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Improving The Mechanical and Electrical Performance Of Composite Laminates By Including Nano-particles: Review Article

***Lina H. Ali*[1], *Farouk O. Hamdoon*[1], *Hussein K. Dalfi*[1], *Khayale Jan*[2]**

[1] Department of Mechanical Engineering, University of Wasit, Wasit, Iraq

[2]BZU College of Textile Engineering, Multan, Pakistan

Corresponding Author Email: Lina.haidar@uowasit.edu.iq

ABSTRACT

These days, researchers have focused on improving the mechanical performance of composite laminates owing to a broad range of their applications in fields like aerospace, military, civil, marine, etc. In this regard, efforts have been made to improve the mechanical and electrical properties of composite laminates by using nanoparticles. For developing high-performance composite laminates, the dispersion of nanoparticles in the composite laminates is significantly important; however, it remains a challenge. This review study focuses on strategies that have been adopted for developing appropriate chemical and physical methods to achieve controlled dispersion of nanoparticles in composite laminates. The effect of nanoparticles on mechanical properties such as tensile and impact strength, compression, and fracture toughness have been discussed thoroughly in this study. Further, this study proves that the addition of conductive nanoparticles to the composite laminates can change their dielectric properties and make them sensors for damage failures during applied loading.

Keywords: Nano-particles, nano-composites, mechanical properties, interfacial bonding strength, dielectric properties, conductivity

1. Introduction

Recently, polymeric nanocomposites have gained considerable attention in both industrial applications and nano-materials[1], [2] . It has been found that nanoparticles provide polymers with better electrical, mechanical and optical performance compared to micro- and macro- particles. For the manufacture of nanocomposites, homogeneous dispersion must be free of agglomerations in the polymer matrix and is very necessary for superior performance[3], [4]. Large aggregates of nanomaterials can cause stimulation of premature breakage of composite materials and stress concentrations [5], [6], [7]. The dispersion of nanoparticles is currently evaluated using transmission electron microscopy through the qualitative interpretation of microscopic images, which is a prerequisite for mass productions of nano-composites [5], [8]. Nanomaterials are having the ability to enhance different properties of polymers; for instance, by adding carbon nanotube to epoxy resin, the mechanical properties (i.e. tensile strength, Young's modulus and fracture hardness) are significantly increased[5] . Furthermore, the electrical properties of composite materials such as dielectric, conduction responses, and electromagnetic wave dissipation have been controlled by nanoparticles.

2. Dispersing Nanoparticles in a Polymer Matrix

Nanoparticles are considered the strongest and most durable support media for composite materials that have polymer matrices. As a result, nanoparticles with distinctive physical and chemical properties have gained significant attention in recent times**.** However, the higher interactions between nanoparticles and the challenge of controlled dispersion of nanoparticles in polymer matrices are limiting their application in composite materials [9]

Van Son et al. [10] used ultrasound to disperse AL_2O_3 and ZnO nanoparticles at different solution concentrations of organic solvents and polymer solutions. They adopted dynamic light scattering to measure the size of nanoparticles at diverse focus in both polymer solutions and organic solvents. It was found that in stable pendants, the smallest size achieved or the total size of nanoparticles was freelance of the solid content and solvent type at the tested scale. In addition, the nanoparticles in polymer solutions and simple solvents had identical cluster size development and almost identical final size, which was very useful for improving the dispersion of nano-fillers in nanocomposites and polymer solutions. It was shown that when suitable ultrasound amplitudes were used, the advanced dispersion execution of very dilute pendants could be transferred to concentrated pendants or even to polymeric pendants as shown in Figures 1 & 2. Figure 3 presents the SEM images of the nanocomposites; it was found that both Aluminum Oxide and Zinc Oxide nanoparticles were well distributed in the P(VDF-TrFE) matrix with cluster sizes similar close to cluster sizes.

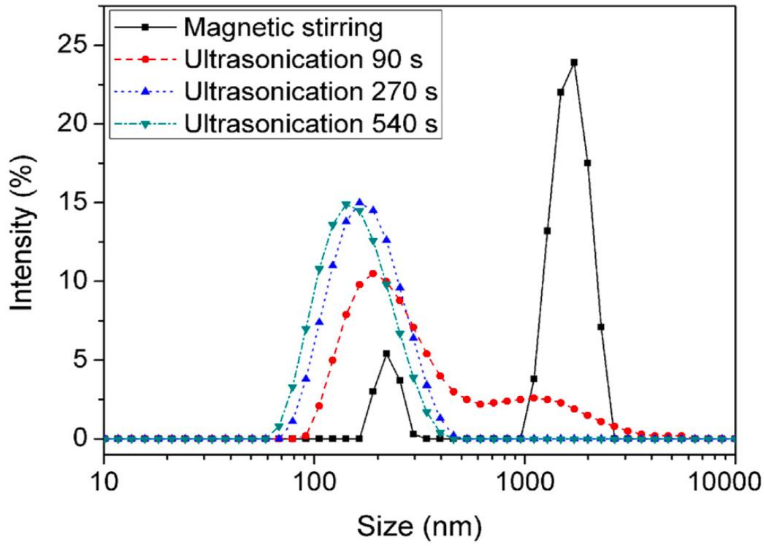

Figure 1: Particle population of Aluminum Oxide/$P_{18}Et_2$/MEK focus 1 mg/1 mg/ml as a function of the duration of exposure to ultrasonic time [10].

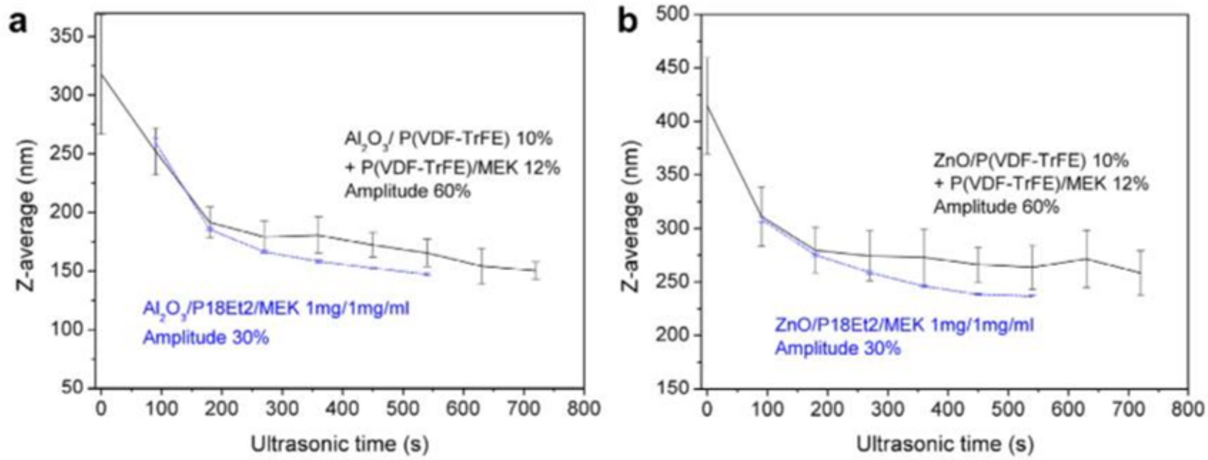

Figure 2: the evolution of mean particle size of (a) Aluminum Oxide and (b) Zinc Oxide over time during exposure to ultrasonic in Methyl Ethyl Ketone and solutions of P(VDF-TrFE) [10].

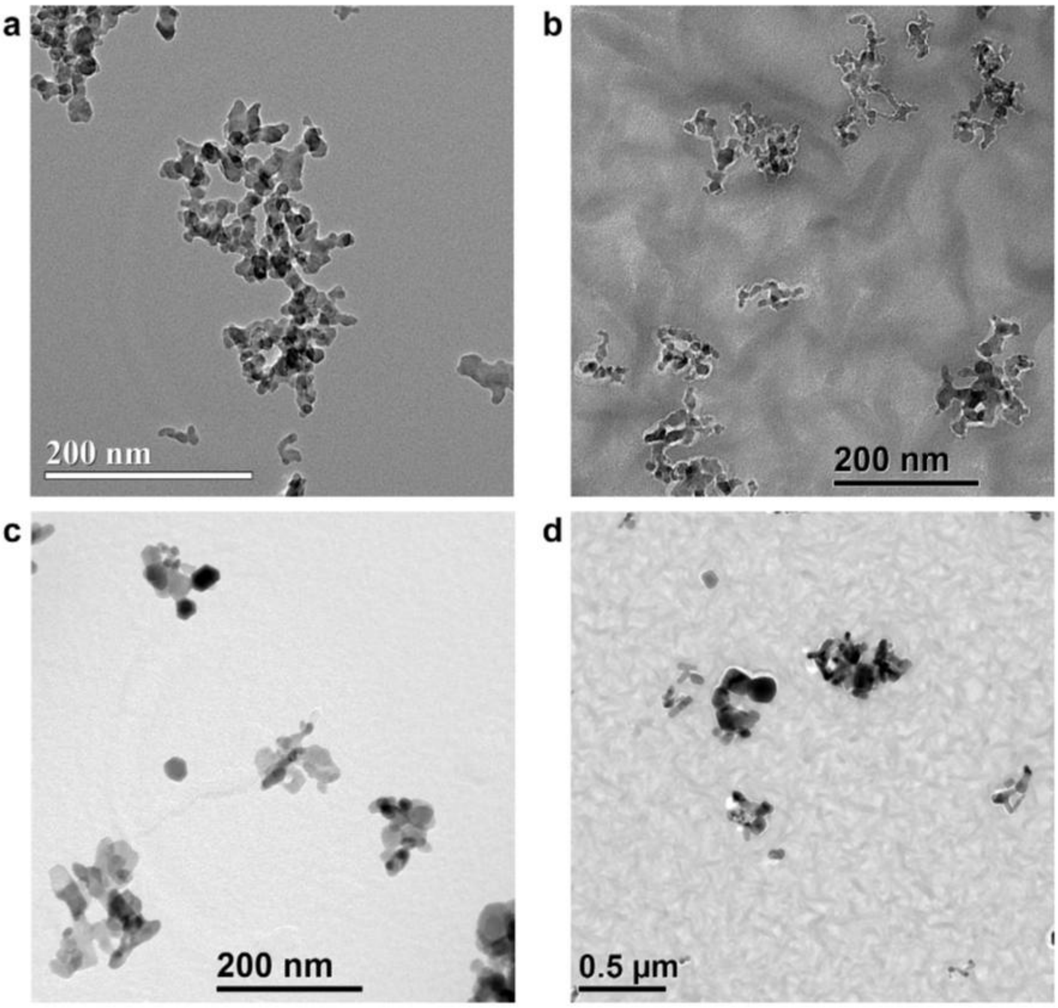

Figure 3: SEM of Aluminum Oxide /P18Et2/ Methyl Ethyl Ketone focus 1 mg/1 mg/ml (a), nanocomposites of P(VDF-TrFE)/ Aluminum Oxide 10 wt.% (b), Zinc Oxide /P18Et_2/ Methyl Ethyl Ketone focus 1 mg/1 mg/ml (c) and nanocomposites of P(VDF-TrFE)/Zinc Oxide 10 wt.% (d)[10].

Botao et al. [11] investigated the dispersion of nanoparticles via electrospinning process. They applied a sufficiently high voltage to a liquid droplet, and an electrically charged jet is ejected from the droplet through the electrostatic repulsion force overcoming the surface tension. Then the jet is stretched and whipped, resulting in thin and long fibers. At the same time, the solid fibers are randomly deposited on the collector, and the solvent is evaporated. This technology can fabricate polymer/nanoparticle composite films, polymer films, and inorganic films. In their preliminary study, they successfully prepared polymer/meso-porous silica nanocomposites by electrospinning and observed that the mesoporous silica particles had a homogeneous distribution in the nanocomposite.

Based on this observation, they proposed that the electrospinning technique could be used to enhance the dispersion of nanoparticles in polymer/nanoporous composite films. In this study, they used an environment-friendly polymer (polyvinyl butyral (PVB)), and used silica nanospheres, which have excellent optical and mechanical properties, as a template polymer. Silica nanospheres are prepared by the classical Stöber method, and then the electrospinning technique is used to fabricate silica nanosphere composite films with different nano loading content of silica (50%; 0%; 100%; with respect to the weight of PVB) as shown in figure 6, in order to explore whether the electrical spinning can be used to investigate from the dispersion of nanoparticles in the polymer matrix. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are selected to investigate the dispersibility of silica nanospheres in the PVB matrix as shown in figures 4 & 6. In order to verify the universality of this method, a composite film of PVP/mesoporous silica nanoparticles is also fabricated. The results indicate that the silica nanospheres are well encapsulated inside the fibres without any agglomeration. Even at very high or low content of silica nanospheres, the nanospheres in the composite film are still well dispersed.

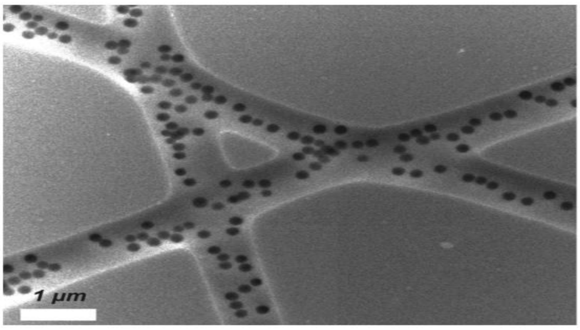

Figure 4: SEM of Poly vinyl pyrrolidone /50% mesoporous silica nanoparticle be of important value in effectively preventing agglomeration in the composite film [11].

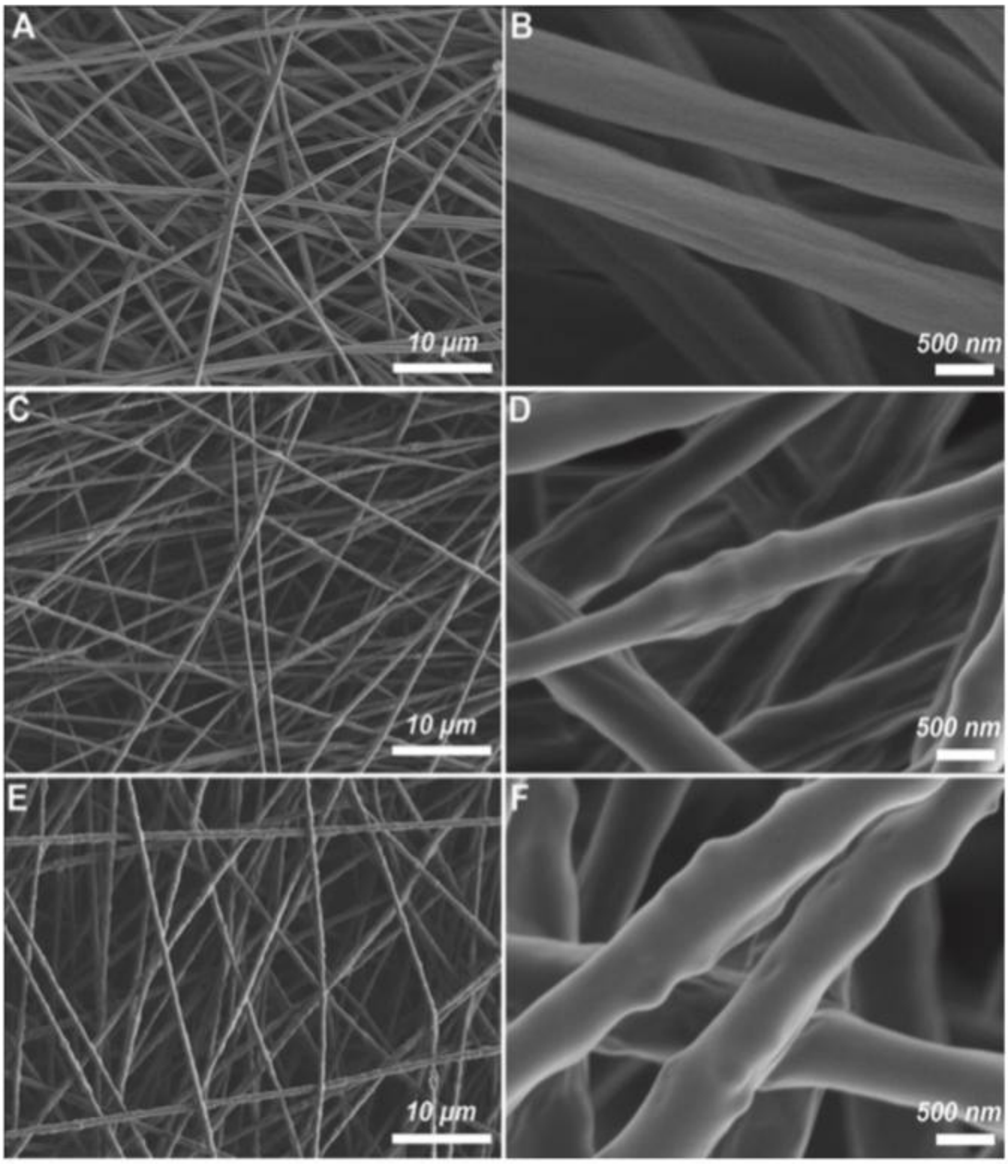

Figure 5: Scanning electron microscope picture of pure Poly vinyl pyrrolidone film (A), (B), Poly vinyl pyrrolidone /50% silica nanosphere composite film (C), (D) and Poly vinyl pyrrolidone /100% silica nanosphere composite film (E), (F) [11]

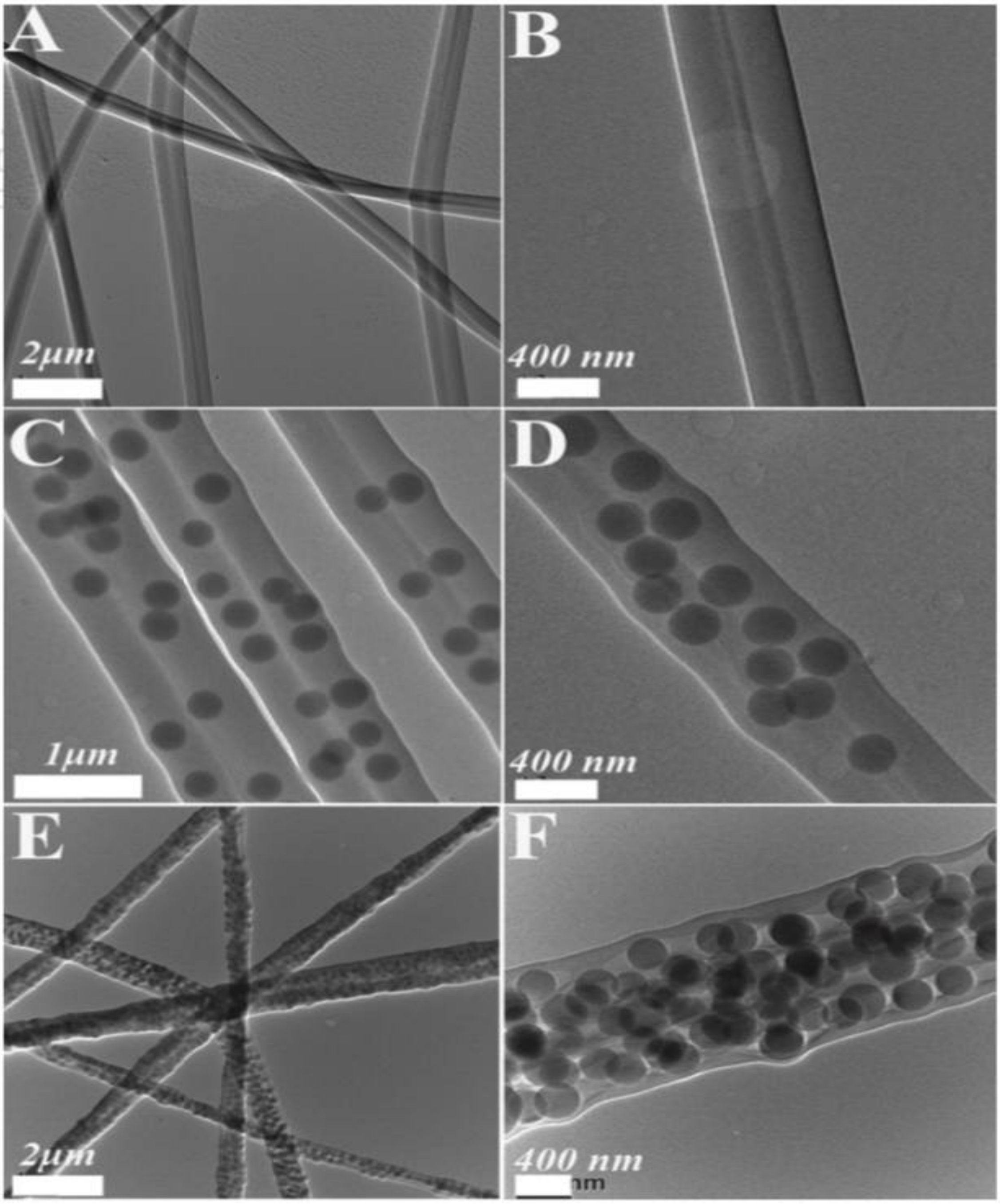

Figure 6: Transmission electron microscopy pictures of pure Poly vinyl pyrrolidone film (A), (B), Poly vinyl pyrrolidone /50% silica nanosphere composite film (C), (D) and Poly vinyl pyrrolidone /100% silica nanosphere composite film (E), (F) [11].

Syed et al. [12] used bath ultrasound with a modified acrylic-based surfactant to disperse multi-walled carbon nanotubes. They also prepared a solution of surfactant and water to achieve good dispersion of multi-walled carbon nanotubes in water. Then, they added the specified amount of multi-walled carbon nanotubes to the solution. The solution was ultrasonicated for 20 min at 25±5 °C. They evaluated the dispersion qualitatively by bellyful test tubes with the scattered multi-walled carbon nanotubes solution and monitoring the colour of the solution for the next 48 hours. They noticed that the multi-walled carbon nanotubes were effectively dispersed due to their instability in the test tube but stayed in the solution. The details of the synthesis of the solution containing the widespread multi-walled carbon nanotubes are presented in the Table 1.

Table1: Solution containing dispersed multi-walled nanotubes [12]

Designation	Water (g)	Surfactant (g)	MWCNTs (g)	Comments
C	100	2.0	0.000	Mix containing 0.00% MWCNTs by mass of cement
C0p05	100	2.0	0.125	Mix containing 0.05% MWCNTs by mass of cement
C0p10	100	2.0	0.250	Mix containing 0.10% MWCNTs by mass of cement

Yong et al. [13] designed a cationic and anionic ligand to act as dispersants, emulsifiers, and co-components in different steps of preparing highly dispersed polymer nanocomposites. They incorporated commercial nanoparticles Al_2O_3, $BaTiO_3$, Ag, and TiO_2, and uniformly dispersed them in polymethylmethacrylate (PMMA) and polystyrene (PS) matrices by means of a designed cationic/anionic ligand as shown in figures 7, 8 & 10. By using the cation/anionic ligand as a dispersant, the sizes of nanoparticle aggregations were reduced from thousands of nanometers to tens of nanometers. Then, polymeric nanocomposites were prepared using ligands as emulsions. The ligands and polymer matrices were then polymerized together at the end of the emulsion polymerization process which reduced the nanoparticle sizes to several nanometers in the polymer matrix. Even after hot pressing, the nanoparticles were able to maintain a stable dispersion state. It was found that there was an increase in tensile strength by 77% of P(MMA-co-VDAC)/$BaTiO_3$ compared with PMMA as shown in Figure 9. Further, the thermal decomposition temperature was also improved by 24 °C of P(St-co-MAMS)/Al_2O_3 compared with PS.

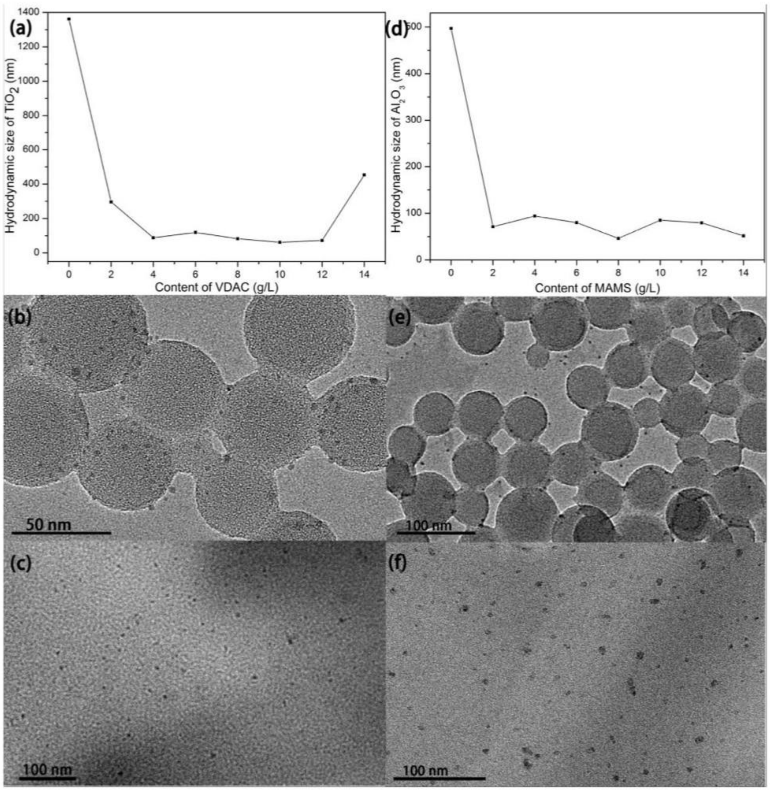

Figure 7: Dispersion states of Titanium dioxide and Aluminum oxide in PS matrix. **(a)** and **(d)** Dynamic light scattering measurement of Titanium dioxide /VDAC/H_2O system and Al_2O_3/MAMS/H_2O system, **(b), (c), (e) and (f)** SEM of P(St-co-VDAC)/TiO_2 latex, P(St-co-VDAC)/TiO_2ultrathin section, P(St-co-MAMS)/Al_2O_3latex, and P(St-co-MAMS)/Al_2O_3ultrathin section respectively [13]

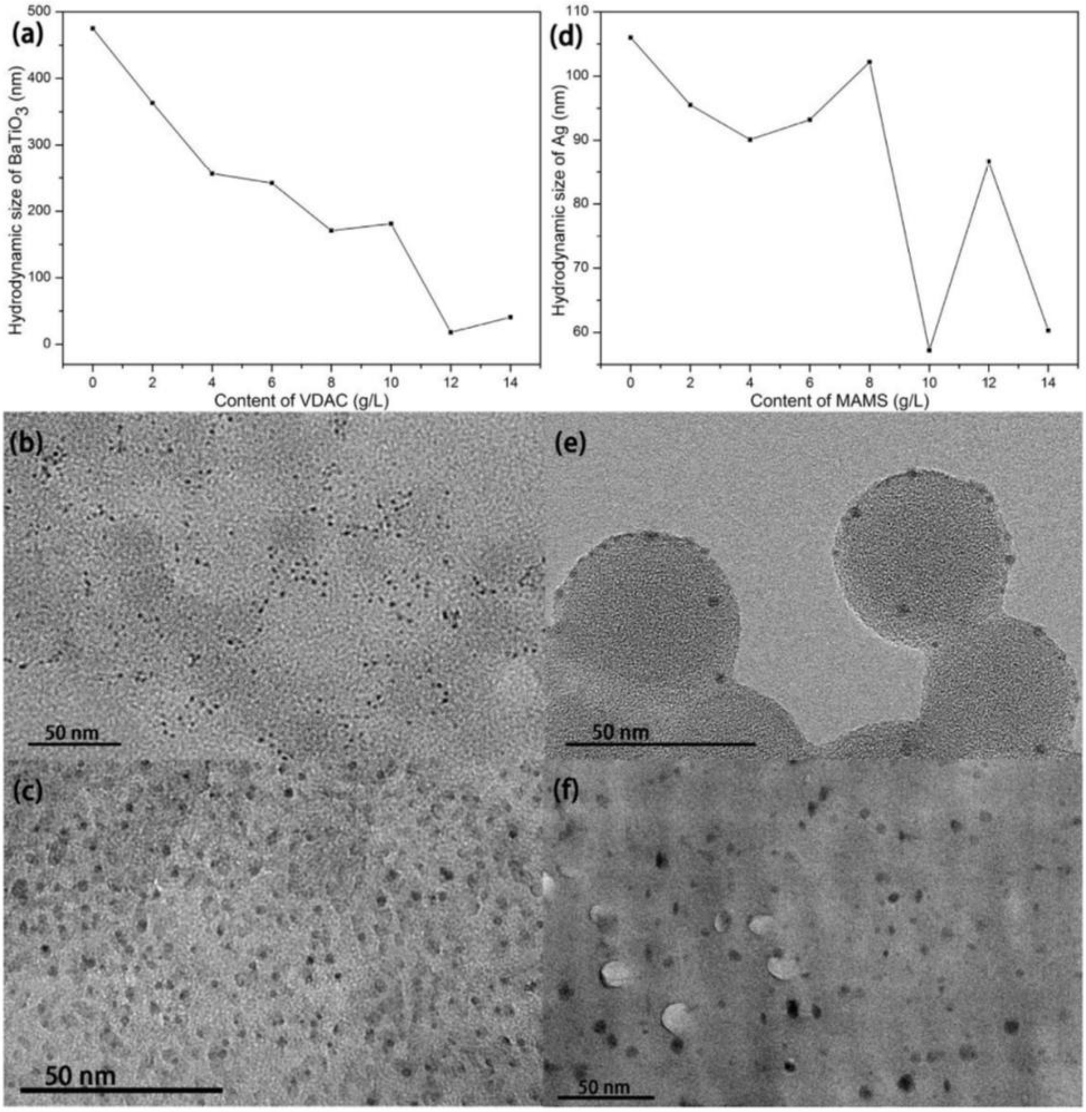

Figure 8: Dispersion states of Barium titanate and silver in PS matrix. **(a)** and **(d)** Dynamic light scattering measurement of Barium titanate /VDAC/H_2O system and silver /MAMS/H2O system, **(b), (c), (e),** and **(f)** SEM of P(St-co-VDAC)/$BaTiO_3$latex, P(St-co-VDAC)/$BaTiO_3$ultrathin section, P(St-co-MAMS)/Ag latex, and P(St-co-MAMS)/Ag ultrathin section respectively [13]

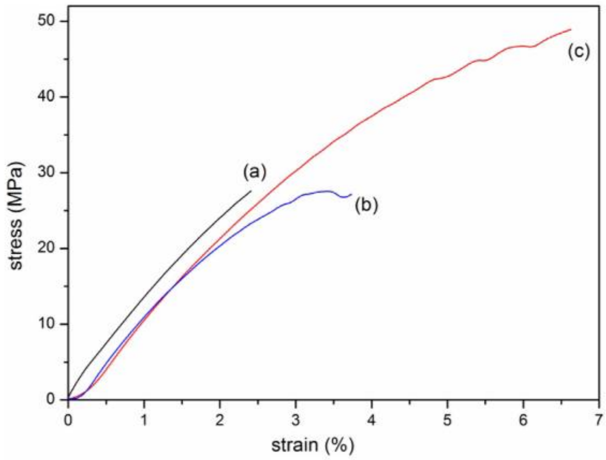

Figure 9: Stress strain curves of (a) Polymethyl methacrylate, (b) Polymethyl methacrylate /SDS/ Barium titanate, (c) P(MMA-co-VDAC)/ Barium titanate [13]

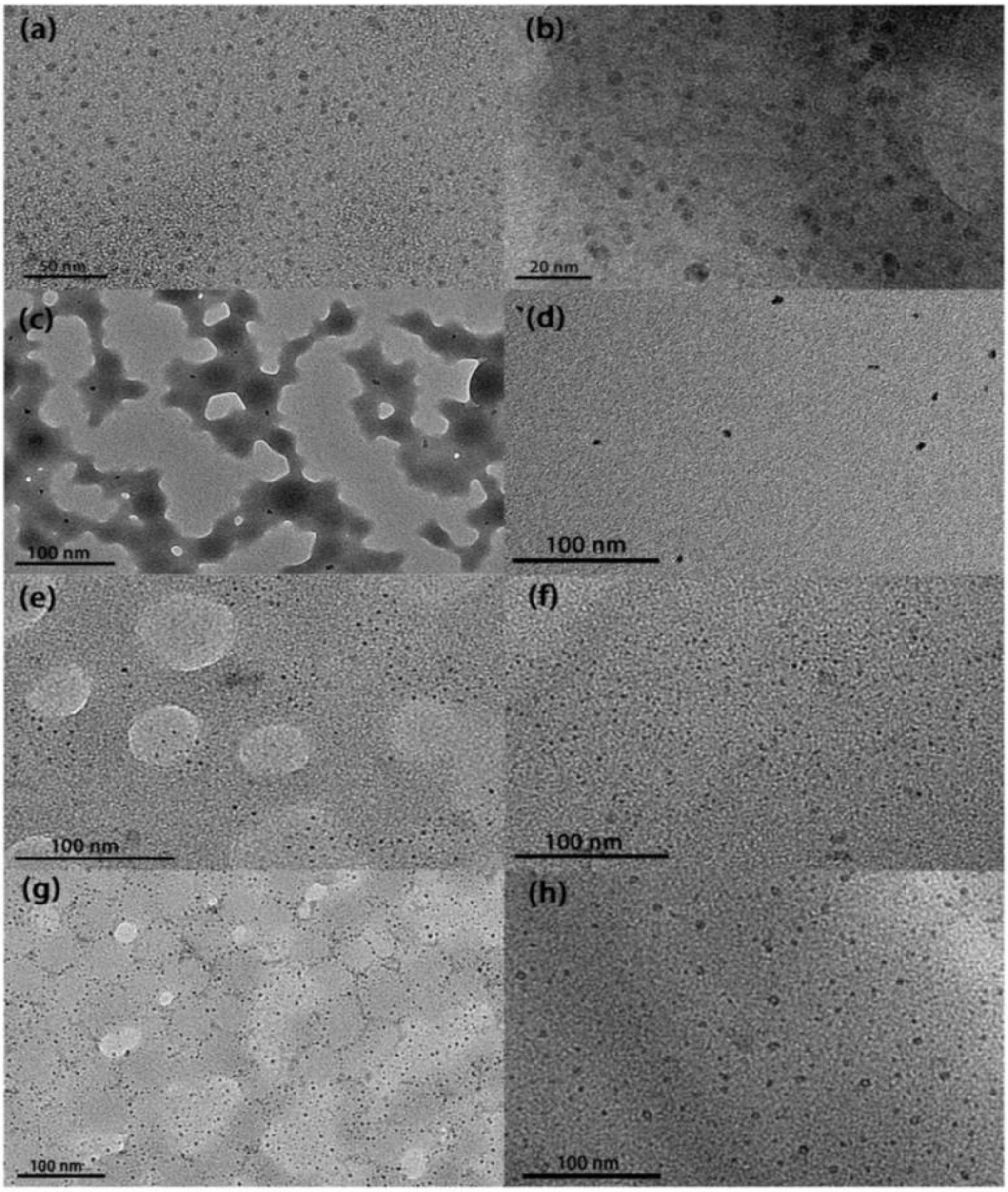

Figure 10: Dispersion states of nanoparticles in Polymethyl methacrylate matrix, **(a), (b)** SEM of P(MMA-co-VDAC)/$BaTiO_3$latex and ultrathin section. **(c), (d)** SEM of P(MMA-co-VDAC)/TiO_2latex and ultrathin section. **(e), (f)** SEM of P(MMA-co-MAMS)/Ag latex and ultrathin section**. (g), (h**) SEM of P(MMA-co-MAMS)/Al_2O_3latex [13]

Y. Sui [14] reviewed the effect of nanoparticle size, thermodynamic parameters and surface chemical properties on the dispersion state of nanoparticles inside polymer nanocomposites and described some key measures that led to the improvement of the dispersion of these nanoparticles.

When the particle size reaches less than the radius of rotation of the polymer chains and the particle surface reacts with the matrix, an optimal dispersion can then be achieved in the polymer melt of the nanoparticles. Determining the appropriate thermodynamic parameters in the polymer solution is very important to ensure balanced interactions between the solvent and the polymer particles, and this also leads to the successful preparation of a polymer nanocomposite with an ideal structure. From these results, they proposed a good theory for the design of polymer nanocomposites. However, even if the dispersion process is thermodynamically favorable, equilibrium dispersion may not be achieved without favorable kinetic parameters.

Md Mahbubur et al[15]. studied the effect of the dispersion of nanoparticles on the properties of nanocomposites, as well as in the search for strategies that improve the dispersion of nanoparticles. They have found various methods that enhance dispersion and improve compatibility between nanoparticles and polymers, including double screw extrusion, on-site polymerization, nanoparticle surface modification, sol-gel processes, solution casting, and other techniques such as advanced synthesis techniques involving self-healing compounds and additive fabrication technology. Therefore, improving the dispersion of nanomaterials has improved the functions of nanocomposites such as conductivity, increasing mechanical strength, chemical resistance, and thermal stability, and this has made nanocomposites of great importance in many industrial applications such as automotive, electronics, aerospace, packaging, and pharmaceuticals.

These studies dealt with many techniques that help disperse nanomaterials in a homogeneous polymer matrix, including the use of ultrasound, which contributed to the distribution of nanomaterials very well.

It was also shown through these studies that when the nanoparticles are small in size, they are distributed perfectly using electrospinning technology, and determining the appropriate thermodynamic parameters in the polymer solution is critical to ensure effective distribution. The researchers also found other techniques that promote improved dispersion, including double screw extrusion, in situ polymerization, nanoparticle surface modification, sol-gel processes, solution casting, and other techniques. In the future, more than one technology can be used together to enhance distribution, and simulation programs can be used to understand distribution behavior and improve system design before starting practical experiments. In order to avoid the dangers of environmental nanoparticles as a result of their use, the impact of these nanoparticles on the environment must be studied.

3. Improving the Mechanical Performance

Composite materials are of great importance in many industrial and engineering applications. Therefore, the manufacture of new composite materials aims to enhance the applicability of materials. The properties of nanocomposites depend largely on the organic matrix, the content of nanoparticles, and their shape and size, as well as the method of preparing the nanocomposite. The good mechanical properties of carbon nanotubes, such as high tensile strength and elastic modulus, make them the most promising and ideal for supporting the mechanical properties of polymer/carbon nanotube composites. It is common knowledge that the interactions between nanotubes and polymer matrices greatly affect the mechanical properties of composites [16]. In order to improve the mechanical performance of composite materials containing nanomaterials, the effect of these materials on the mechanical properties must be understood through the following tests.

3.1. Tensile strength

S. A. Meguid et al. [17] studied different properties of composite interfaces including shear, tensile and delamination properties, and reinforced them with more than one type of uniformly distributed nanofiller, nano-alumina powder and carbon nanotubes. They used composite adhesives made of 6061-T6 aluminum alloy and carbon fiber/epoxy flakes. The results revealed that changing the weight percentage of nanofillers in the epoxy matrix adhesive had a positive effect on the shear and delamination properties of the interface as shown in figure 11. The results also indicated that the interface strength decreased when the amount of nanofillers was increased beyond a certain percentage of the adhesive weight. This is due to the reliance on the properties of the nano-reinforced interface, which include tensile and shear properties, due to the final interlocking between the diverse mass and the solid epoxy material, as well as the large surface area.

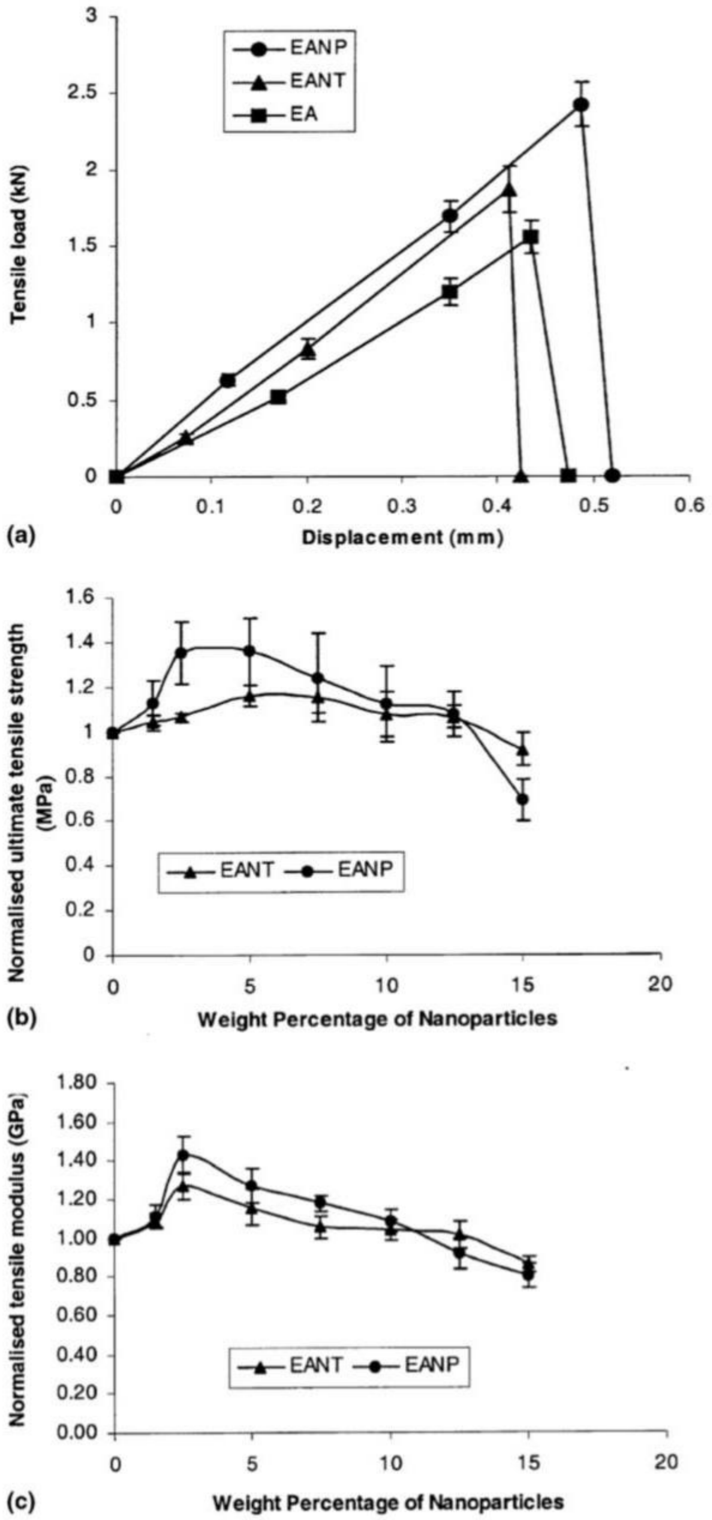

Figure 11: Tensile load-displacement plots for nanofiller-reinforced interfaces **(a),** the effect of nanoparticle weight percentage on ultimate tensile strength **(b),** and the effect of nanoparticle weight percentage on tensile modulus **(c)** [16].

Yasser et al. [18] presented a clear model for determining the tensile/yield strength of polymer nanocomposites containing spherical nano-fillers based on the interphase and material properties. By comparing with the experimental strength of several samples from the literature, the accuracy of the proposed model was estimated. In addition, based on the proposed model [eq. 1], the tensile strength (σ_i) and the effects of the radius (R) and thickness (t) of the interphase as well as the volume fraction (φ_f) of the nanoparticles on the tensile strength were explained as shown in figure 12. The high strength of nanoparticles presents in nano-composites (> 100

GPa) often led to overestimation of the tensile strength of these compounds, although accurate estimation of interphase properties led to accurate calculations. At σ_i < 38 MPa, the tensile strength of the nanocomposites did not change, but increased by 140% at t = 20 nm and $\sigma_i = 90$ MPa. However, a maximum increase of 14% in tensile strength was obtained with the appropriate values of $\varphi_f = 0.04$ and R = 10 nm. Therefore, the size and concentration of nanoparticles had little effects on the tensile strength of the nanocomposites, but the main effects of the strength and thickness of the interphase were obvious.

$$\sigma_R = 1 + 1.21\left[\frac{\sigma_i}{\sigma_m}\left(1+\frac{t}{R}\right)^2_{-}\left(1+\frac{t}{R}\right)^2\right]\varphi_f^{2/3} \quad \text{.....................} \ (1)$$

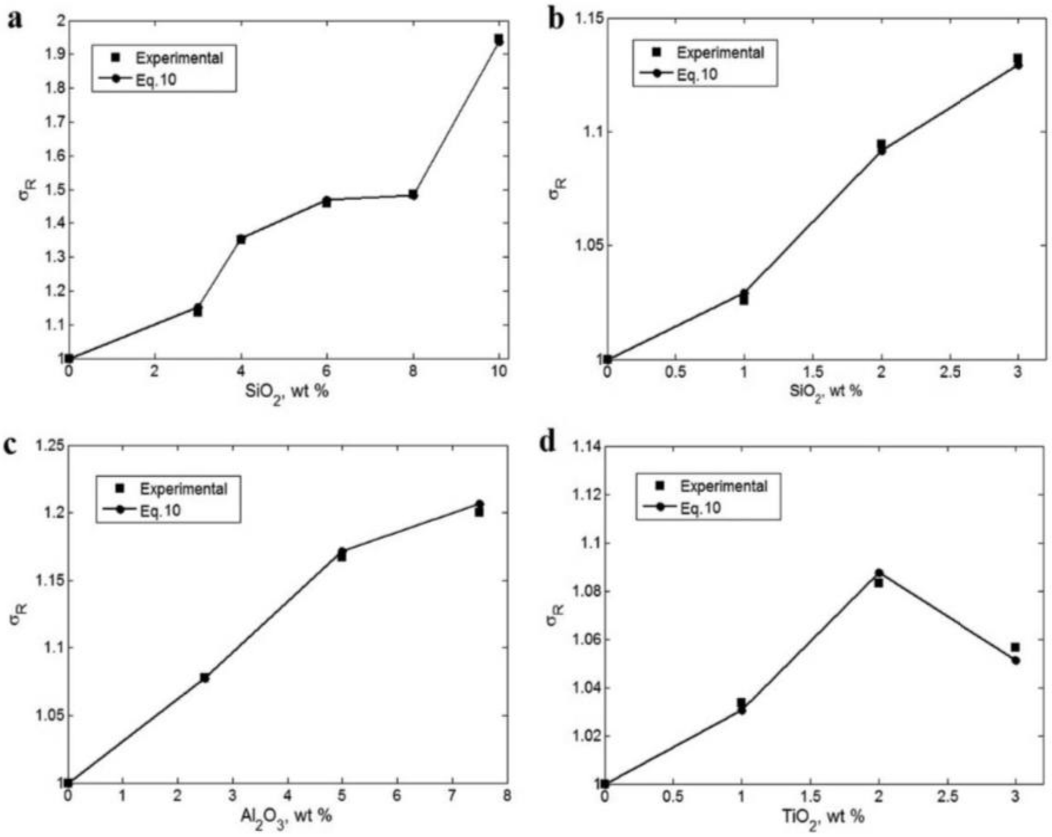

Figure 12: Experimental data and predictions of eq. (1) assuming correct interphase (t = 5 nm and different interphase strengths) for (a) Linear Low-Density polyethene/Silicon Dioxide, (b) Low-Density Polyethylene/Organic functionalized silicon Dioxide, (c) Polyetheretherketone/Aluminum Oxide, and (d) High impact Polystyrene/Titanium Dioxide samples. [18]

Shankar A Hallad et al. [19] focused on improving the properties of epoxy resin by adding multi-walled carbon nanotubes (MWCNTs) at low concentration (up to 0.4% by weight). Through mechanical studies of compounds with multi-walled carbon nanotubes added in epoxy resin, the results showed that nanocomposite samples have a much higher tensile strength than samples consisting of epoxy only[19].

Chanachi Thongchom et al. [20] studied the mechanical properties (i.e. impact strength, tensile strength, and modulus of elasticity) of polypropylene (PP)-based nanocomposites strengthened with graphene nanoflakes, basalt fibers, and nano clay. They designed it Box-Behnken (BBD) as the experimental design and they adopted response surface methodology (RSM). They used an internal mixer to make composites with 0, 0.75, and 1.5% graphene nanoflakes, 0, 3, and 6% nano clay, and 0, 10, and 20% basalt fibers. Figure 13 shows the effect of adding these ratios of graphene nanoparticles, nano clay and basalt fibers to composite materials on tensile strength. They prepared the samples by hot-pressing machine which was used for mechanical testing. The tensile strength and modulus of elasticity were determined by conducting tensile tests, and to evaluate the impact strength, they performed Charpy impact tests. The tensile strength was increased by 32%, the modulus of elasticity was increased by 64%, and the impact resistance was increased by 18% as a result of adding basalt. Also, the tensile strength increased by 15% and the impact strength increased by 20%, due to the incorporation of lightweight graphene nanoflakes, and the overall elastic modulus improved by 66% due to the addition of graphene nanoflakes. Similarly, the elastic modulus increased by 59%, and the tensile strength was improved by 17% due to the addition of nano clay, but adding more of it reduced the impact strength by 19%. Through this experiment for the mechanical property, they obtained values very close to the values resulting from the improvement of the desirability.

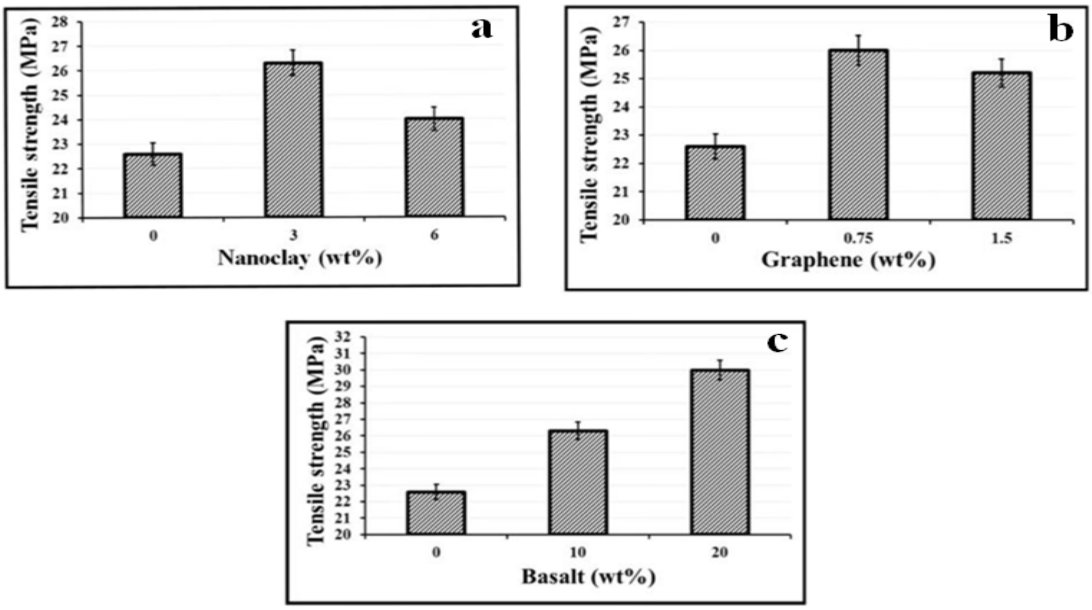

Figure 13: (a), (b), and (c) the effect of nano clay, grapheme, and basalt on the tensile strength of composite laminates respectively. [20]

3.2. Interfacial Bonding Strength

Wei et al. [21] grafted silicon dioxide nanoparticles (SiO_2 NPs) onto high-strength, high-elastic modulus particles such as polyvinyl alcohol (PVA) for amelioration of the bond strength between cement and PVA and used γ-(2,3-epoxypropoxy) propitrimethox-silane) KH560) as a linking factor. They supplied the cement with PVA particles that have high chemical reactivity and were grafted onto a nano-rough surface. Through experimental results, they concluded that the optimal grafting rate between SiO_2 NPs and PVA was 8.5% by weight, and the percentage by weight of the catalyst was 10% by weight. The reaction time was 2 hours, and the reaction temperature was 110 degrees Celsius. The bonding strength and tensile strength of cement were increased by 21% and 43% respectively due to the reinforcement with SiO_2-doped PVA particles compared with pure PVA particles. Finite element analysis and fiber drawing proved the enhancement of the interface behavior between cement and PVA particles. The bonding strength between the interface and cement under slight deformation can be improved when SiO_2 nanoparticles are grafted onto PVA particles, which leads to the enhancement of reinforcement and improvement of crack resistance of cement. This effect is due to the synergistic forces of chemical bonding and friction between the cement and the SiO_2 nanoparticles. ***Yunpeng Jiang.*** [22] studied the bonding strength between the surfaces of carbon fiber/epoxy composites through several experiments in which single-lap jointed specimens were used to measure the bonding strength, and they were bonded using a hybrid adhesive based on epoxy resin that was mixed with three different types of nano powders to improve the bonding strength namely: gold nanoparticles, silicon carbide and silicon dioxide nano-whiskers as shown in figure 14. The addition of these nano powders helped to increase the bonding strength between the surfaces to varying degrees. It was concluded that the bonding strength was significantly affected by the shape and hardness of the composite specimens through scanning electron microscope observations of the fractured surfaces.

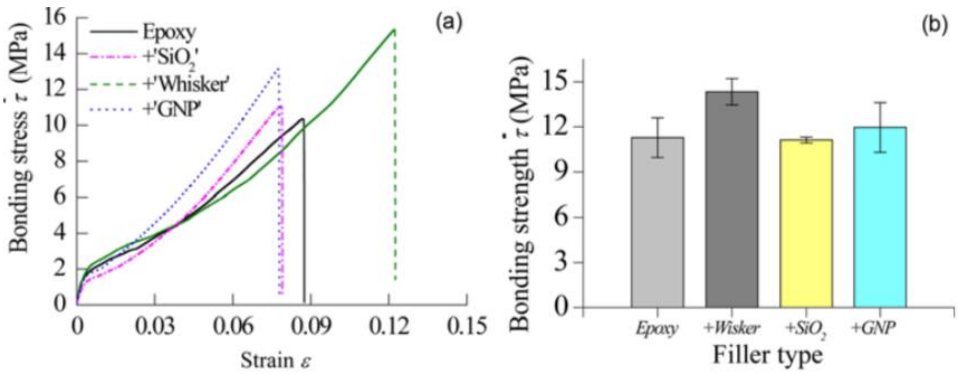

Figure 14: The bond stress and strain for four different types of CF/epoxy composites and (a), and the average bond strength of the samples (b) [22].

Tao et al. [23] investigated the effect of nanomaterial modification by determining the nano-buckling value and the bonding strength of the interface transition zone, in addition to the interface microstructure and the layered mineral composition, because the properties of concrete containing nanomaterials are clearly affected by the interface transition zone. The results showed a significant increase in the bonding strength of the samples that were improved by adding nanomaterials due to the "de-agglomeration effect" and "phase organization effect" of nanomaterials on the hydration products. However, there was a clear difference as a result of modifying different nanomaterials. As a result of reducing the thickness of the interface transition zone and improving the nano-buckling value, the effect of nano-silica was optimal compared to other nanomaterials. In addition, a slight increase in the bonding strength between the interfaces occurred due to the agglomeration of nano-graphene oxide and nano-calcium carbonate on the interface and the inactive core of nano-titanium dioxide [23].

3.3 Inter-laminar Fracture Toughness

Vahid et al. [24] investigated the effect of using a reinforcing agent such as multi-walled carbon nanotubes (MWNT) for laminated composites as shown in figure 15. Using a resin film infusion technique, they fabricated carbon fiber laminates where the resin flowed in the thickness direction. They found a 17% improvement in the stress intensity factor (KIc) of the modified polymer systems, while up to 48% improvement in the laminated composites in the first mode while in the second mode, the fracture toughness improved by 143%.

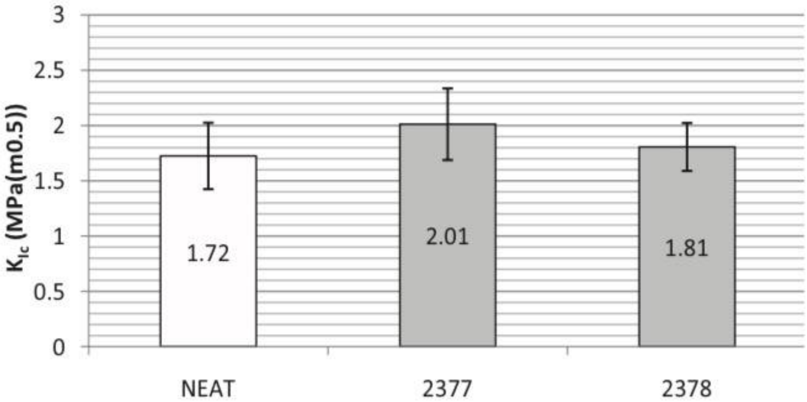

Figure15: Shows the effect of fracture toughness when multi-walled carbon nanotubes are added to the resin film [24].

C. Kostagiannakopoulou et al. [25] developed a new class of carbon fiber reinforced polymers (CFRPs) with a nano-modified matrix based on graphene nanoparticles. Their main goal was to increase the inter-laminar fracture toughness of carbon fiber composites filled with different types of graphene nanoparticles under first-mode compression. They fabricated three types of CFRP composite sheets: two filled with graphene oxide or graphene nanoparticles and one with a neat matrix. To determine the inter-laminar fracture toughness in first-mode compression, they tested different double-arm beam couplings while simultaneously recording acoustic emission (AE) activity .When the nanoparticles were graphene there was a significant increase of about 50% in the interlayer strain energy release rate for the nano-doped Gic composites. ***Vijay. Et al.*** [26] demonstrated that CFRPs exhibit specific fracture toughness due to the inter-laminar cracking properties. They demonstrated that by adding nano-fillers the fracture toughness of CFRPs can be improved as shown in figure 16. They used epoxy resin with or without 3% nano-fillers to produce CFRP samples. They used three types of nanomaterials as fillers namely: carbon black (CBs), graphene nano-sheets (GnPs), and multi-walled carbon nanotubes (MWCNTs). They prepared specimens to characterize the mode I and mode II fracture toughness and inter-laminar shear strength of pure CFRP/epoxy composites, 3wt% CFRP/epoxy composites, 3wt% graphene nano-sheets/ CFRP/epoxy composites, and 3wt% carbon black/CFRP/epoxy composites, using short beam shear (SBS), end bending (ENF) and double cantilever beam (DCB) tests. They concluded from the results that the inter-laminar fracture toughness of pure CFRP/epoxy composites in mode I and mode II increases when graphene nano-sheets and multi-walled carbon nanotubes are added due to stronger interaction between the fibers, matrix and nanoparticles and improved toughness. However, the CFRP composite filled with carbon black particles had lower values than pure CFRP, multi-walled carbon nanotube-CFRP and graphene nano-sheets-CFRP composites.

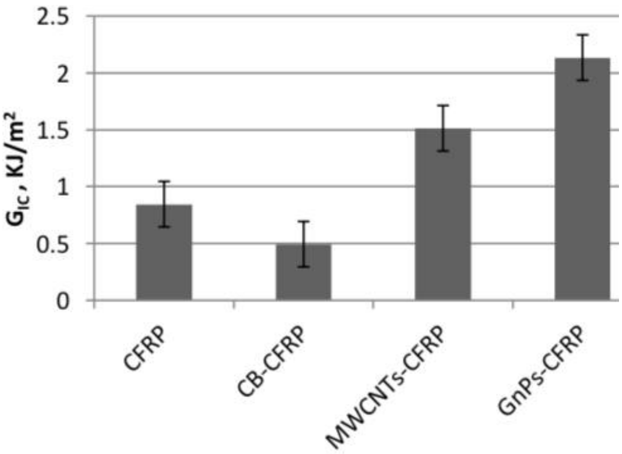

Figure 16: Shows the extent to which the fracture toughness between the composite sheets is affected by adding carbon nanotube fillers [26]

Yong Chul Shin et al. [27] increased the fracture strength between the plates, so they used carbon nanotube (CNT) bucky paper as well as a carbon fiber reinforced polymer composite (CFRP) which is overlapping with carbon nanotube (CNT) bucky paper. The results observed an increase in the fracture strength between sheets in CFRP. Also, the fracture strength increased by 45.9% among the Carbon Fiber Reinforced Plastic Type II sheets .

Gongdong Wang et al.[28] used the wet phase transition method to prepare hybrid films of polyether sulfone (PES)/carbon nanotubes (CNTs)/graphene oxide (GO), and seven different ratios (with a total concentration of 1%) of graphene oxide and carbon nanotubes were used, these ratios are 0:5, 1:4, 2:3, 1:1, 3:2, 4:1, and 0:5 to improve the fracture strength of the inner layers of carbon fiber reinforced polymer (CFRP) compounds. Significant improvement in fracture strength in the first and second positions of the sheets when 20% PES weight is added to the membrane at 3:2 and 2:3 carbon nanotube to graphene oxide ratios respectively. Increases in fracture strength reached 123.66% and 204.55% respectively compared to the original samples. In addition, they closed the gap of the impact of the low-temperature environment on the fracture performance of the interlayer of high-performance compounds by adding carbon nanotubes/aluminum oxide (3:2) where the fracture performance increased by 111.84%, and gave the best reinforcement in the first mode test.

3.4. Flexural Strength

Khashaba [29] studied the effect of nanoparticles on properties such as flexural strength and vibration damping. Their research focused on the effects of Al_2O_3 and Sic nanoparticle infusion on the vibration, flexural and interface properties of glass fiber reinforced epoxy laminates (GFR/E). Unidirectional (UD-GFR/E) and quasi-identical (QI-GFR/E) laminates were incorporated with stacking sequences of [0/±45/90]s and [90/±45/0]s by the optimal percentages possessed by the nanoparticles. From the off-axis bending forces of UD-GFR/E, it was concluded that a strong bond between the nanofibers/matrix occurred. The shear stress between the layers of the bonded layers with different stresses of the ductile QI-GFR/SiC/E sheets resulted in a decrease in the flexural strengths by 24.3% and 9.1% for the stacking sequences [0/±45/90]s and [90/±45/0]s respectively, and an increase in the dispersed surface friction energy and hence the damping by 105.7% and 26.1%. The damping was increased for the QI-GFR/E, QI-GFR/SiC/E, and QI-GFR/Al_2O_3/E sheets with the stacking sequence [90/±45/0]s by 111.4%, 29.7%, and 32.9%, respectively compared to the stacking sequence [0/±45/90].

Luiza et al. [30] evaluated the grade of transformation of Di-methacrylate resins containing various quantities of montmorillonite nano clay (MMT) as filler and containing similar quantities (in terms of volume) of barium glass particles as controls to test a series of these composites. They also studied eight formulations comprising a polymer matrix based on BisGMA/TEGDMA (bisphenol A di(2-hydroxy-3-methacryloxypropyl) ether/triethylene glycol dimethacrylate), four of which were added to MMT and four others were added to barium glass at different volume concentrations of 20, 30, 40 and 50 vol%. The degree of conversion was determined using near-infrared spectroscopy. The flexural strength and elastic modulus were determined by performing a three-point bending test. X-ray diffraction and transmission electron microscopy (TEM) analysis were also used to determine the dispersion of MMT nanoparticles. Barium glass and Montmorillonite fillers interacted with BisGMA/TEGDMA based polymer matrix in a distinctive manner. Although the addition of montmorillonite nanoparticles resulted in a similar degree of conversion and the highest elastic modulus values at all concentrations tested, the flexural strength was statistically higher at 20 vol% compared to the barium glass filled control groups as shown in figure 17. This may be due to the need to optimize the montmorillonite concentration for all types of polymer matrices in order to improve or modify the mechanical properties The addition of low concentrations (less than 1 20% by volume) of montmorillonite nanoparticles to dental composite resins – such as hybrid or additive fillings – should be studied in order to improve mechanical properties, reduce polymerization shrinkage, and improve the new technology for use in future applications.

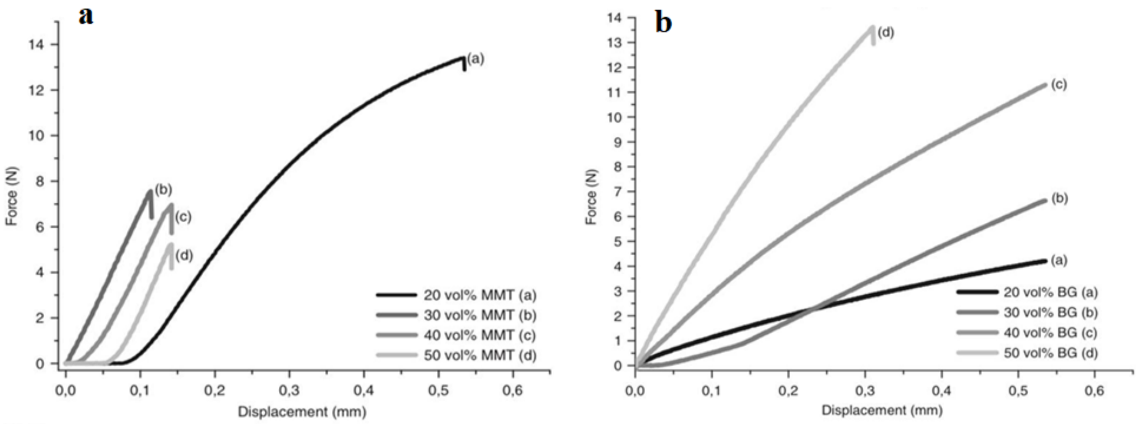

Figure17: Force-displacement curves of the flexural properties of (a) composites filled with montmorillonite nano clay and (b) composites filled with barium glass [30].

Wan et al. [31] prepared an epoxy nanocomposite by adding non-functional fluorescent nanoparticles (ARGNPs) and using Tween 80 surfactant (T80GNPs) in epoxy resins, and a mechanical motor was used to add functional fluorescent nanoparticles. They used un-functionalized fluorescent nanoparticles as received but by absorbing the surfactant on the surface of the fluorescent nanoparticles using ultrasonication procedure in an ultrasonic bath they induced functionalized fluorescent nanoparticles. They concluded from the flexural test that there was an increase in the elastic modulus of the nanocomposites to 72.1% for ARGNPs and 82.6% for T80GNPs, when 0.9 wt% of ARGNPs and 0.9 wt% of T80GNPs were added to the epoxy relative to pure epoxy. With the addition of the same quantity of particle content, the strength of both nanocomposites increased; and the strength was 70.5% for ARGNPs and 87.8% for T80GNPs compared to pure epoxy. Figure 18 shows the elastic stress-strain curve for pure epoxy, epoxy enhanced with non-functionalized fluorescent nanoparticles, and epoxy enhanced with Tween 80.

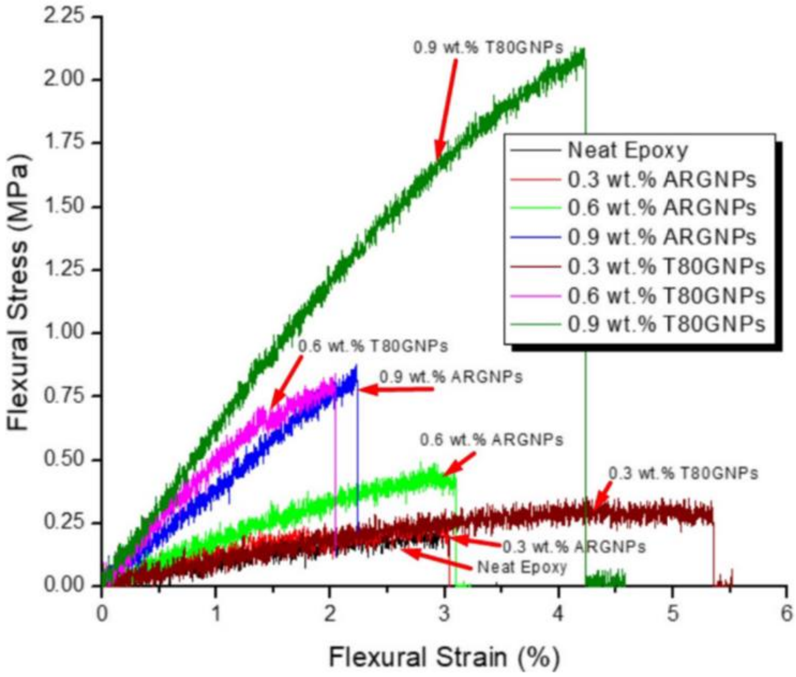

Figure 18: Flexural stress–strain curve for pure epoxy, epoxy reinforced by un-functionalized fluorescent nanoparticles, and epoxy reinforced by Tween 80 [31]

4. Improving the Electrical Performance

Many studies have been conducted on improving the electrical properties of polymers containing nanomaterials due to the increasing need for lightweight and flexible materials that have the ability to conduct electricity efficiently[32]. Due to the excellent electrical properties possessed by nanomaterials, carbon nanotube/polymer composites can be used as flexible and lightweight materials for electrical conductivity, due to their low density [33]. Improving the electrical performance of nanocomposites also involves improving various electrical properties, such as dielectric response, conductivity response, and electromagnetic wave dissipation. Some studies related to these properties are listed below.

4.1. Dielectric response

Yang et al. [34] prepared novel polymeric nanocomposites by solution processing using fillers of core/shell nanoparticles that are carbon shell coatings surrounding silver cores. The organic carbon shells act as spacers between the silver cores and the polymer matrix. They demonstrated the importance of the electrical properties of the interlayers in determining the dielectric behavior of nanocomposites. The dielectric layers create voltage barriers that reduce the tunnelling current between adjacent silver cores, which contributes to giving the nanocomposites high and stable dielectric constants and low and dielectric losses. In addition, by adjusting the thickness of the interlayers, the stable dielectric constants of the nanocomposites can be tuned. A decrease in voltage barrier occurs when the conductivity of the interlayers increases making conventional permeable composites and the dielectric behavior of nanocomposites very similar.

Santanu et al. [35] examined the dielectric properties of TiO_2, ZnO and Al_2O_3 which are epoxy nanocomposites with the use of insulating nano-fillers at low weight concentrations as shown in figure 19 & 20. They prepared epoxy nanocomposite samples and the nanoparticles were well dispersed in the epoxy matrix and conducted experiments to measure alternating dielectric strength, dielectric permeability, delta tan (400 Hz - 1 MHz) and DC volume resistance. They found some useful electrical properties for applications in many current and potential electrical systems when the nanoparticle loads are very low. They also synthesized precision epoxy composites for the same systems to compare their insulating properties with the results they already obtained for nanocomposites. These characteristic insulating properties of epoxy-based insulating nano systems have been attributed to the large volumetric fraction of the interfaces in the bulk of the material as well as the interactions that occur between the surface of charged nanoparticles and epoxy chains.

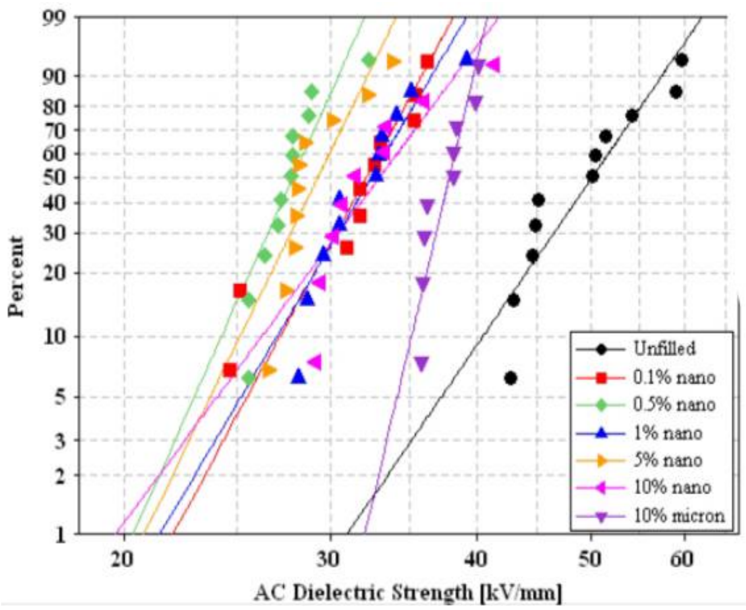

Figure 19: Whipple diagram showing the AC dielectric strength of epoxy-titanium dioxide compounds [35].

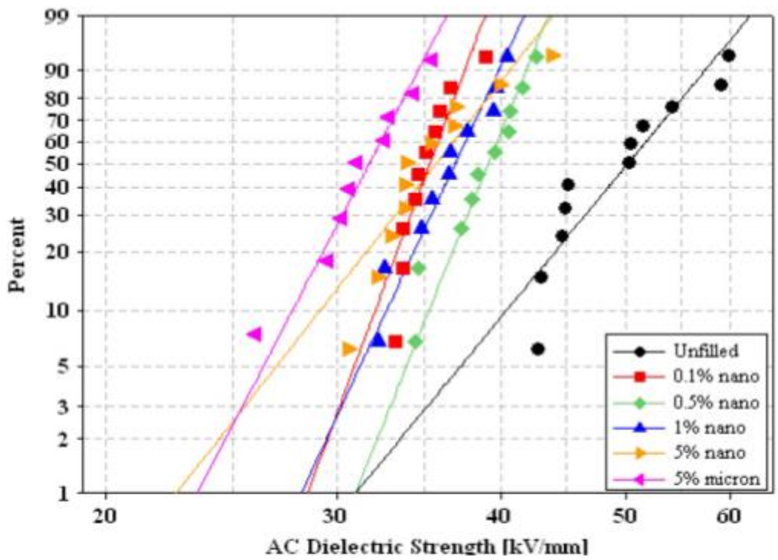

Figure 20: Whipple diagram shows the alternating insulated wattage in an epoxy-Al2O3 vehicle [35].

Tao et al. [36] compared the dielectric properties of nanocomposites between poly (vinylidene fluoride) (PVDF) with multi-walled carbon nanotubes (MWNTs) and surface-modified multi-walled carbon nanotubes (MEB) with core/shell structure as filler materials as shown in figure 21. When multi-walled carbon nanotubes/poly (vinylidene fluoride) composites were compared with composites surface-modified multi-walled carbon nanotubes/ poly (vinylidene fluoride), MEB/PVDF composites showed higher dielectric transmittance and lower shadow loss. They suggested that the main reason for the improvement of dielectric properties is the conductive/non-conductive core/shell structure of surface-modified multi-walled carbon nanotube filler. The leakage-based balancing of multi-walled carbon nanotube networks is responsible for improving the dielectric permeability, and the non-conductive emerald core layer of the surface-modified multi-walled carbon nanotube filler supports the low conductivity and low shadow loss in the poly (vinylidene fluoride)/surface-modified multi-walled carbon nanotube composites.

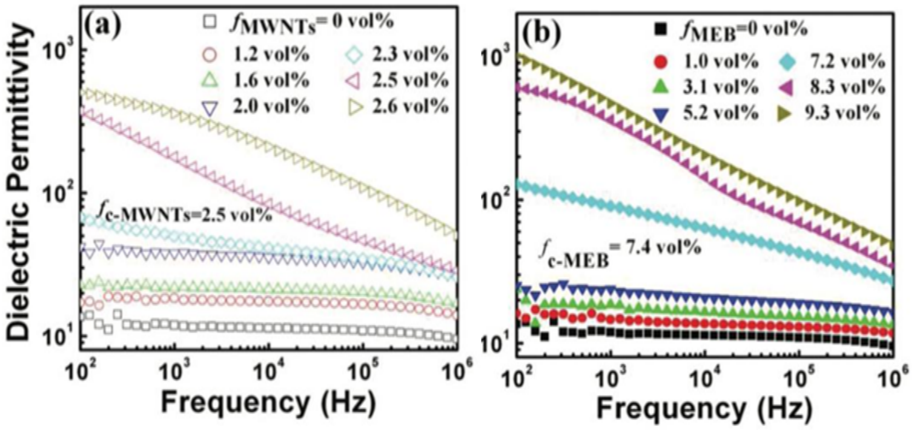

Figure 21: The frequency and dielectric constant of (a) multi-walled carbon nanotubes/poly (vinylidene fluoride) nanocomposites and (b) composites surface-modified multi-walled carbon nanotubes/ poly (vinylidene fluoride) at different filler contents [36]

Xin Chen et al. [37]used a combination of poly (1,4-phenylenedyl ether sulfone) (PES) with spiral chain polymers to control microstructure, such as polyether imide (PEI). Using the matrix, the nanocomposites were diluted to a concentration of up to 0.65 volumes. They observed a significant improvement in dielectric performance, i.e. an increase in the dielectric constant K from PES K = 3.9 (and PEI K = 3.2) to dilute nanocomposites K = 7.6, when loading alumina nanoparticles (size 20 nm). They found much better improvement when comparing these results to dilute nanocomposites using pure polymers as the matrix. They concluded a much better isolation improvement in polymer mixtures with specially designed nanoforms as a matrix in dilute nanocomposites compared to pure polymers as a matrix.

Taeyoon Lim et al.[38]developed high-quality epoxy compounds with excellent insulating properties and thermal conductivity by combining microscopic hexagonal boron nitride (BN) employed on the surface with aniline (PN) and diethylene diamine (DN). The epoxy compound is produced to form its basic structure from microscopic hexagonal boron nitride to form a thermally conductive lattice, while silica molecules work to reduce the dispersion of the phonon on the interface and also act as bridges to regulate heat transfer. They used different percentages of the contents of the compound filler (ranging from 10 to 80%), and these prepared compounds were subjected to careful examination. At a filler ratio of 60% by weight, they found that the DNBN/epoxy compound had a thermal conductivity of (47.03 W/m², K/k²), the Pima PNBN/epoxy compound (33 W/m², K/k²), and BN/epoxy (39.40 W/m², K/k²). The results found that at 60% by weight of DNBN/epoxy, the dielectric constant was excellent (approx. 6.15).

4.2. Conductivity Response

Y. Ngabonziza et al. [39] verified experimentally and theoretically the electrical conductivity of compounds consisting of polypropylene (PP) and reinforced by the addition of multi-walled carbon nanotubes (MWCNTs). The polypropylene samples were manufactured and multi-walled carbon nanotubes (MWCNTs) were manufactured using injection Mould and used different injection speeds. They used carbon nanotubes at a ratio of 0 to 12% by weight as shown in figure 22. They studied the effect of volumetric fractionation and injection velocity of multi-walled carbon nanotubes on the electrical conductivity of nanocomposites. The effect of injection speed on electrical conductivity was observed, leakage theory to study the electrical conductivity of a nanocomposite system in terms of nanotube content was applied. They used various models from Kirkpatrick (1973) [40] and McLachlan et al. (2005) [41] to determine the leakage threshold which is the transition from low conductivity to high conductivity. They found that the leakage threshold ratio of carbon nanotube composites is approximately 3.8%.

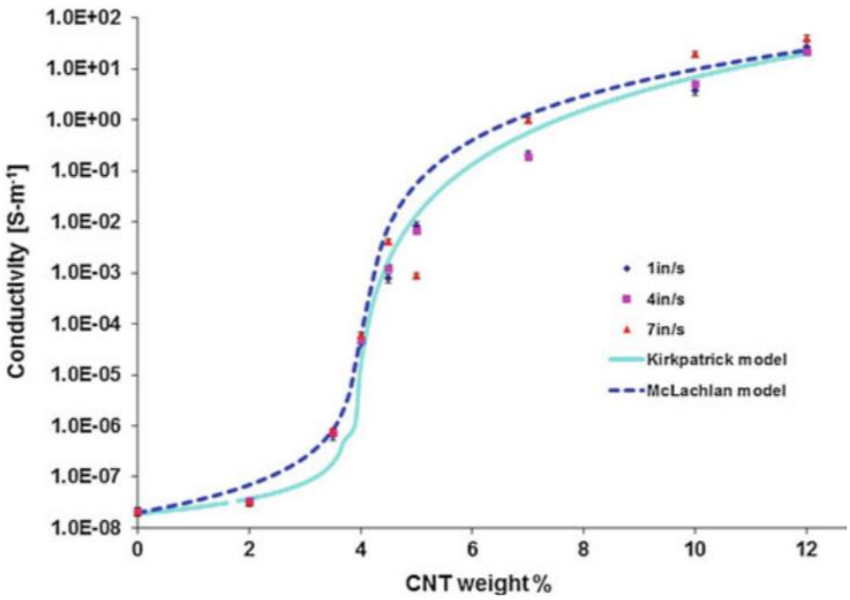

Figure 22: The electrical conductivity of MWNT-PP nanocomposites and the percentage weight of carbon nanotubes at injection speeds of 1, 4 and 7 inches/s, respectively [39].

While ***A. Kovalcıkova et al***. (2012) [42] studied the impact of the addition of multi-walled carbon nanotubes (MWCNT) on the basic electrical properties of silicon nitrate ceramic materials. They used different ratios (1 or 3% by weight) of multi-walled carbon tubes with equal hot pressure to prepare the composite materials from silicon nitrate ceramics. Improved electrical conductivity was observed when carbon nanotubes were added (2 S/m in 3% of the Si_3N_4/CNT nano) and 1% by weight of Si_3N_4/CNT remained insulated. ***M. Haghgoo et.*** [43] studied two-step method called the analytical electrical conductivity method to calculate the effective electrical conductivity of a hybrid composite consisting of carbon (CF)-carbon nanotubes (CNT)-polymer. First, they dispersed the carbon nanotubes in the non-conductive polymer matrix and then obtained the electrical conductivity of the carbon nanotube compound-polymer. They randomly distributed carbon nanotubes in the carbon-polymer nanotube compound and estimated the effective electrical conductivity of the carbon nanotube compound-polymer hybrid. They evaluated the impact of critical parameters, including alignment, volumetric fraction, aspect ratio of carbon nanotubes, lumpy state, and potential barrier height of the polymer on the electrical conductivity of the hybrid compound. They also investigated the effect of carbon nanotube content as well as the effect of aspect ratio on the electrically conductive behavior of polymeric hybrid vehicles as shown in figure 23. The results show that the polymeric hybrid compound with the highest aspect ratio and matching of carbon nanotubes gives higher electrical conductivity.
Yasser Zare et al.[44] In this study, they presented a model for predicting the conductivity accuracy of polymer compounds containing carbon fiber nano, namely the Ouali model, by combining the contributions of conductivity of CNFs, active CNF quantity, tunnel areas, and interphase zone. The composite becomes dielectric when the interphase depth (t) is less than 8 nm, while at an interphase depth of 40 nm, the conductivity of the compound is at its highest peak at 0.04 S/m and the interconductivity is 400 S/m. Through these results, they concluded that the conductivity and interphase depth have a significant impact on the overall electrical performance of the vehicles. In addition, the compound becomes dielectric when the contact diameter (D) is less than 10 nanometers and the length of the carbon nanofiber (liter) is less than 13 micrometers. In contrast, the conductivity of the compound reaches 0.1 Siemens/m at a contact diameter (40 nm) and the maximum length values of the carbon nanofiber (80 µm). These results show that the effect of nanofiber length and wider tunnels was a positive effect on the electrical conductivity of multi-core carbon nanofibers.

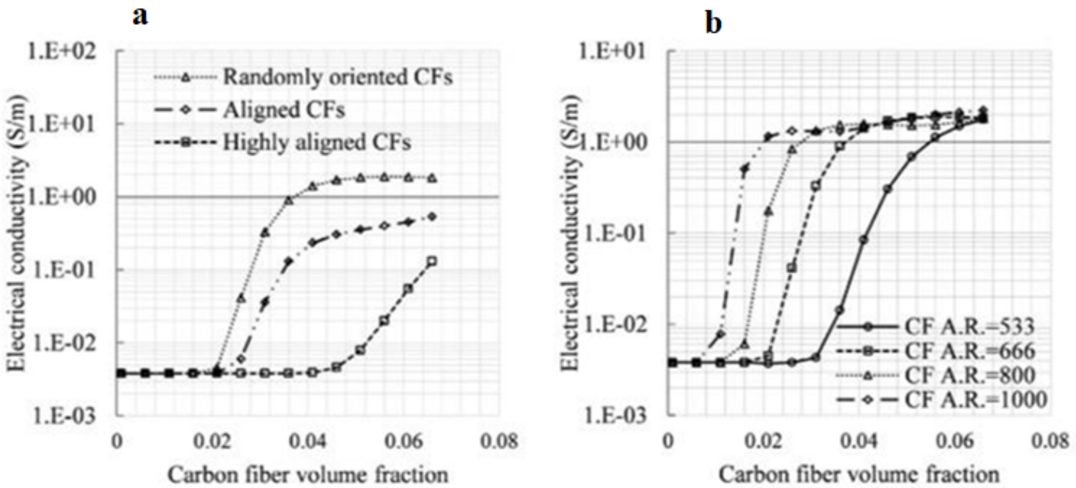

Figure 23: The electrical conductivity of the CF-CNT Bomer compound was measured at different values (a) the angle of alignment of CFs and the height of (b) the ratio of width to height of CF [43].

4.3. Electromagnetic Wave Dissipation

Electromagnetic pollution is a major concern for human health with the rapid development of wireless information technologies and electronic devices, which have had negative effects on the normal operation of sensitive electronic devices [45], [46]. It is thus important that the ideal electromagnetic wave absorber should have light weight, thin thickness, and high absorption of electromagnetic waves, wide width, multi-functionality, and adjustable absorption frequency [47]. There are studies on the development of nanocomposites added to polymeric materials and the mechanism of absorbing electromagnetic waves. ***C. Zou et al.*** [48] synthesized nanocomposites consisting of Fe_3O_4/C that possess the structure of the yolk shell and used an appropriate strategy with the help of silica. Fe_3O_4/C nanocomposites showed clear integrations between magnetic loss, dielectric loss and improved electromagnetic absorption capacity in 17.3~19.3 GHz range. These nanocomposites consisting of Fe_3O_4/c are very useful in the future for the preparation and design of highly efficient and lightweight microwave pipettes. It may also be used in catalysts and biomedicine etc.

N. Yesmin et al. [49] studied the effectiveness of EMI-SE protection. They coated the composites with fiberglass/epoxy and combined with Fe_3O_4 nanoparticles and carbon nanotubes (CNTs) with additional reinforcement by carbon microfibers along the direction of the thickness. Using the vacuum leakage process used in the manufacture of compounds and the electro agglomerate process, the carbon microfiber was optimized towards the thickness between the plates. X-band frequency band (8-12 GHz) was used to measure the protection capacity of electromagnetic interference of vehicles. They also investigated the effect of carbon fibers of three different lengths (80, 150, and 350 μm) and different percentages of amounts of Fe_3O_4 nanoparticles (0.5 and 1% by weight) with two different fiber densities (1000 and 2000 fibers/mm2) on the total protection capacity against electromagnetic interference including absorption and reflection.

Reza Gholipur. [50]Due to concerns of radioactive electromagnetic contamination, incorporate materials that have the ability to dilute electromagnetic energy into home decorations. Use nanocomposites consisting of peanut husks/CoFe2O4/graphene reducing oxide/polyvinyl alcohol (PS/CF/(RGO)x/PVA) whose magnetic and electrical properties can be adjusted by adjusting the amount of RGO in the mixture. They discovered a direct relationship between improved absorption and higher RGO content by examining the absorption capabilities of the compound.PS/CF/(RGO)x/PVA nanocomposites have exceptional mitigation capabilities of -20.98404 dB for a thickness of 1 mm and are also characterized by good impedance matching due to the harmonious effects of magnetic dielectric properties as well as the presence of different paths for the transmission of electromagnetic waves through the three-dimensional porous structure, in addition to the numerous defects in the carbon produced from peanut husks. Due to the light weight and flexibility of PS/CF/(RGO)x/PVA nanocomposites, they have been used in the production of flexible electronic devices, such as optical resistors, and these nanocomposites are similar to the absorption equipment used in industry.

5. Conclusions

In this paper, we demonstrate the importance of adding nanomaterials due to their unique properties, which play a significant role in improving the overall properties of composite materials. The addition of nanomaterials to polymer matrices has led to the development of polymer-based nanocomposites characterized by superior mechanical strength, enhanced electrical conductivity, and other important properties. In addition, this research addresses several studies and techniques that help homogeneously disperse nanomaterials within the polymer matrix to achieve high-quality composites. Given the importance of dispersing nanomaterials within polymers and their effects on electrical and mechanical properties, careful control must be exercised when selecting the manufacturing method for polymer nanocomposites and the selection of operating parameters. Studies are also being conducted to understand the effect of these nanoparticles on the mechanical and electrical properties of polymer nanocomposites.

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