



# Estimation of Thermal and Mechanical Properties of Clay and Titanium Oxide Epoxy Hybrid Nanomaterials

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**Abstract:** Today's composite materials are often optimized to achieve the right balance of properties in an application. As the properties of composites are affected, significant efforts have been made to improve the properties of these materials by modifying them at the nanoscale. For this reason, composite materials are filled with nanomaterials to achieve better performance. In this research, clay-epoxy nanocomposites are produced from different materials and have different properties. Tensile and flexural strength were evaluated on universal testing machine, and hardness was evaluated on a Vickers hardness tester. The best results of strength and hardness were obtained using 2% by weight nanoclay composition. Then, different amounts of TiO<sub>2</sub> were added to fix 2 wt.% nanoclay. It was observed that the prepared epoxy hybrid nanocomposites had improved mechanical and thermal properties.

**Index Terms** - Clay, epoxy, elastic modulus, flexural strength, nanocomposites, tensile strength, titanium oxide (TiO<sub>2</sub>)

## I. INTRODUCTION

Composite materials are products formed by combining two or more materials with different physical or chemical properties that are separate and distinct at the macroscopic level in the finished structure. Composites are macroscopic combinations of two or more different materials, the differences between which are defined. In composite materials, the two phases are the matrix phase and the reinforcement phase. When the matrix material used is a polymer, the composite material is called polymer nanomaterial. Polymers are the best materials because they are easy to process, lightweight and require mechanical properties. Composite materials are used not only for their intended purpose but also for electrical, thermal and environmental applications. Modern materials such as composites are often optimized to achieve the right balance of components in an application. However, as a practical term, composite materials can be referred to materials containing strong, solid, continuous components that bond together and give the product with a balance of the material's properties. Although composites like other materials (including high-performance models) can be made from different types of components that meet the standard definition, the composite material created for the model has been shown to work well in other workplaces as well. The simple interpretation of the composition formula therefore provides a useful summary for many of the products available. [1] Composites generally have a fiber or particle phase that is harder and stronger than the continuous matrix phase. The term "organic-based composites" is generally considered to include two types of composites: polymer-based composites (PMC) and carbon-based composites (often called carbon-carbon composites). Carbon-based composites are often made from PMC with the additional step of carbonizing and densifying the original polymer matrix. In the R&D community, intermetallic matrix composites (IMCs) are sometimes specified under a different classification than MMCs. However, basic commercial applications of IMC do not yet exist, and in a sense these materials do not have completely different properties from MMC. In all of these systems the matrix is generally a continuous phase throughout the assembly. The interface is the interface between the additive material and the matrix material. When there is an interface, there must be two interfaces on either side of the interface and its associated objects. These two types of materials are also called two-level composite materials. These two levels are given below.

### 1.1 Matrix Phase

The main phase with fixed properties is called the matrix. The matrix is generally the more ductile, less rigid phase. It fits the dispersed phase and distributes the charge with it. The various functions of the matrix phase are as follows: (i) the matrix material holds the fibers together. (ii) Protect fibers from environmental influences. (iii) Easy load distribution (iv) Improves the properties of the laminate. (v) It increases the impact and breakage resistance of the product. (vi) It carries the shear between layers.

### 1.2 Dispersed (Reinforced) Phase

The second phase (or phase) is embedded in the matrix in a discontinuous form. This second phase is called the dispersion phase. The dispersed phase is generally stronger than the matrix and is therefore sometimes referred to as the reinforcement phase. Various functions of additives are as follows: (i) It gives energy to the mixture. (ii) Tighten the skin. (iii) Offer similar products. (iv) Provide elements that the source element does not have.

### 1.3 Nanocomposites

The definition of nanocomposites is that the size of the matrix or reinforcement material is in the nanoscale range. The physical properties and properties of nanocomposites can vary greatly from material to material. According to the matrix type, nanocomposites can be divided into ceramic-based nanocomposites, metal-based nanocomposites and polymer-based nanocomposites.[2] Nowadays, polymer composites need extensive research because there is a need to improve the body and strength of polymer materials in many areas of today's economy.

Polymer nanocomposites (PNCs) are polymers (thermoplastics, thermosets, elastomers) added with small amounts (less than 5 wt.%) of nanoparticles. There is no molecular interaction between the polymer and nanofillers. The space between nanoparticles in the polymer matrix creates a very large interfacial area per unit volume between the nanoparticles and the host polymer. The large internal space and nanoscale dimensions of nanoparticles fundamentally differentiate PNC from conventional composites and plastic containers. The incorporation of nanoparticles into the polymer matrix provides a very low loading efficiency. The most common nanofillers are Montmorillonite organoclay (MMT), Carbon nanofiber (CNF), Carbon nanotube (CNT) and Metal Nanoparticles. The need acquiring PNC technology is that it provides additional properties that pure polymers do not have, without compromising the performance and properties of polymer materials. Some of the main advantages of polymer nanocomposites are:

- High adhesion of nanoparticles to the polymer matrix increases the strength of nanocomposites compared to the original material.
- As the size of nanoparticles decreases, the size of nanocomposites also decreases. Voids form where the matrix is exfoliated by the filler. This also leads to greater effort.
- Adding small amounts of nanoparticles to polymers can improve the adhesion of the polymer to different materials.

## II. LITERATURE REVIEW

Polymer composites are widely used in materials such as the aerospace, automotive, marine and sports industries due to their attractive properties, fatigue and corrosion resistance, as well as their light weight and particularly high density. Tension and power. We conducted a comprehensive literature review to determine the research question. Most studies have been conducted to characterize composites by adding nanofillers to the matrix system. The next section describes the literature review. Meskoff et al. (2003) investigated the effect of montmorillonite concentration and temperature on the curing rate and mechanical properties of composites. The addition of clay to the epoxy-amine curing agent affects the curing reaction. The presence of clay increases the modulus of the glassy and rubbery area. Clay produces a second peak at higher temperature; This is due to the formation of a polymer layer on the clay surface with limited movement. The addition of fine clay improves the tensile properties of the epoxy system. Brenner et al. (2006) investigated whether nanomodified epoxy resin matrices could produce better delamination in fiber laminates compared to laminates with thin epoxy resin as the matrix material. For nano-modified epoxy resins prepared by adding 10% by weight functionalized organosilicate clay and many other materials, approximately 40-50% increase in fracture toughness and 10-20% increase in energy release, close to pure epoxy resin, were observed. The properties of the nanomodified epoxy resin were improved, for example, more than 50% increase in tensile and compressive modulus was observed. The most special thing by far is the ultimate tensile strength, elongation at break and glass transition temperature, which are all reduced.

Chowdhury et al. (2006) produced epoxy-modified woven carbon/epoxy laminates using Nanomer I-28E nanoclay (different weight of organic modified clay). Thermomechanical and bending strengths of nanophase composites were determined and compared with control samples. Microstructure characterization was performed by scanning electron microscopy. The results showed that the bending test results of the samples after thermal treatment showed the highest strength and structure, at approximately 31% and 21%, respectively. From the DMA results, it can be seen that the samples continue to increase for different weight percentages. Therefore, the change in mechanical properties is due to the physical properties of the nanoclay rather than changes in the structure of the polymer network. Moreover, 2 wt.% nanoclay appears to be the best filler for carbon/SC-15 epoxy composites in terms of mechanical and thermal properties. Microstructural studies show that nanoclay promotes good adhesion between fibers and matrix, thus improving all properties. Lee et al. (2007) replaced the epoxy resin with nano-SiO<sub>2</sub>, standard SiO<sub>2</sub> particles with diameters of 30–40 nm and 3 μm, and γ-glycidoxypropyltrimethoxysilane. As shown in the infrared spectrum, stable bond is formed between nano-SiO<sub>2</sub> and epoxy resin by γ-glycidoxypropyltrimethoxysilane. Thermogravimetric analysis showed that the impact strength and volume index, initial decomposition temperature, impact strength and volume resistance of the epoxy resin-based composite material first increased and then decreased. After the nano-SiO<sub>2</sub> content reaches 4 wt.%, the low and optimum value is 323 °C, 89.2 kJ m<sup>-2</sup>, and 3.56 × 10<sup>14</sup> Ω cm, and similar behavior is also observed in the standard SiO<sub>2</sub>/epoxy matrix composite; the best is 308 °C, 17.13 kJm<sup>-2</sup> and 2.80 × 10<sup>14</sup> Ω cm. SEM analysis shows that when the content of nano-SiO<sub>2</sub> and standard SiO<sub>2</sub> reaches 4 wt.%, the toughness of nano-SiO<sub>2</sub>/epoxy resin-based composite materials and standard SiO<sub>2</sub>/epoxy resin also first increases and then decreases. Kim et al. (2008) mixed nanoparticle additives such as carbon black and nanoclay with epoxy resin to increase the fracture toughness of epoxy resin. Fracture toughness is measured at room temperature (25°C) and low temperature (-150°C) using single-sided notched bending specimens. The results showed that nanoparticle supplements increased bone strength at room temperature, but reduced bone strength at low temperatures despite the toughening effect. In case of using nanoparticle reinforced matrix in composite laminates, interlayer fracture toughness and properties can be improved at room temperature, while unreinforced epoxy can offer better properties at low temperatures. Fu et al. (2008) studied and discussed the effects of particle size, particle/matrix interfacial adhesion, and particle charge on the hardness, strength, and toughness of such particulate polymer composites. An important understanding of the hardening, strengthening and toughening mechanisms of composites required for the development of high-performance particulate composites is discussed. Experimental results are compared with theoretical and experimental results. Uddin and Sun (2008) developed a method to increase the strength of unidirectional composites through nanoparticle infusion to improve matrix properties. To fabricate the fiber material, a commercial product containing a standard DGEBA epoxy resin containing silica nanoparticles (Nanopox F 400) as the matrix was used, and the silica nanoparticles in Nanopox were grown in situ by a sol-gel

process. in amounts of up to 40% by weight and is then used to produce fibres. Dilute to 15% particle loading by weight. After the experiment, the TEM image showed that the silica nanoparticles were highly dispersed with a particle size of 20 nm. Compression testing showed that the elastic modulus of the modified epoxy resin increased significantly (40%). Finally, the compression test results were analyzed using the micro buckling model. Xu and Hoa (2008) prepared epoxy resin/clay nanocomposites (ENC) made of TGDDM epoxy resin and montmorillonite nanoclay and produced carbon fibers through thermal fusion layer and autoclave process. Reinforced epoxy resin/clay nanocomposite (CFRENC). After adding 4 parts of nanoclay to the epoxy resin, the interlayer fracture toughness of CFRENC increased by 85%. Adding a small amount of nanoclay (2 parts) to the epoxy resin of carbon/epoxy composites can increase the flexural strength by 38%. Sundaram et al. (2008) prepared nanocomposite FRP by combining polyester resin, alkali-free glass fiber and nanomontmorillonite (nanoclay) and examined the properties of the nanocomposite. The tensile behavior of various combinations of experimental nano-FRPs was examined at room temperature at a value of 0.833. This results in a slight increase in tensile strength, elongation and yield strength, Poisson's ratio and a decrease in area. Hilder et al. (2010) research shows that fiber-reinforced composite materials are indispensable in today's lightweight construction areas such as aerospace and automotive industries. In general, an increase in product viscosity and batch size leads to an increase in the strength of the dispersion process in agitation mills and three-roll mills. As the alumina content in cured alumina-epoxy resin composites increases, Young's modulus and fracture strength increase, while fracture stress decreases. Kuilla et al. (2010) reviewed the progress in graphene modification and production of graphene-based polymer nanocomposites. The analysis shows that graphene produces improved performance at very low concentrations. Modification of graphene/graphene oxide and the use of this material in the preparation of nanocomposites with different polymer matrices. Mimohseni and Zavareh (2010) developed an epoxy-based nanocomposite hardened with a combination of thermoplastic, layered and particulate nanofillers, with the main purpose of adding poly(acrylonitrile-co-Butadiene-co-styrene). By adding clay (layer nanofiller) and nano-TiO<sub>2</sub> (granular nanofiller) to the epoxy matrix, nanocomposites with high impact strength and low-cost quaternary materials and other materials such as tensile strength can be obtained without impact. Taguchi method was used to optimize the nanocomposite composition, and the results showed that the quaternary nanocomposite with the best composition exhibited the largest impact and tensile strength, increased by 168% and 64%, respectively, and the Synergistic effect was found from XRD. and by SEM technology, the distribution of clay nanolayers, TiO<sub>2</sub> and ABS nanoparticles in the epoxy resin matrix was obtained as the morphology of quaternary nanocomposites.

Ayetullahi et al. (2011) investigated the effect of multi-walled carbon nanotubes (MWCNTs) on the mechanical properties of epoxy/MWCNT nanocomposites, focusing on fracture toughness under bending and shear loading conditions. Various finite element (FE) analyzes were performed to determine appropriate shear load limits for single-sided notched flexural specimens (SENB). Scanning electron microscope (SEM) images were taken from the bone to examine the fracture, and there was a correlation between the characteristics of the fracture and the mechanical behavior observed on bone examination. O et al. (2011) performed TGA and mechanical tests and evaluated the effect of nano-CaCO<sub>3</sub> on the thermal and mechanical properties of epoxy resin castings. By preparing the KH550/nanoCaCO<sub>3</sub> masterbatch, the silane coupling agent KH550 was incorporated as a substitute for the nanocomposite; The results showed that the castable epoxy resin containing nanoCaCO<sub>3</sub> particles had higher thermal stability and the overall strength. This improvement is due to the surface modification of the nanoparticles, which improves the bonding properties of the nanoCaCO<sub>3</sub> filler and epoxy resin. The results showed that the mechanical properties of nano-CaCO<sub>3</sub>/epoxy resin/carbon fiber composites based on modified epoxy resin matrix were also improved. (2011) obtained new epoxy-modified phosphazene nanotubes (EPPZT) in two simple steps, prepared EPPZT/epoxy resin composites and used them to reinforce the epoxy resin matrix. Mechanical tests were performed and the results showed that the mechanical properties depend on the degree of dispersion of EPPZTs in the matrix. A thermal stability test was also performed and the results showed that the addition of EPPZT increased the residual load and reduced the weight. Chen et al. (2012) created hybrid multiscale composites using vacuum-assisted molding technology using glass microfiber fabric and nano-epoxy resin containing electrospun glass nanofibers (EGNF), and it was thought that after the incorporation of EGNF into the epoxy resin. By dispersing a small amount thereof, the mechanical strength (especially the out-of-plane mechanical strength) of the resulting hybrid multiscale composite product is significantly improved. Interlayer shear strength, bending strength, impact absorption strength and tensile strength of the composites were evaluated. The properties of nano-epoxy composites containing 0.25 wt% EGNF were improved. Ionita (2012) performed atomistic and mesoscopic simulations and predicted the effect of single-walled carbon nanotube (SWCNT) diameter and weight ratio on the mechanical behavior and glass transition temperature (T<sub>g</sub>) of SWCNT-reinforced epoxy composites. The results show that the addition of SWCNTs with a diameter of 10 to 14× has a positive effect on processability and glass transition temperature (T<sub>g</sub>). Alamri and Low (2012) studied the effect of water absorption on the mechanical properties of epoxy nanocomposites reinforced with nanofiller and investigated the effect of nanofillers such as nanoclay sheets, HNT and n-SiC on the strength of epoxy impact of mechanical equipment. Nanocomposites. Also, the effect of mechanical properties and problems of epoxy-based nanoclays on the compressive stress-strain behavior and compressive strength of Epicoate 828 polymer was studied. It was found that the compressive strength depends on the removal of clay nanoplatelets in the epoxy resin, and the decrease in compressive strength was noted for 1 wt.% and 3 wt.% nanoclay. This may occur due to intercalation structure of the nanoclay causing surge in pressure in the area in the matrix during compression leading to premature failure.

### III. PROBLEM FORMULATION

From the thorough review of the literature, it can be stated that it is necessary to create a combination in which nanoparticles are added to obtain the desired product without intervention. The addition of nanoparticles can improve the properties of nanocomposites. It is possible to find extensive studies in the literature on the addition of different materials to the mixture and their effects on mechanical properties. However, not much work has been done on the effect of adding nanoparticles (e.g. TiO<sub>2</sub>) to epoxy resin along with nanoclay on the properties of polymer nanocomposites. Therefore, the current work is to add nanoclay and titanium dioxide to create polymer nanocomposites and test the product to find different properties.

#### IV. METHODOLOGY

The research work focused on estimation of thermal and mechanical properties of hybrid nanoparticles. The methodology followed and different apparatus used for the experimentation is shown in Fig.1

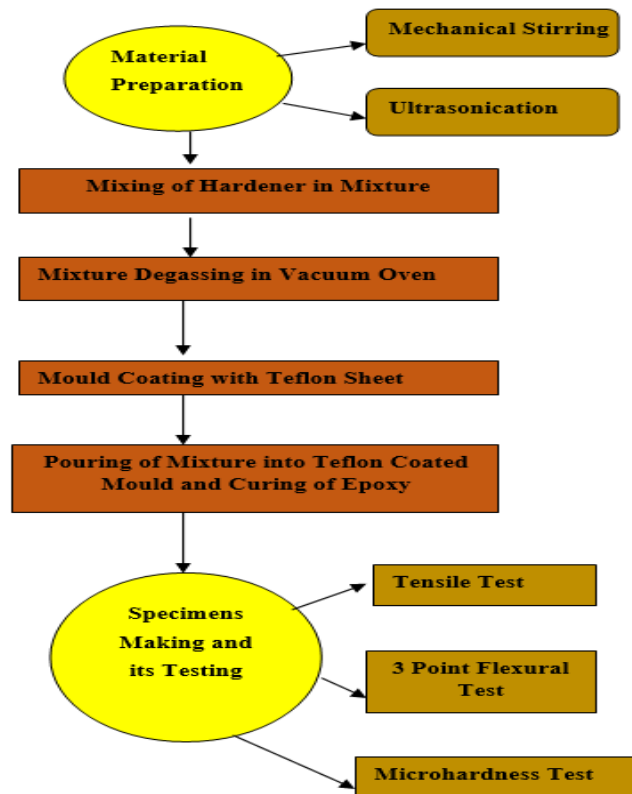


Fig.1 Research Methodology

#### 4.1 Materials Procurement

The present research work is based on Epoxy Nanocomposites fabrication. The materials used are DGBA-based Epoxy Resin L12, Amine-based Hardner K12, and Accelerator K13 supplied by Atul Ltd., Gujrat, India. TiO<sub>2</sub> (Degussa P-25), which was 99% pure and size less than 20 nm, was supplied by Degussa company, Frankfurt, Germany. It has a BET surface area of 50+15 m<sup>2</sup>/g and is 80% in anatase crystal form and 20% rutile with an average particle size of 30 nm. Organically modified Nanoclay Cloisite 30B was supplied by Connell Bros., Mumbai, India.

#### 4.2 Material Preparation

The Nanocomposites were prepared by following a standard procedure after an intense study of the literature. There are many methods for the preparation of nanocomposites, the one used in the present work is the Hand Layup Method. For the preparation of the specimens various types of apparatus and types of equipment were used i.e., Borosilicate beakers, electronic weight Machines, Mechanical stirrers, Water Bath Sonicator, etc. Different steps used for material preparation are given below:

##### 4.2.1 Mechanical Stirring

The epoxy base is transparent in colour and thick fluid. It is quite difficult to mix nanoparticles into it manually. So a mechanical stirrer is used for the proper mixing of Nanoclay as shown in Fig.2. Mechanical stirring was done for two hours at 2000 rpm. Different weight percentages of clay - 0, 1, 2, 3, and 4 % by weight of epoxy, were added and stirred for 2 hours

##### 4.2.2 Ultrasonication

Mechanical stirring was followed by Ultrasonication. Sonication is the process in which sound energy is applied to agitate particles in a sample. In the laboratory, it is usually carried out using an ultrasonic bath (shown in Fig.3) known as a sonicator. Sonication can be used to speed dissolution, by breaking intermolecular interactions. Sonication was done for evenly dispersing nanoparticles in liquids. After mechanical stirring the epoxy solution container was placed into the ultrasonication bath for 2 hours.



Fig. 2 Mechanical Stirrer



Fig.3 Ultrasonication Bath



Fig.4 Cutting with Hacksaw Blade

#### 4.2.3 Mixing of Hardner

After Ultrasonication, the solution is mixed with the hardener in a ratio 1:1 by weight, and a 1% accelerator is also added as per the instructions of the epoxy system resin. After mixing, mechanical stirring was done for 15 minutes, followed by ultrasonication for 15 min which results in proper dispersion of nanoparticles.

#### 4.2.4 Degassing and Fabrication of Nanocomposite

After the sonication process, a large number of bubbles were present, which can cause defects in the samples and can lead to negative results. To remove the bubbles degassing was done in a vacuum oven for 1 hour. The bubble-free mixture was then poured into the Teflon-coated mould and dispersed with the help of a steel scrapper.

A commercially available aluminum plate was used to make the mould for the samples. The aluminum plate was coated with the Teflon sheet (1 mm thick), so the cured samples were easily removed from the mould. The full curing of the sheet was done by leaving it for one day at room temperature and then curing at 1200 C for 2 hours.

#### 4.3 Specimen Preparation

Once the Epoxy was fully cured, the prepared sheet was manually cut into the specimen as shown in Fig.4. The size of the specimens was as per ASTM D638 and ASTM D790 for tensile and bending tests respectively

#### 4.4 Mechanical Properties Testing

The following mechanical properties were tested from the prepared samples.

##### 4.4.1 Tensile Strength Testing

A Universal Testing Machine (UTM) shown in Fig.5, was used to find the strength of the prepared samples. The test specimens were prepared as per dimensions. The tensile test was performed with a test speed of 5mm/min and a preload of 0.1 MP



Fig. 5 Specimen in UTM



Fig.6 Specimen positioning in three-point bend test on UTM

#### 4.4.2 Three-Point Flexural Test

Three-point Flexural test of the specimen was carried out using UTM. The jaw setting on the UTM for the three-point flexural test is shown in Fig.7. The flexural test was performed with a test speed of 1%/min and a preload of 0.1 MPa.

#### 4.4.3 Micro Hardness Test

Micro hardness tests were conducted on the prepared samples using a Micro Hardness Tester, shown in Fig.7. Vickers' Hardness value was determined by applying a preload of 50gm. The Dwell time used during the load application was 20 seconds. With the application of load, an indent was formed on the surface of the prepared specimen. A view of one such indent is shown in Fig.6.



Fig.7 Micro Hardness Equipment

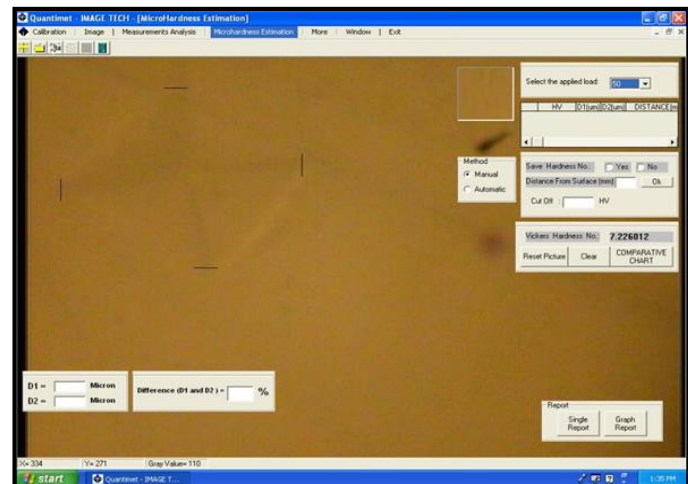


Fig.8 Indent of Specimen

The indent was marked on the different random points on the specimen to take the average hardness value as in Fig.8. The Hardness value was calculated from the marked indent.

## V. RESULTS AND DISCUSSION

### 5.1 Results of Experimentation

The different mechanical properties were tested on the prepared samples of Epoxy with variations of Nanoclay content. After experimentation, data was compiled and analyzed in the form of tables and plots.

Table 1: Tensile Strength

Clay/Epoxy (wt. %)	Tensile Modulus (MPa)	Tensile Strength (MPa)
0	119.97	8.97
1	92.18	12.13
2	81.19	12.93
3	55.09	13.2
<b>Average</b>	<b>66.81</b>	<b>11.8</b>

Table 2: Flexural Strength

Clay/Epoxy (wt. %)	Elastic Modulus (MPa)	Flexural Strength (MPa)
0	4679.67	77.41
1	4371.67	95.37
2	3147.66	137.67
3	3026	153.33
<b>Average</b>	<b>3806.25</b>	<b>115.96</b>

Table 3: Microhardness of Sample 1,2 and 3

Clay/Epoxy (wt. %)	1	2	3
0	6.48	6.32	6.48
1	6.52	6.71	6.54
2	6.89	6.59	6.63
3	6.51	6.48	6.35
<b>Average</b>	<b>6.6</b>	<b>6.525</b>	<b>6.5</b>

Table 4: Tensile Strength

Clay/TiO <sub>2</sub> (wt. %)	Tensile Modulus (MPa)	Tensile Strength (MPa)
0	81.19	12.93
2	148.67	13.13
<b>Average</b>	<b>114.93</b>	<b>13.03</b>

Table 5: Flexural Strength

Clay/TiO <sub>2</sub> (wt. %)	Elastic Modulus (MPa)	Flexural Strength (MPa)
0	3147.67	137.6
2	3806.67	132.7

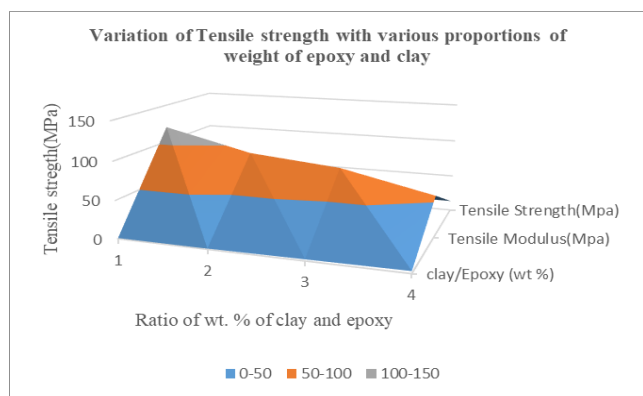
4	4371.66	126.4
<b>Average</b>	<b>3775.40</b>	<b>132.2</b>

Table 6: Microhardness of samples 1,2 and 3

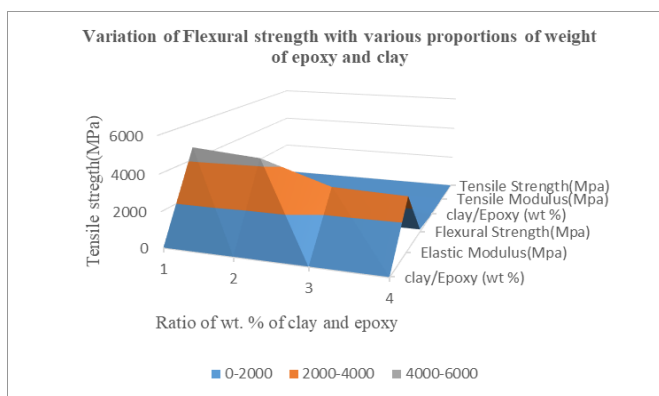
Clay/TiO2 (wt. %)	1	2	3
0	6.89	6.79	6.63
2	7.23	7.26	7.27
4	7.86	7.56	7.48
<b>Average</b>	<b>7.33</b>	<b>7.20</b>	<b>7.13</b>

### 5.2 Graphical representation of results

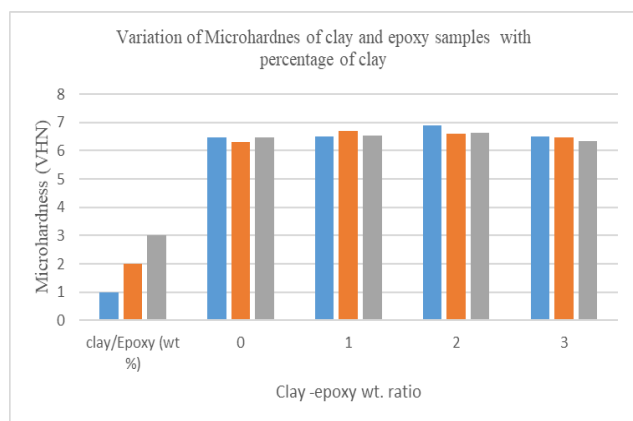
Graphs were plotted from results depicting the variation in properties with change in composition



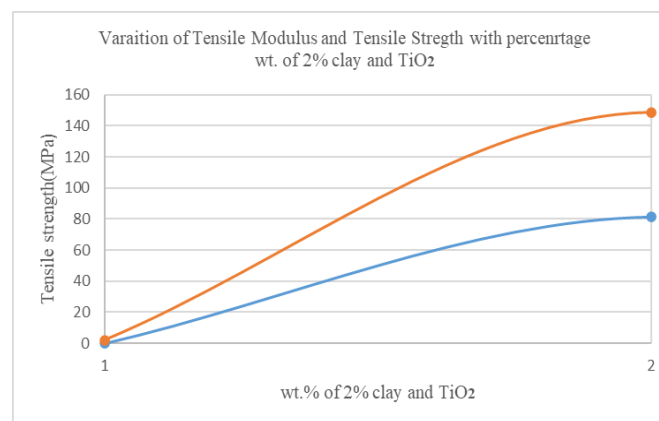
Graph 1: Tensile Strength variation with wt.%



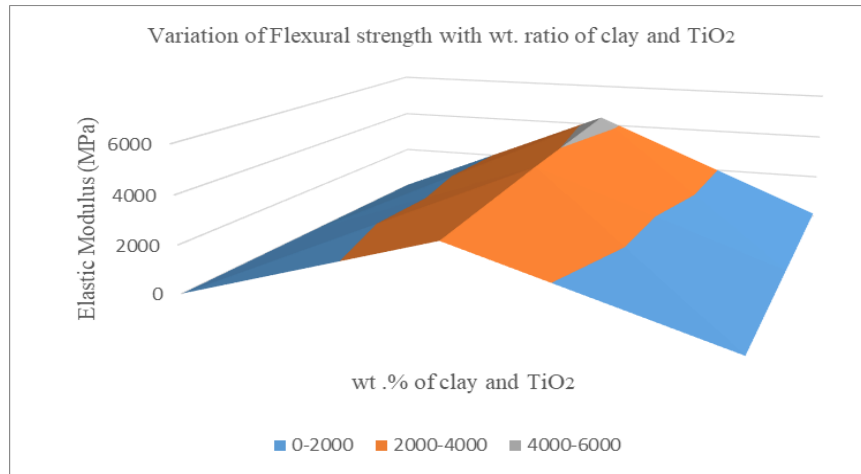
Graph 2: Three-point Flexure Strength variation with wt.%



Graph 3: Microhardness test for clay-epoxy wt. ratio



Graph 4: Tensile strength for clay -TiO<sub>2</sub> ratio

Graph 5: Flexural Strength of wt.% of clay and TiO<sub>2</sub>

## V. CONCLUSIONS

From the observation from the graph and tables obtained during experiment, following conclusions can be drawn :

- The tensile strength of nanoclay epoxy nanocomposite samples increases with the increase in wt.% of nanoclay, and the tensile strength increases when the nanoclay content is 2 wt.%. This strength is approximately 44% higher than pure epoxy nanocomposites. However, as the nanoclay content increases, the strength decreases. After optimization, different amounts of
- TiO<sub>2</sub> were added to 2 wt.% nanoclay-modified epoxy resin.
- With the addition of TiO<sub>2</sub>, the tensile strength of the nanoclay/TiO<sub>2</sub> epoxy nanocomposite structure increases and reaches the highest value when the TiO<sub>2</sub> content is 2% by weight. This maximum strength is slightly higher than that of nanoclay epoxy nanocomposites.
- The increase in the strength of the epoxy structure should result from the increase in the area of nanofillers. However, adding TiO<sub>2</sub> content has no significant effect on tensile strength.
- Flexural strength increases with increasing nanoclay content and reaches maximum strength when the nanoclay content is 2% by weight. The strength of the sample with 2 wt.% nanoclay content increased by 77% compared to the pure epoxy nanocomposite.
- The improvement in flexural strength is attributed to the improvement of interfacial energy, which is responsible for stress change and elastic deformation in the presence of clay nanoparticles. However, as the nanoclay content increases, the bending strength decreases. Additionally, bending strength decreases with the addition of TiO<sub>2</sub>. Therefore, the addition of TiO<sub>2</sub> does not have a significant effect on the bending strength of nanocomposites.
- As the nanoclay content increases, the Vickers hardness value also increases. Samples with 2% nanoclay content by weight have the highest hardness. However, as the nanoclay content increases, the hardness decreases significantly. Therefore, adding a small amount of nanoclay to polymer-based materials will increase the strength of the product.
- The hardness value can be increased by adding TiO<sub>2</sub> up to 2% TiO<sub>2</sub> by weight. However, as the TiO<sub>2</sub> content increases, the hardness value decreases. Therefore, a small addition of TiO<sub>2</sub> can increase the strength.

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