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Abstract

Many industries, such as those in the fields of medicine, textiles, cosmetics, agriculture, optics, food packaging, optoelectronics, semiconductors, aerospace, building materials, and catalysis, utilise nanoparticles and nanocomposites in a variety of applications. A unique class of materials, polymeric nanocomposites outperform their microparticle counterparts by fusing organic polymers with inorganic nanoparticles. Consequently, they ought to advance the field of engineering applications. The presence of inorganic nanoparticles can significantly alter the properties of a polymer matrix. Titanium dioxide ($n\text{TiO}_2$) and zinc oxide ($n\text{ZnO}$), two nanoparticle reinforced polymer flexible composites, offer new design opportunities with exceptional mechanical and chemical capabilities. The mechanical, morphological, and thermal properties of polypropylene (PP) composite materials filled with $n\text{TiO}_2$ and $n\text{ZnO}$ were investigated in this study. Nanoparticles made up between 1 and 5 weight percent of the matrix. For improved surface adherence and fine dispersion, nanoparticles were coated with maleic anhydride grafted styrene ethylene butylene styrene (SEBS-g-MA) and silane, respectively, prior to melt mixing. To investigate the effects of modified and unmodified nanoparticles at various concentrations on the mechanical characteristics, morphological, and thermal properties, PP/nanoparticle nanocomposites were made using a twin-screw extruder and a heat press. Due to the stiff structure of nanoparticles, impact strength and elongation at break have decreased while all tensile parameters, such as yield strength and tensile strength, have increased. In spite of the fact that $n\text{TiO}_2$ has a higher hardness than $n\text{ZnO}$, nanocomposites containing it showed more elongation than those containing the latter. The PP/ $n\text{TiO}_2$ nanocomposite produced more than SEBS-g-MA due to the presence of silane. However, compared to $n\text{ZnO}$ nanocomposites, silane-modified $n\text{TiO}_2$ nanocomposites have better tensile properties. Reduced elongation at break is

guaranteed in this case since the more refined structure of nTiO₂ with PP has been induced. The better compatibility of nTiO₂ with silane is probably to blame for this. Additionally, thermal analysis was done to figure out the melt temperature, crystallization temperature, and crystallinity level.

Keywords: Nanocomposites, polypropylene, nano-TiO₂, nano-ZnO, morphology, mechanical properties.

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INTRODUCTION

The usage of plastic materials is increasing as a result of their advantageous physical and chemical properties, as well as technological development. These advantages of polymers are what make them popular in industrial applications. In order to give products more functional advantages than conventional polymers, reinforcements comprised of glass fiber, graphite, or metal oxide are applied to polymer surfaces. Components made of metal, ceramic, and glass are starting to be replaced by these materials, also referred to as composites. They can be used in a variety of industrial contexts [1, 2]. The use of nanocomposite materials is widespread, and their production rates are rising as nanotechnology develops. With a size of 100 nm, nanocomposite is one of the phases of a multiphase material system. Nanocomposite materials have a high area-to-volume ratio because the filler particles are so tiny. Nanocomposite has many benefits, including as low weight, mechanical strength, resistance to chemical corrosion, and ease of production. The variety of applications for these excellent resources has increased [3-5].

There are several different methods that can be used to create nanocomposite materials. Solution blending, melt blending, and in-situ polymerization are the most popular ones. The ideal method is melting and mixing. Melt mixing is a step in the production of polymer nanocomposites. An extruder is initially used to melt the polymer and combine it with the necessary number of nanoparticles. Instead, the polymer and strengthening components are mixed dry, heated in a mixer, and sufficiently sheared to produce the required polymer nanocomposites. Melt blending provides numerous benefits over in situ polymerization and polymer solution mixing. Melt blending is environmentally beneficial because it doesn't utilize organic solvents. The possibility of using the melt blending process in industrial applications has led to its increased popularity [6]. This approach is also more affordable when compared to alternative ones [7]. These products feature antibacterial, high mechanical, high UV, and nonflammability properties [8, 9].

Polymers are commonly used in the creation of nanocomposite materials due to their excellent properties, including as flexible structures, simple manufacturing procedures, superior form, and mechanical behaviors [4, 10, 11]. As a result of numerous studies on nanocomposites that focused on the polymer that would be used as the matrix phase, the quality of the polymer is noticeably improved even when very small amounts of nanoparticles are added. Large-scale phase contact is possible due to the high area-to-volume ratio of the reinforcing nanoparticles and their nanoscale size [12]. Polymer-based nanocomposites are preferable to those made of metal or ceramic matrix [13]. Polymer nanocomposites are made using the process of melt fiber spinning. Using this method, nanoparticles are integrated into the polymer matrix. The usage of

polymer matrix nanocomposites can provide composites with increased tensile strength and practical properties [4, 14, 15].

Polypropylene is one of the most important commercial polymers. In the production of containers, cars, cables, ordinary plastics, etc., it is commonly utilized [16-18]. It has outstanding thermal and tensile properties at room temperature. Additionally, it has a high rating for chemical resistance [2, 19]. The textile industry uses polypropylene (PP) to provide textile products functionality. It has what seems to be a flat, waxy fiber structure. Polypropylene fibers are required for the production of carpets, textiles, and technical textile products. They are preferred due to their superior strength, economical manufacture, and chemical resistance. The physical properties of polypropylene are listed in Table 1.

Table 1. Polypropylene properties.

Properties	Value
Melting point (°C)	160–175
T _g (°C)	40
Density (gr/cm ³)	0.9
Degradation temperature (°C)	328–410

The production of fiber, which can be generated from a number of sources, is one of the essential fundamental materials utilized in the textile industry. Alternative fibers are becoming more and more popular even though cotton fiber, which comes from natural sources, is still the most commonly used fiber in industry. In order to create useful textile products, one of these fiber types-which is polymer-based-is reinforced with reinforcing components. The development of unique products and the reduction of manufacturing problems are the main advantages of fiber matrix polymer nanocomposites [20, 21].

It is important to remember that nanoparticles give composite materials their special characteristics, which are then improved and reinforced by reinforcing components to make composites more robust and useful. TiO₂, SiO₂, CaCO₃, and ZnO are just a few of the inorganic nanoparticles that are being used to improve the mechanical properties of polymers [12, 22]. Although cost savings are the main advantage of utilizing inorganic filler in polymer composites, other mechanical properties like as rigidity, toughness, and dimensional stability can also be improved [23]. Numerous researchers in this field combined zinc oxide with polymer composites to produce a material with excellent properties. Wacharawichanant et al observed that the tensile strength did not considerably increase even when ZnO was added to polypropylene composite [24]. Similar outcomes, including a decrease in the composite's elastic modulus, yield strength, and tensile strength, were observed in related comprehensive tests conducted by other researchers [25]. Similar results were obtained when CaCO₃ and other inorganic fillers were added to polypropylene composites, producing low values of tensile strength [26]. Since TiO₂ is non-toxic, it has garnered a lot of interest from manufacturers of inorganic fillers. Additional advantages of TiO₂ include its high hardness, chemical inertness, affordability, and ability to filter UV rays. Several researchers have investigated the use of TiO₂ with PP to improve the composite's physical and mechanical properties. As a result, PP composite's tensile strength is greatly increased when TiO₂ is added [27-31].

Polymers reinforced with nano metal oxides are becoming more and more popular due to their improved mechanical strength and design flexibility as well as their improved chemical, electrical, and optical properties [32]. Agglomeration of the nanoparticles, on the other hand, may degrade the properties of the nano composites. In order to resolve this issue, dispersant and coupling agents are used [12]. Another difficulty that is regularly encountered is the stiffness of the inorganic material causing the impact strength to decrease. Researchers utilise elastomeric natural materials to increase the durability of composites [33]. This study looked at the mechanical, morphological, and thermal aspects of polypropylene reinforced with titan dioxide and zinc oxide at the nanoscale. Improved tensile properties were reached by using silane and SEBS-g-MA for improved dispersion and surface adhesion between the metal oxide and the matrix.

EXPERIMENTAL

Ingredients & Production of the Nano Particles

With a melt flow index of 14g/min and a density of 0.900g/cm³, PP was purchased in pellet form from Lotte Chemical Titan Malaysia. The Chinese Nabond Company employed ZnO and TiO₂ as nanomaterials. For better surface adhesion and dispersion, the nanoparticles were coated with vinyltrimethoxysilane (VTMS, Aldrich) and SEBS-g-MA (FG1901X, Kraton, Shell Company). To coat the nano metal oxide particles, they first utilized SEBS-g-MA and subsequently silane. It was anticipated that the coupling agent function of SEBS-g-MA would work better when used as a compatibilizer when coated onto the powders. The silane coating resulted in more evenly disseminated SEBS-g-MA coated particles in the polymer matrix. Coating was carried out by combining SEBS-g-MA with nanoparticles dissolved in toluene over a period of 48 hours at 25°C. The mixture was dried for eight hours at 50 degrees Celsius, and then the SEBS-g-MA coated nanoparticles were ground. 96 percent pure alcohol, 4 percent distilled water, and 1 percent silane were combined to create the coating solution. Nanoparticles coated with SEBS-g-MA were gradually added to this mixture after three hours of mixing. The mixture was ground after an eight-hour 50°C drying time.

The two types of compatibilizers (SEBS-g-MA and silane) and a predetermined amount of PP, as well as varying amounts of nanoparticles (1, 3, and 5 wt%) and a fixed amount of 3 wt% of the nanoparticles, were used to form the nanocomposite samples. The following code applies to both coated and uncoated nanocomposites: For uncoated, PP/1 wt% nTiO₂ (marked as PP/1UnTiO₂), PP/3UnTiO₂, PP/5UnTiO₂ and PP/1UnZnO, PP/3UnZnO, PP/5UnZnO and for coated, PP/silane coated 1 wt% nTiO₂ (indicated as PP/1SnTiO₂), PP/3SnTiO₂, PP/5SnTiO₂ and PP/SEBS-g-MA coated 1 wt% nZnO (designated as PP/1SEnZnO), PP/3SEnZnO, PP/5SEnZnO. PP and nanoparticles were put into the 44 L/D twin-screw extruder, designated the ZE-25A UTX, manufactured by KraussMaffei Berstorff GmbH in Germany. The screw rotated at a speed of 100 rpm while operating in a temperature range of 180°C and 220°C. Extruded strands are ground into tiny pellets, and the resulting pellets are then used in a hot press machine to produce thin plates.

Characterizations

TEM and SEM were used to study the fracture surfaces and nanoparticle dispersion. A SEM, JSM-6360LV from JEOL, Tokyo, Japan, was used to analyze the fracture surfaces of nanocomposites. The samples were coated with gold before imaging. Transmission electron microscopy (TEM, JEM-2100F, JEOL) was used to assess how well PP and nanoparticles dispersed.

The tensile test was measured using a Shimadzu Universal Testing Machine (type AG-1, Japan). The samples were 2 mm thick, 10 mm wide, and 50 mm in gauge length. At a crosshead speed of 10 mm/min, we examined the yield strength, tensile strength, tensile modulus, and elongation at break. The Izod impact test was carried out on a Zwick impact test machine with notched specimens and a 5.4 J pendulum hammer. In compliance with ASTM-D 638-03 standard, five repeat tests were conducted to obtain an average value for each sample for all experiments [34].

Differential Scanning Calorimetry (DSC)

A nitrogen environment was employed to study the melting and crystallization behaviors using differential scanning calorimetry (DSC; Perkin Elmer DSC-7). The samples (5-8 mg) were heated from 40 to 180 degrees celsius at a rate of 10 degrees per minute for 5 minutes, then cooled back to 40 degrees celsius at a rate of 10 degrees per minute for 5 minutes. The thermal history of the samples was then removed using a second heating cycle. We took readings for the crystallization degree (X_c), crystallization temperature (T_c), and melting temperature (T_m). The fusion enthalpy of the 100% crystalline phase of the PP was used as 209 J/g to calculate the degree of crystallization of the blends [35].

A Discussion on the Final Results

Mechanical Characteristics

Metal oxide nanoparticles are used to enhance the polymer matrix's mechanical characteristics [36]. The variation in yield strength and tensile strength of PP, PP/uncoated nTiO₂, PP/uncoated nZnO, PP/silane coated nTiO₂, PP/silane coated nZnO, PP/SEBS-g-MA coated nTiO₂, and PP/SEBS-g-MA coated nZnO is shown in Figures 1(a) and (b). It can be seen that the yield strength and tensile strength increased when the nano-metal oxide content was increased up to 3 wt% (yield strength increased by 16.9% and tensile strength increased by 20% for PP/UnTiO₂ nanocomposites compared to PP and yield strength increased by 6% and tensile strength increased by 12% for PP/UnZnO nanocomposites, respectively), and then decreased by 5 wt%. Neither the yield strength nor the tensile strength of the material is eventually impacted by any portion of the external load in this scenario because the agglomerated nanoparticles are swiftly separated from the polymer. Results from Zaman et al. were validated [37]. The modification of PP/nTiO₂ or PP/nZnO nanocomposites to strengthen the interfacial interaction between PP and nano-metal oxide particles was made possible by silane and SEBS-g-MA. The introduction of silane in PP/nTiO₂ or PP/nZnO nanocomposites significantly improved the interfacial interaction between nano-metal oxide and PP as compared to PP/UnTiO₂ or PP/nZnO nanocomposites. At 3 weight percent of nano-metal oxide concentration, the greatest yield strength and tensile strength of PP/SnTiO₂ and PP/SnZnO nanocomposite, which were around 32%, 31%, 20%, and 19% greater than PP matrix, were 28.9 MPa and 26.3 MPa, respectively. PP/SnTiO₂ provided the

highest yield and tensile strength, and PP/SnZnO came in second. The strength of the compatibilized system has increased due to the stronger distribution that the compatibilizer generates and enhanced solid-state adhesion, which can transmit more stress from the matrix to the dispersion phase. PP/SEnTiO₂ or PP/SEnZnO has a lesser strength while having the same quantity of nano-metal oxide as PP/SnTiO₂ or PP/SnZnO since it also contains the elastomeric phase of SEBS-g-MA.

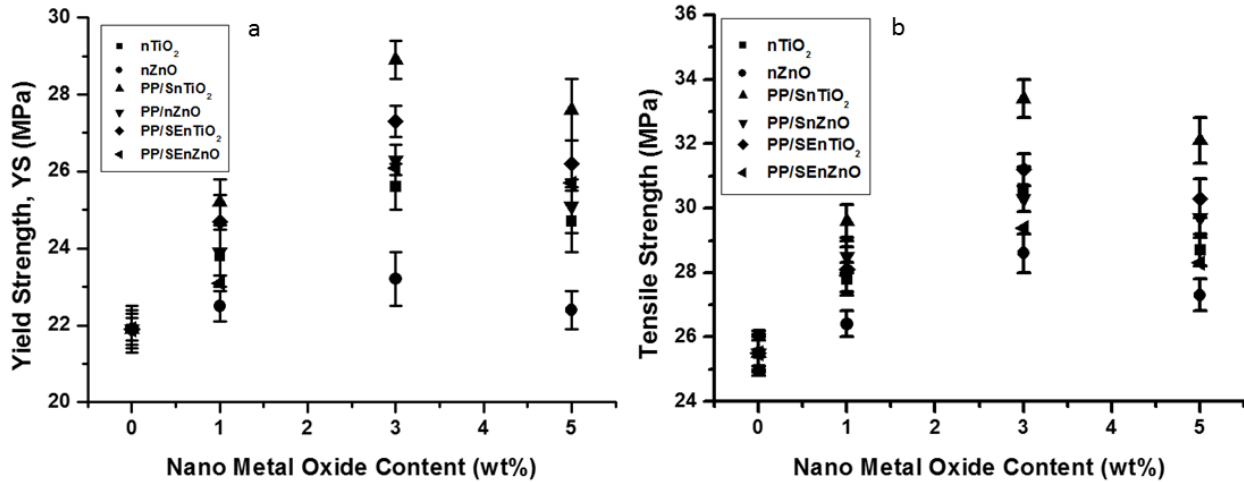


Figure 1. Tensile properties of PP nanocomposites reinforced with nanoscale titanium dioxide and nanoscale zinc oxide; (a) yield strength; and (b) tensile strength.

Figures 2(a) and (b) display the nanocomposites' tensile modulus and elongation at break as a function of nano-metal oxide content. With the addition of nano-metal oxide, tensile modulus increased consistently while elongation at break reduced gradually. By developing the modulus, the stress may be efficiently transferred from the PP to the nano-metal oxide particles. The fact that elongation decreased when nano-metal oxide was added, on the other hand, suggested that the substance might interfere with or deform PP. The mechanical restraint of the PP and personal contact were the causes of this interference. When there was 5% nano-metal oxide content, silane significantly raised the tensile modulus. The silane-coated nano-metal oxide particles were finely dispersed, and the PP and nano-metal oxide particles had a strong adhesion, which will be covered in more detail later. As a result, the tensile modulus was enriched. SEBS-g-MA nanocomposites, on the other hand, showed strong tensile moduli with a nano-metal oxide level of 5% by weight. The coating of nZnO particles on SEBS-g-MA was not distributed as finely as nTiO₂ particles, though, as shown by the results of the tensile test. Materials with higher yield strengths, tensile strengths, and tensile modulus have been developed using nTiO₂ because of its rigid structure and higher hardness than nZnO. Instead, it was anticipated that PP/nTiO₂ nanocomposites would exhibit reduced elongation when compared to nZnO-reinforced nanocomposites; instead, the opposite was actually demonstrated to be true to a larger than 1 wt% degree. This suggests that nTiO₂ and silane or SEBS-g-MA may have interacted with each other more efficiently than nZnO.

The impact features found during the impact test are displayed in Figure 2(c). Nano-metal oxide was added, but the harder particles resulted in a reduction in the impact strength. However, when PP/SnTiO₂ and PP/SEnTiO₂, as well as PP/SnZnO and PP/SEnZnO, were compared with the aforementioned nanocomposites that had silane or SEBS-g-MA, the impact strength was increased. The addition of silane produces the nanocomposite toughness through the improved impact strength and PP's molecular flexibility. With an increase in nano-metal oxide content, the impact strength reduced because of the presence of agglomerates, which will be discussed later. As the amount of nano-metal oxide increased, agglomerates developed and the interfacial nano-metal oxide-PP adhesion decreased because the SEBS-g-MA did not provide as excellent of a dispersion as it did in the silane. As a result, despite the presence of the elastomer phase, inadequate impact strength has been reported in the nanocomposite of PP/SEnTiO₂ and PP/SEnZnO. It is well knowledge that each agglomeration has the effect of cracking and reduces the material's impact strength.

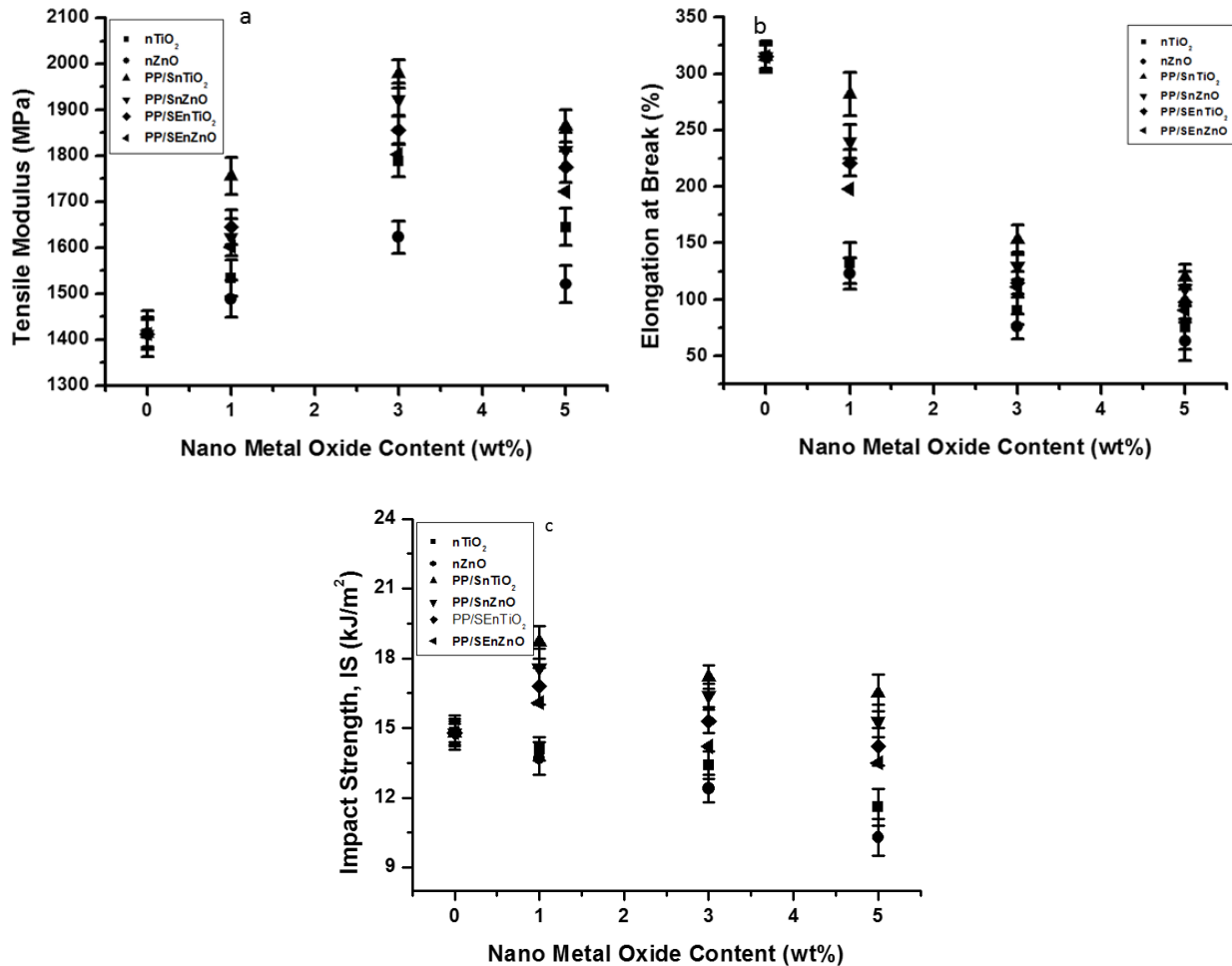


Figure 2. Tensile and impact properties of PP nanocomposites reinforced with nTiO₂ and nZnO, such as (a) tensile modulus, (b) elongation at break, and (c) impact strength.

Surface Morphology and Particle Dispersion

The homogeneity of different morphologies, domain sizes, and shapes, as well as their relationship to mechanical properties, are thought to be among the most important factors in determining the degree of dispersion of interactions between the two phases [38]. TEM images of PP/nTiO₂ nanocomposites formed of 3 weight percent nTiO₂ (designated as PP/3UnTiO₂), 3 weight percent nTiO₂ that has been coated with PP/silane (designated as PP/3SnTiO₂), or 3 weight percent nTiO₂ that has been coated with PP/SEBS-g-MA are shown in Figure 3(a-c). The significantly bigger nTiO₂ particles in Figure 3(a) are not intercalated and most likely form a "micro composite" structure because there is no silane or SEBS-g-MA present. The PP continues across the remaining space, and the nTiO₂ tactoids are visible in the black shape. The poor dispersion of some nTiO₂ particles, however, may be represented by specific black forms. Figure 3(c) shows a lower number of nTiO₂ particles compared to Figure 3(a), and they have been blended into lighter parts. Silane, which functions as a compatibilizer and intercalator between PP and nTiO₂ (Figure 3, b), might be added, though, to get a better dispersion. The PP/3SnTiO₂ systems demonstrate better and more uniform nTiO₂ dispersion in the PP matrix due to the silane's black shape being less obvious than in the PP/3SEnTiO₂ system. Figures 3(d) through 3(f) show TEM images of the nanocomposites PP/3UnZnO, PP/3SnZnO, and PP/3SEnZnO. The very large nZnO particles in Figure 3(d) that are not intercalated show strong dispersion between PP and nZnO. The TEM photomicrographs of the PP/3SnZnO shown in Figure 3(e) showed that the nZnO particles were evenly distributed throughout the matrix and were almost completely immersed in it. This ensures both the compatibility of the two materials and the strong bonds produced between nTiO₂ and PP. When the SEBS-g-MA coating was applied, however, the dispersion of nZnO particles was less than in Figure 3(e) (Figure 3(f)), even though some nanoparticles were split into lighter parts during the mixing process. In addition, the silane coating on nZnO particles enhances surface adhesion and fine dispersion when compared to the silane coating on nTiO₂ particles.

The fracture surfaces of nanocomposites are depicted in SEM photomicrographs in Figure 4. Figures 4(a) and (d) respectively illustrate the placement of uncoated nTiO₂ or nZnO with nanocomposites at random in the PP matrix. Several huge agglomerates larger than 1 μm in size were exposed above the fracture surface. The PP to PP/3UnTiO₂ nanocomposite has big particles since there is no functional polymer present and the interfaces seem to be individually wet and/or weak to the adhesion of the components. This illustrates the high impact resistance and low tensile properties of the nanocomposites discussed above. Figure 4(b) and (e) respectively depict nanocomposites made of 3SnTiO₂ and 3SnZnO particles. These nanoparticles spread more evenly across the PP matrix and efficiently dispersed without aggregating. This demonstrates that soaking the nanoparticles has a major impact on the connection, adhesion, and direct contact between TPE and nTiO₂/nZnO. 3SnTiO₂ particles were more equally dispersed in the PP matrix than 3SnZnO particles. This lends even more credence to the advantages of the improved mechanical properties of the nanocomposites.

Figures 4(c) and (f) depict the morphological structures of nanocomposites including 3SEnTiO₂ and 3SEnZnO particles. The PP/3SEnTiO₂ or PP/3SEnZnO systems contain some large parts and smaller average particle sizes than the PP/3UnTiO₂ or PP/3UnZnO systems. By comparison to 3UnTiO₂/3UnZnO, 3SEnTiO₂/3SEnZnO and SEBS-g-MA were more compatible, as shown by this. However, nanoparticle agglomerates formed in some regions of the PP matrix decreased the tensile characteristics of the PP/3SEnTiO₂ or 3SEnZnO nanocomposites. The superior surface

adhesion and fine structure of 3SnTiO₂ particles to PP, as compared to 3SnZnO particles, confirm the findings of the superior tensile properties of the PP/3SnTiO₂ nanocomposite.

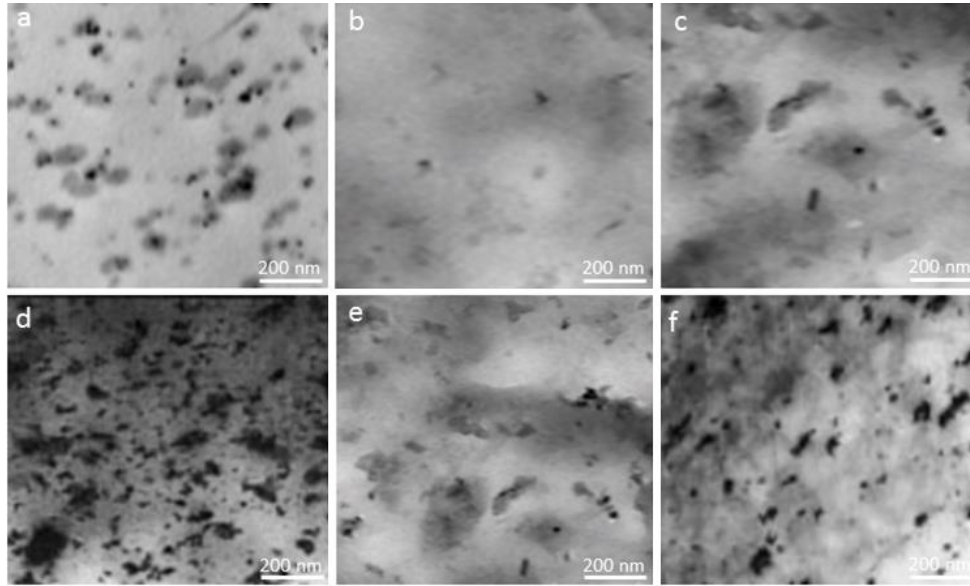


Figure 3. TEM images of (a) PP/3UnTiO₂, (b) PP/3SnTiO₂, (c) PP/3SEnTiO₂, (d) PP/3UnZnO, (e) PP/3SnZnO, and (f) PP/3SEnZnO.

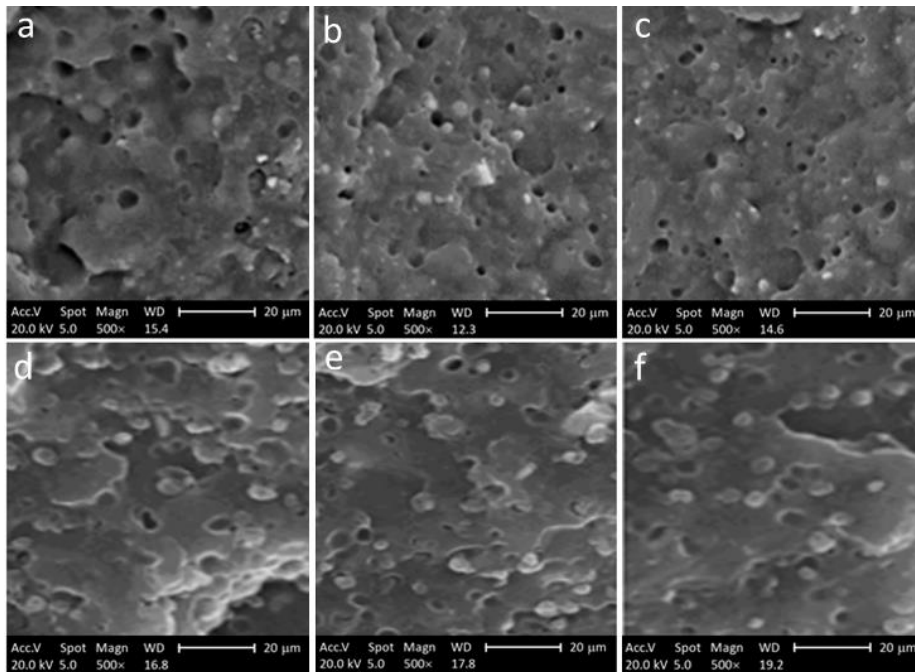


Figure 4. SEM pictures of (a) PP/3UnTiO₂, (b) PP/3SnTiO₂, (c) PP/3SEnTiO₂, (d) PP/3UnZnO, (e) PP/3SnZnO, and (f) PP/3SEnZnO.

Thermal Characteristics

The DSC results for the composites are shown in Table 2. The melt temperature (T_m) and crystallization temperature (T_c) were unaffected by the addition of $nTiO_2$ and $nZnO$. On the other hand, the addition of $nZnO$ reduced the level of crystallization more than the addition of $nTiO_2$ did, showing that the $nTiO_2$ particles had no impact on the stability of the PP. The physical hindrance effect of the nano-zinc oxide on the molecular chains and the retarding effect on the PP crystals were more pronounced in PP/ $nZnO$ composites. The increased physical compatibility of $nTiO_2$ with SEBS-g-MA and finer nanoparticle dispersion are likely responsible for this outcome. Numerous studies have been conducted on the effect of nanoparticles on crystallization degree. Different experimental findings led to different results, and some of them recognized these particles as nucleating agents [39, 40]. For instance, as the amount of nanofiller rose in PP with nano $CaCO_3$ filler, the crystallinity remained unaltered [39]. However, further study on clay/PP composites revealed either an increase or a decrease in crystallinity [40, 41]. The findings of this experiment are also supported by Chandramaouleswaran et al.'s [16] discovery of a decrease in crystallinity of PP/nano ZnO composites. Most research on nano titan dioxide reinforced composites [42, 43] came to the conclusion that $nTiO_2$ had no substantial effect on the degree of crystallinity or function as a nucleating agent [25, 44].

Table 2. Thermal properties of nanocomposites.

Mixture	T_m (°C)	T_c (°C)	Enthalpy (J/g)	X_c (%)
Pure PP	166.5	126.7	87.3	42.4
PP/1 $nTiO_2$	165.7	124.9	84.5	41.3
PP/3 $nTiO_2$	166.3	126.5	83.6	40.7
PP/5 $nTiO_2$	166.5	127.3	85.2	41.8
PP/1 $nZnO$	166.6	125.4	69.5	33.5
PP/3 $nZnO$	165.8	125.7	67.5	31.6
PP/5 $nZnO$	165.8	125.4	68.2	31.9

Conclusions

Metal oxides enhance mechanical properties, however each metal oxide behaves differently based on its physical, mechanical, and chemical properties. In order to make PP/nano-metal oxide nanocomposites, a melt mixing process under the supervision of a hot press machine was used. In this study, the inclusion of two nano metal oxides, $nTiO_2$ and $nZnO$, improved the mechanical properties of the polypropylene composites. In this study, the effects of surface-modified nano metal oxide particles were examined along with the mechanical, morphological, and thermal properties of PP/nano metal oxide nanocomposites. Due to the inclusion of metal oxide nanoparticles, PP/nano metal oxide nanocomposites exhibit stronger tensile properties than pure PP matrix, however impact strength and elongation at break have reduced. The addition of silane or SEBS-g-MA coated metal oxide nano-particles significantly changes the tensile properties of PP, such as yield strength, tensile strength, and tensile modulus, but decreases impact strength and elongation. Stronger surface bonding was provided by SEBS-g-MA coated metal oxide nanoparticles in addition to fine dispersion with silane-coated nanometal oxide. Materials with greater yield strengths, tensile strengths, and tensile modulus have been

developed using nTiO₂ because of its rigid structure and higher hardness than nZnO. However, it was anticipated that PP/nTiO₂ nanocomposites would exhibit less elongation than nZnO-reinforced nanocomposites; however, the opposite was actually demonstrated to be true to a larger than 1 wt% degree. As a result, it can be shown that nTiO₂ and silane were more compatible than nZnO. In addition, the presence of nano metal oxide agglomerates in particular areas of PP reduces the tensile properties of PP/nZnO nanocomposites. The tensile characteristics and crystallinity of the PP/nZnO composites were also decreased by nZnO agglomerates that developed in some locations of the matrix.

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