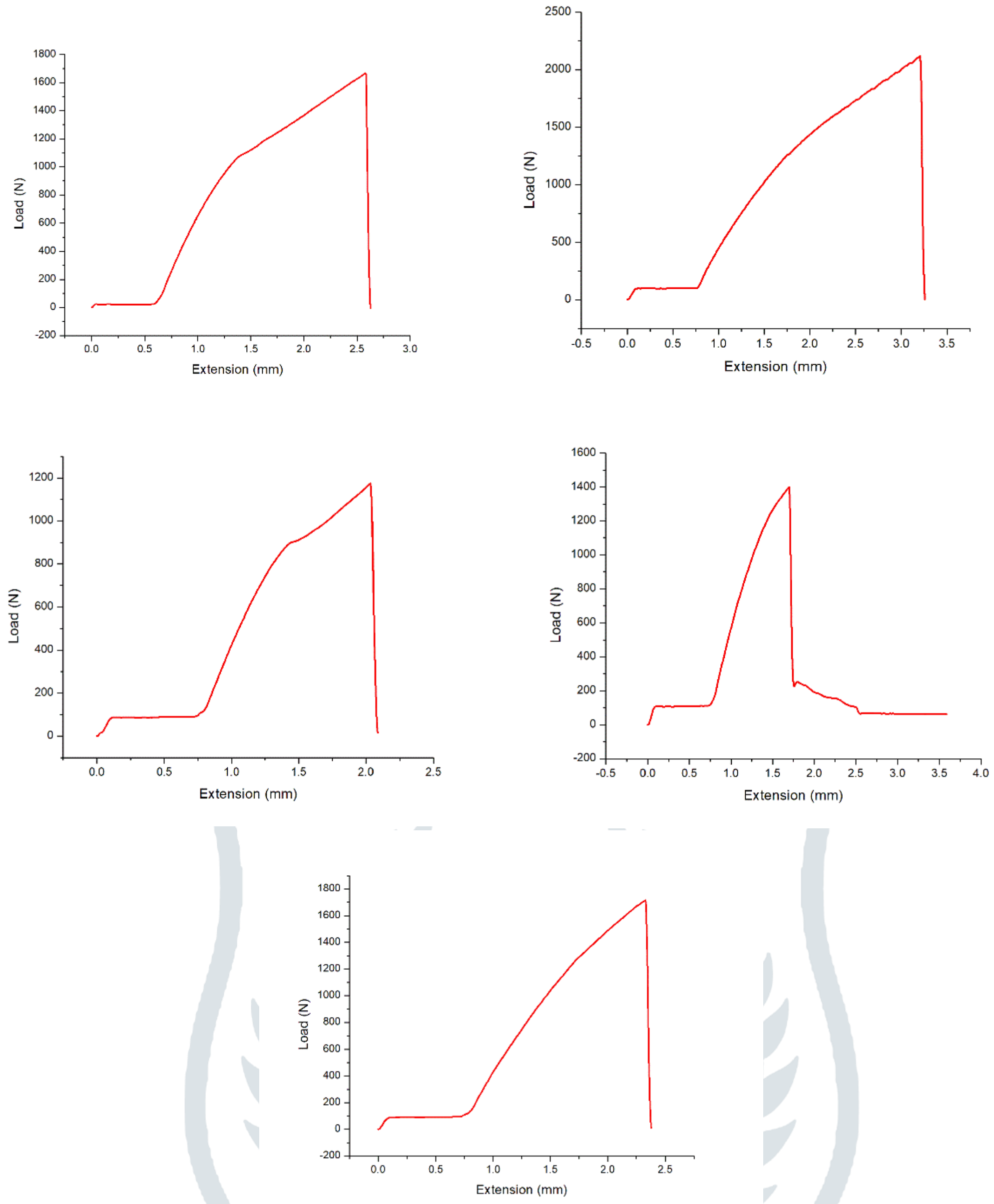


**Figure 4.1 Load variation with extension at individual composition and variation**

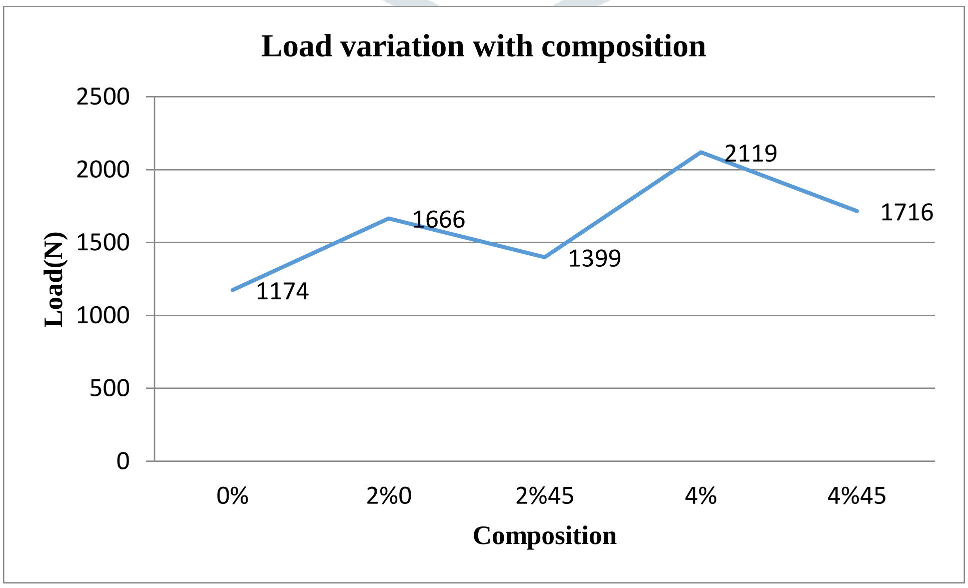


**Figure 4.2 Load variation with composition**

As shown in figure 4.2,in tensile strength properties, maximum load (N) increaseswithincreaseinwt%ofnano fillerstill2wt% andthendecreases at 2%45° and then further increases till 4%0° and then a sharp decline at 4%45.

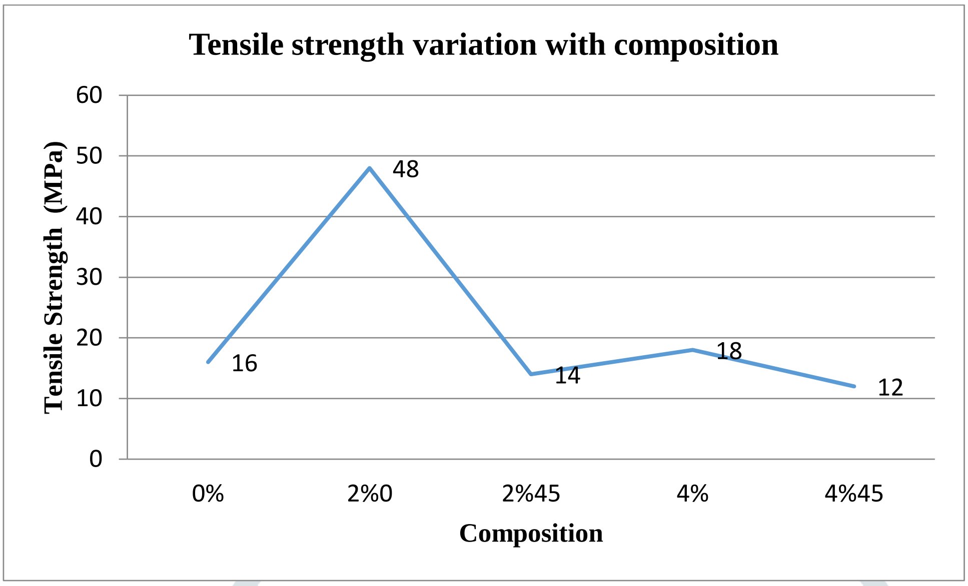


**Figure 4.3 Tensile strength variation with composition**

As shown in figure 4.3, tensile strength (MPa) increases with increase in wt% of nano fillers till 2 wt% and then decreases due to segregation of nano particles at higher weight percent.

### 4.2 Flexural strength variation with composition

Following graphs below depicts the flexural load vs extension plots of various composition variations as well as orientations. It could be seen clearly over here is each and every change in wt% of SiO2 as well as orientation of fiber leads to comprehensive changes in ultimate load as well as extension.

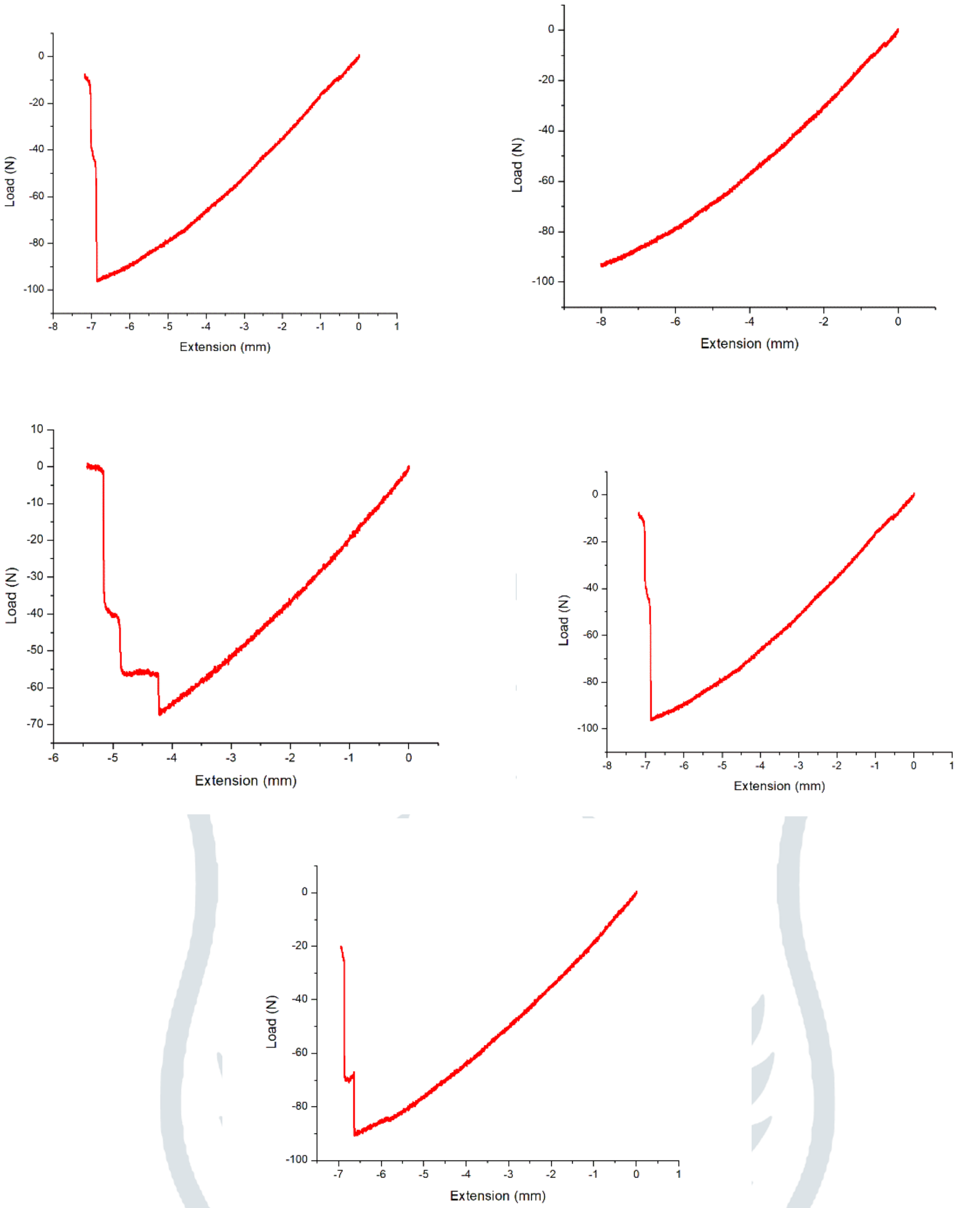


**Figure 4.4 Flexural Test Load v/s elongation curves**

Fig. 4.4 (a-e) represents flexural Load v/s extension graphs of individual compositions and orientations

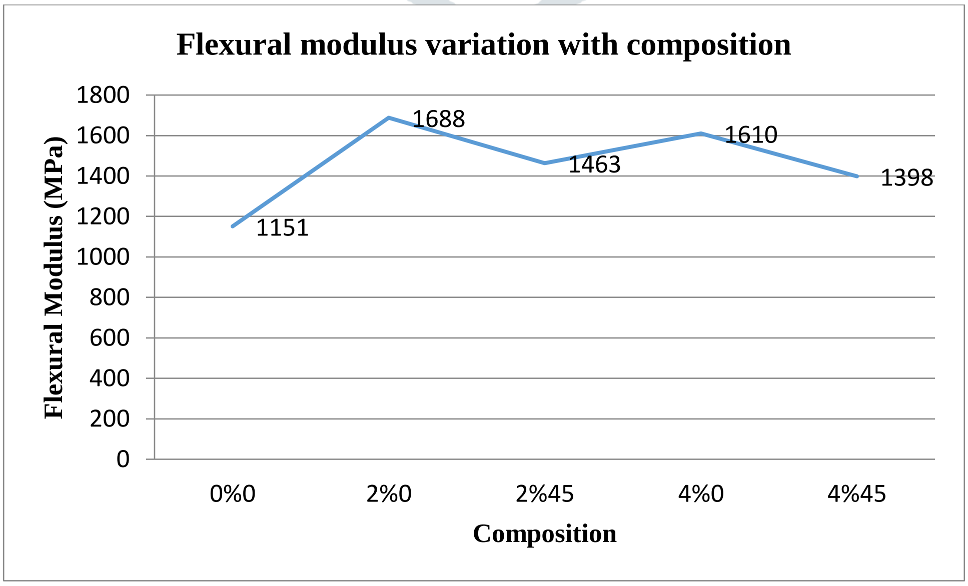


**Figure 4.5 represents flexural modulus variation with composition and orientation**

Figure 4.5 shows variation of flexural modulus with wt% of nano $SiO_2$ as well as fiber orientation. Flexural modulus increases till 2% 0º orientation and after that there is a fast decline at 2% 45º, this may be due to inhomogeneities caused by hand layup method at the time of fabrication. On further increment in wt % of nano $SiO_2$ there is an increment in Flexural modulus but the value is much lower compared to 2%0 suggesting that there is segregation and formation of bundles of Nano particles at higher wt%.

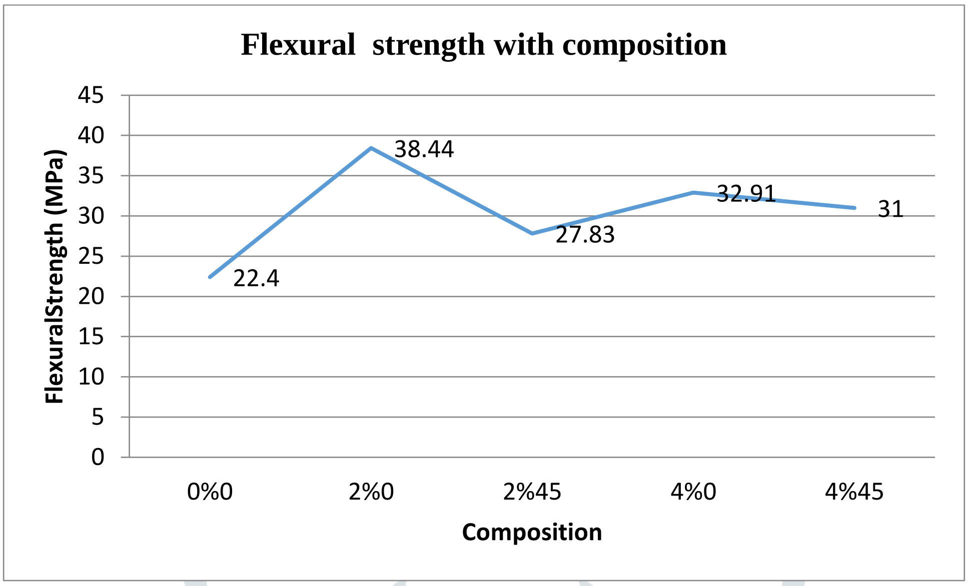


**Figure 4.6 represents flexural strength with composition and orientation.**

Figure 4.6 shows variation of flexural strength with wt% of nano $SiO_2$ as well as fibre orientation. Flexural strength increases till 2% 0º and after that there is decline at 2% 45, this may be due to inhomogeneities caused by hand layup method at the time of fabrication. On further increment in wt % of nano $SiO_2$ there is an increment in Flexural load and strength but the value is much lower compared to 2%0 which is due to segregation of Nano particles at higher wt%.

### 5.3 Impact strength with composition

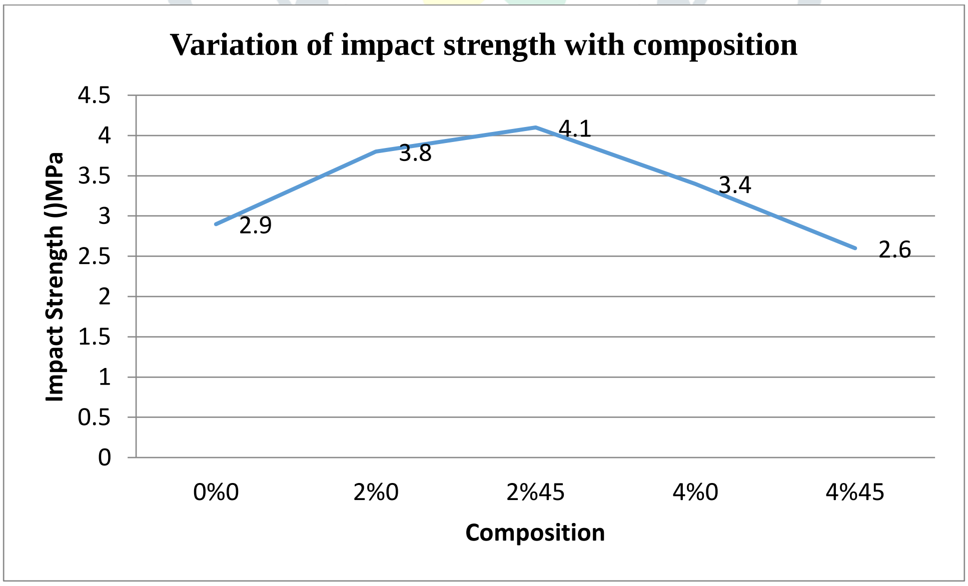


**Figure 4.7 Variation of impact strength with composition**

Figure 4.7 shows variation of impact strength with wt% of nano $SiO_2$ as well as fiber orientation. Impact strength increases till 2% 0º and further increase 2% 45. On further increment in wt % of nano $SiO_2$ there is a decrease which is due to segregation of Nano particles at higher wt% and the bundles of nano particles become the site of crack initiation.

### 4.4 Impact energy with composition

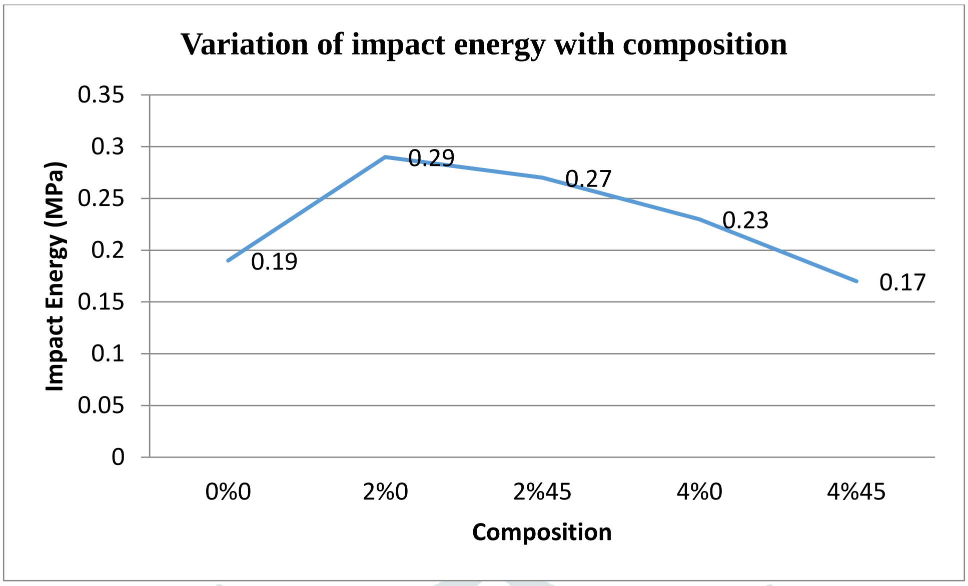


**Figure 4.8 Variation of Impact energy with composition**

Figure 4.8 shows variation of impact energy with wt% of nano SiO2 as well as fiber orientation. Impact energy increases till 2% 0º and after that there is a slight decrease in 2% 45, this may be due to inhomogeneities caused by hand layup method at the time of fabrication. On further increment in wt % of nano SiO2 there is further decrease Impact energy suggesting that there is segregation of Nano particles at higher wt%.

### 4.5 Hardness with composition

As shown in figure 4.9 hardness is found to increase continuously with increase in wt% of nano silica. This is due to the fact that the nano particles causes hinderance to indentation load, resulting in decrease in size of indentation mark during hardness test.

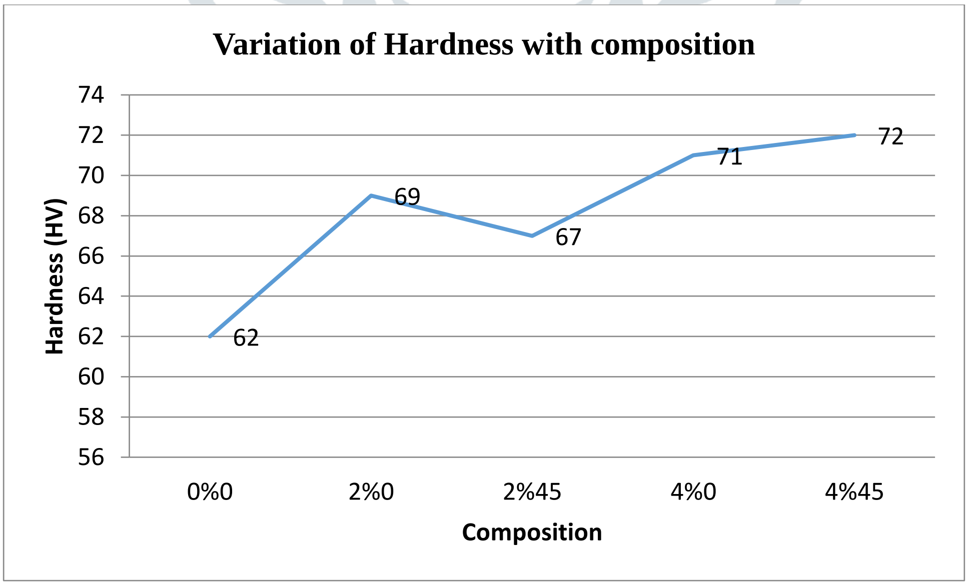


**Figure 4.9 Variation of Hardness with composition**

### 4.6 Results of Natural frequency test(FFT)

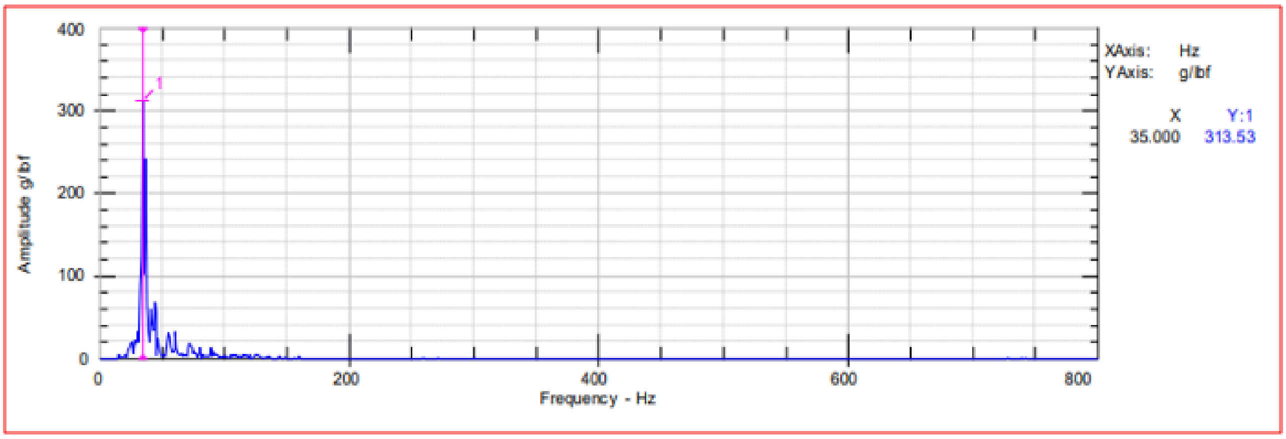


**Figure 4.4 Graph showing variation of Amplitude (g/br) vs Frequency (HZ) w.r.t to different wt% of nano SiO2 in both PMC and Hybrid Composite with 2 layers of wild wild date palm**

## Conclusion:

Based on the results obtained, the following conclusions can be drawn.

- Another new class of polymer composites that use other natural fillers.
- Investigate the effects of other wear modes such as sliding, wear, and erosion on the same composite.
- Examine the thermal behavior of fabricated composites, as natural fillers are known to be inherently insulating.
- The strength and properties of the composite are enhanced by a two-layer palm fiber (WDPF) hybrid composite reinforced with polyester resin and nanoSiO2.
- Sonication with an ultrasonic bath correctly disperses the nano silica particles in the polyester resin.
- From the Izod impact tests, it can be concluded that the impact resistance increases until the nano silica content in the hybrid polymer matrix composite reaches 2 wt% and then gradually decreases.
- Tensile tests concluded that the tensile strength increased up to 2 wt% nano silica in the hybrid polymer matrix composite and gradually decreased.
- The flexural tests conclude that the flexural strength increases until the nano-silica content in the hybrid polymer matrix composite reaches 2% by weight and then gradually decreases.
- From the hardness test, it can be concluded that the hardness value increases with increasing wt% SiO2.
- Inadequate mechanical properties were observed at the 45° orientation. This is because only one layer of fibers is accessible in the direction of the load, while the other layer is angled at a 45° angle, which reduces reinforcement in the direction of the load.

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