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Study of Mechanical Ad Rheological Properties of Thermoplastic Polyurethane Reinforced with Various Concentrations of Reduced Graphene Oxide

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Abstract:- This study investigates the incorporation of various weight fractions of Reduced Graphene Oxide (rGO) as a nano-filler material to enhance thermoplastic polyurethane (TPU) polymer properties. Specifically, we examine the influence of rGO weight fraction on the mechanical characteristics of the resulting TPU/rGO nanocomposites. To assess the impact of preparation methods on the final properties of the TPU/rGO composites, we employed a range of fabrication techniques, including both mechanical (dry) and solvent (wet) mixing. Our results demonstrate a significant improvement in compressive strength and melt flow index when comparing the various mixing techniques to the pure TPU polymer processed under identical conditions. Notably, dry mixing exhibited superior mechanical and viscosity properties compared to wet mixing. The TPU/rGO nanocomposites achieved optimal compressive strength at a 0.1 weight percent rGO loading, outperforming composites with 0.5 and 1.0 weight percent rGO, which were produced using the dry mixing technique. These findings indicate that the processing method plays a crucial role in the formation of TPU/rGO nanocomposites, with effective dispersion of the graphene nanofiller particles within the TPU matrix being a key factor. This research paves the way for innovative applications of TPU/rGO nanocomposites across various industries.

Keywords*:* Compressive strength, polymer matrix, Nanocomposites, Graphene, nano filler, and TPU

Introduction

With the increasing interest in enhancing polymeric materials, extensive research has centred on modifying polymers through the addition of inorganic fillers as a second phase, a practice that has become standard in polymeric systems. Studies have demonstrated that effectively incorporating nanoscale inorganic particles into a polymer matrix can lead to the development of new materials with exceptional properties, addressing industry demands and replacing existing materials with limited performance. These innovative reinforced materials, known as Polymer Nanocomposites (PNCs), exhibit significant enhancements across various properties, including thermal, electrical, mechanical, optical, flammability, and gas-barrier characteristics, tailored to specific applications. Furthermore, PNCs display unique attributes such as improved stiffness, toughness, heat distortion resistance, and reduced mold shrinkage. By combining the advantages of polymers—such as corrosion resistance, lightweight nature, and ease of processing—with the enhanced functional performance provided by fillers, these novel PNCs represent a substantial advancement in material science [1]

Numerous fillers, such as carbon and glass fibers, carbon nanotubes, silica, alumina trihydrate, calcium carbonate, clay, titanium dioxide, and carbon black, have been utilized across a wide range of applications, including household products, packaging, sporting goods, aerospace components, and automotive parts [2]. When using nano-fillers, the required filler content can be as low as a few weight percent, whereas conventional reinforcement methods typically necessitate 20% to 40% filler to achieve similar effects. Nanoparticles are incorporated to enhance the mechanical, thermal, and physical properties of metallic, ceramic, and polymeric materials. Even at these low concentrations, the extensive interface between the filler and the matrix—attributable to the extremely small dimensions of the fillers—facilitates effective transfer of the filler's unique properties to the matrix [3].

The large surface area-to-volume ratios of filler particles in the nanoscale range lead to improved physical properties and enhanced chemical reactivity. This increased surface area allows for greater interaction with the matrix material, resulting in stronger adhesion and more effective load transfer. Additionally, the high reactivity of nanoscale fillers can promote beneficial chemical interactions, further enhancing the overall performance of the composite material. This makes nanofillers particularly valuable in applications where superior mechanical, thermal, and barrier properties are desired [4]. Graphene molecules have emerged as promising fillers, showcasing exceptional applicability across various fields, including molecular electronics and biomolecular nanocomposites. Their remarkable electron transport, mechanical properties, and large surface area contribute significantly to their effectiveness. Graphene consists of a single atomic layer of carbon arranged in a two-dimensional honeycomb lattice. Notably, graphite intercalation compounds demonstrated enhanced basal-plane conductivity as early as 1960, presenting a cost-effective alternative to metal conductors. Since the isolation of graphene in 2004, research into its properties has surged, drawing considerable interest from the scientific community. Due to its outstanding mechanical, thermal, and electrical characteristics, along with its high surface area and affordability, graphene is recognized as a highly promising nano-filler.

Graphene is a two-dimensional, atomically thin sheet composed of sp^2 carbon atoms arranged in a hexagonal lattice. This structure gives rise to various graphene derivatives, including 0-D fullerenes, commonly known as Bucky balls, which are formed by wrapping a graphene sheet. Additionally, carbon nanotubes (CNTs), which represent one-dimensional carbon allotropes, are produced by rolling graphene sheets, while slicing them results in other unique forms of carbon structures [7]. Graphene's numerous functional groups, such as carboxylic acids and hydroxyl (OH) groups, create a strong affinity for organic substances and polymers. This ability to interact with various materials, combined with its exceptional stiffness, strength, and thermal conductivity, enables polymers to be effectively absorbed into its porous structure. This unique combination enhances the mechanical and thermal properties of the resulting composites [8–9].

Thermoplastic polyurethane (TPU) is a remarkable synthetic polymer known for its exceptional properties. It is a block copolymer composed of soft segments (SS) and hard segments (HS), where the SS consists of long, flexible chains made from polyester or polyether that connect two rigid segments. The elastic capabilities of TPU stem from the elastomeric matrix formed by the soft segments, while the hard segments act as multifunctional tie points, providing both physical cross-links and reinforcement. The degree of phase separation between the soft segments can be adjusted, offering opportunities to fine-tune the characteristics of the polymeric matrix. This versatility has led to the widespread use of TPU in various applications, including adhesives, coatings, and fibers. Despite its advantages—such as good extensibility, abrasion resistance, solvent resistance, and high-temperature performance—TPU can face challenges in structural applications, particularly those with a low percentage of hard segments. In such cases, the material may exhibit low stiffness and tensile strength, limiting its effectiveness in demanding environments.

Permeability to gases and water vapor can pose challenges for thermoplastic polyurethane (TPU), potentially limiting its effectiveness in certain applications. To address these weaknesses, rigid layered nanofillers can be incorporated to reinforce the material. These nanofillers improve both mechanical strength and gas barrier properties, enhancing TPU's performance in demanding environments. By optimizing the composite structure, it's possible to achieve a balance between flexibility and resistance to permeation, making the material suitable for a wider range of applications [10–11]. The addition of Graphene Oxide will enhance the properties of thermoplastic polyurethane (TPU), enabling its use in a wide range of applications. These include drug delivery systems, water filtration systems, dental and medical devices, injection molded products, coatings, adhesives, fire retardants, packaging materials, optical integrated circuits, and tissue engineering applications [8]. The fillers can be incorporated into the polymeric matrix via a variety of techniques, including as direct melt-mixing, in situ polymerization, and solvent mixing. When a solid polymer dissolves in a chosen solvent, the filler is added and sonicated to disperse it. This process is known as solvent mixing. Subsequently, the solvent evaporates, allowing the polymer, now infused with the dispersed filler, to solidify. However, there are concerns regarding the sonication energy, which may break the filler into shorter lengths, potentially affecting the composite's mechanical properties. Additionally, the large-scale evaporation of the solvent could pose challenges for mass manufacturing efficiency [12]. On the other hand, melt mixing is frequently used alongside traditional polymer processing methods, such as extrusion and compression molding, due to its high speed and ease of use[13]. An interfacial zone forms between the polymer matrix and the filler upon mixing. This area, due to its proximity to the filler's surface, enhances communication between the two components and acquires distinct properties that differ from those of the bulk matrix [14].

Previous studies have explored various nanocomposites with improved mechanical properties. For instance, reinforcing aluminum with 5% carbon nanotubes resulted in a remarkable 78% increase in hardness [15]. Additionally, earlier research focused on characterizing related nanocomposites utilizing TPU and various fillers. For instance, Quan et al. investigated the incorporation of reduced graphene oxide (rGO’s) into thermoplastic polyurethane (TPU) polymers through melt blend mixing. Their findings revealed that the addition of reduced graphene oxide significantly improved the thermal stability and stiffness of the TPU nanocomposite. Notably, the material retained an impressive elongation at break value of over 600%. Prior to employing melt mixing, a solvent mixing method was utilized for the initial blending process [17]. Barik et al. developed TPU nanocomposites incorporating carbon nanofibers (CNFs) through melt blending to assess the effects of CNF dispersion and loading percentage on material properties. Their thermo-gravimetric analysis (TGA) indicated a significant enhancement in the thermal stability of TPU as the concentration of CNFs increased. Additionally, the inclusion of CNFs improved both the storage modulus and glass transition temperature of the TPU matrix. Differential Scanning Calorimetry (DSC) analysis revealed that the melting point of the soft segments shifted to higher temperatures with the addition of CNFs, further demonstrating the influence of these nanofillers on the thermal characteristics of the composite [18].

Experimental Procedure

Materials

TPU/rGO nanocomposites were synthesized by incorporating reduced graphene Oxide as a filler into thermoplastic polyurethane (TPU). The graphene oxide, supplied by AD Nanoparticle, has a purity of 99.5% and particle size ranging from 6 to 8 nm. The TPU was prepared using the method previously described, utilizing pellets as a starting material [19]. Tetrahydrofuran (THF) with a purity of 99% (Chemex Chemicals) was employed to dissolve both the reduced graphene oxide and TPU. The glassware used in the process was cleaned with methanol (99.9% purity, Chemex Chemicals) and ethanol (99.5% purity, Chemex Chemicals). The mold for the composites was constructed from plated steel, featuring a stainless steel

Frame, with Polished steel used for the top and bottom punches.

Mixing Processes

To prepare TPU/rGO nanocomposite samples containing 0.1, 0.5, and 1.0 weight percent of reduced graphene oxide (rGO) dispersed within the TPU matrix, the quantity of rGO added was carefully adjusted. Two processing methods were utilized for the integration of rGO into TPU: solvent (wet) mixing and mechanical (dry) mixing.

Both in-situ and ex-situ mixing techniques were explored to achieve optimal dispersion and incorporation of rGO in the TPU matrix.

Solvent-Based Blending

The Thermoplastic polyurethane pellets and reduced graphene oxide were mixed in-situ using a Turbula mixer (Turbula T2F). The mixing process lasted for one hour, with the speed set to 96 rpm. The mixer facilitated a three-dimensional motion of the mixing container, employing rotation, translation, and inversion to ensure thorough dispersion of the materials.

Warm Compaction

Melt processing involves applying shear forces to integrate filler components into a melted polymer matrix [13]. Two commonly used melt processing methods are extrusion and compression molding [20]. This study utilizes compression molding for the melt processing of TPU/rGO nanocomposites, which were created using reduced graphene oxide (rGO) at weight fractions of 0.1 wt%, 0.5 wt%, and 1.0 wt%.

The TPU/rGO mixture, in its dry form, was placed in a stainless steel cylindrical mold and subjected to a mechanical press. A pressure of 100 bars was applied to prevent the mixture from leaking out of the mold (known as flashing). Once the mold temperature reached 170 ºC, the mixture softened and flowed into the desired shape of a round compact disc. After cooling, the molded TPU/rGO disc could be easily removed. To ensure easy release from the mold, a silicone-based grease was applied during compaction. Additionally, to minimize contamination, the TPU/rGO disc was thoroughly cleaned with distilled water followed by ethanol after the compression molding process.

Mechanical Testing

An axial compression test was used to assess the compressive behaviour of the TPU/rGO nanocomposite. A Universal testing device, Make -Hem Techsys Pvt. Ltd. (Model HT-U1605-HS) was used to conduct the test. Approx. 8 grams of TPU/rGO sample were placed on top of one-cylinder plate for each TPU/rGO round compact disc preparation. A second cylindrical plate was used to apply vertical compression to the sample at a strain rate of 1.3 mm/min, with an initial preload of 0.1 N. The dimensions of the TPU/rGO round buttons were then mechanically adjusted to achieve a height-to-diameter (HD) ratio of 1:2, in accordance with ASTM D1621 standards. The final measurements of the TPU/rGO specimen were set to H = 12.5 mm and D = 25 mm.

Scanning Electron Microscopy (SEM)

The dispersion of reduced graphene oxide, the homogeneity of the nanocomposite, and the microstructure of the TPU/rGO buttons A scanning electron microscope TESCAN (MIRA-3 LMH)) was used to investigate the polymer matrix.

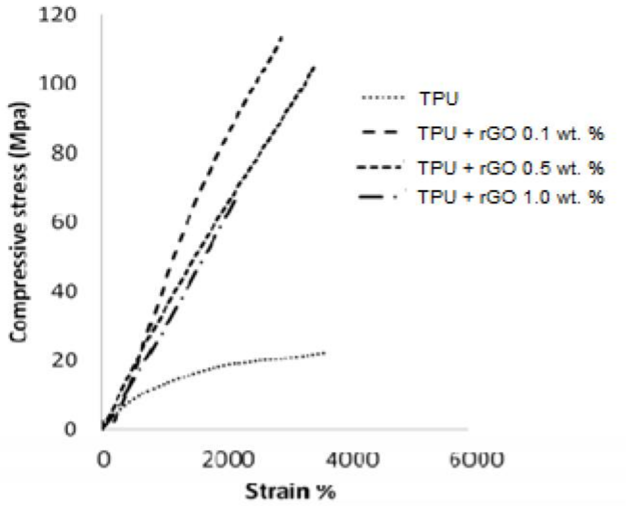
Using Image J program to produce a density histogram that showed the particle size and distribution. Image processing and analysis software is commercially available. The scale bars of every SEM picture are used to set the measurement scale. The required particles and features that show up in the SEM photos have been carefully chosen, considered, and added to the software.

Melt Flow Index

Using a melt flow indexer (MFI), the viscosity of the TPU/rGO was determined. In this method, TPU/rGO nanocomposite particles are arranged inside a column and a stainless steel cylinder is positioned on top of them. The weight of the cylinder has been chosen in compliance with ASTM D-1238, and it is 2.16 kg at 210 ºC. The sample is heated inside the column until it reaches the melting point, at which point the cylinder is supposed to start flowing through the melt to create material stripes. As the material melts and flows through the die, the time taken for a specific amount (usually 10 grams) of polymer to pass through is measured. This flow rate is expressed as the Melt Flow Index (MFI).

Thermogravimetric analysis

Thermogravimetric Analysis (TGA) is a thermal analysis technique used to measure the change in mass of a material as a function of temperature or time. It provides insights into the thermal stability, composition, and properties of materials by monitoring weight loss or gain under controlled temperature conditions.TPU pellets were dissolved in tetrahydrofuran and continuously stirred to achieve a transparent, homogeneous liquid phase, resulting in the formation of TPU/rGO nanocomposites. Following this, the TPU solution was mixed with powdered graphene nanofiller for 60 minutes. The TPU/rGO nanocomposite was then allowed to cure at room temperature in an open environment until its weight stabilized. According to ASTM guidelines for compression molding, the TPU/rGO samples were shaped into compact discs with specified dimensions. The observed increase in compressive strength with varying percentages of reduced graphene oxide is attributed to the extensive carbon network within its structure. The reduced graphene oxide is embedded within both the soft and hard TPU chains, creating a stronger interfacial bond between the reduced graphene oxide nanoparticles and the TPU chains compared to the bonds found in pure TPU.



Given that the compressive strength of the dry mixing technique is 200 MPa, the decrease in compressive strength (140 MPa) produced by solvent mixing, as depicted in Fig. S4, may be explained by the tendency of graphene oxide nanoparticles to agglomerate and the possibility of inhomogeneous dispersion during evaporation, which results in low surface energy and decreased mechanical properties due to the effect of solvent. However, by dropping the TPU/rGO suspension onto a heated substrate (drop casting) or depositing it on a revolving substrate (spin casting), this can be reduced. Pure TPU's compressive strength and various weight percentages of rGO (e.g., 0.1, 0.5, and 1 weight percent) in TPU/rGO Nano composite made through wet (solvent) mixing Stirring for an extended period of time causes flaws in graphene sheets, which are bad for the properties of the nanocomposite. Agglomeration leads to an uneven distribution of reduced graphene oxide in the TPU matrix during slow solvent evaporation with a high amount of GO. The results clearly reveal that the mechanical characteristics are lower in value for the solvent-mixed sample comparison to the dry-mixed sample. This suggests that polymer breakdown has taken place, which is concerning as noted by other researchers and noted in this investigation [16].

Results and Discussion

TPU and reduced graphene oxide were mixed by dry (mechanical) mixing technique, then the mixture was hot compacted as illustrated in Fig. 1. The TPU/rGO nanocomposite produced compact disc's dimensions were chosen for the compression moulding process in accordance with ASTM guidelines. The primary goal in creating the TPU/rGO round compact discs was to prevent sharp edges and to be utilized directly as specimens for compression tests, as seen in Fig 2. This lessens stress concentrations and enhances densification across the sample as a result [21].

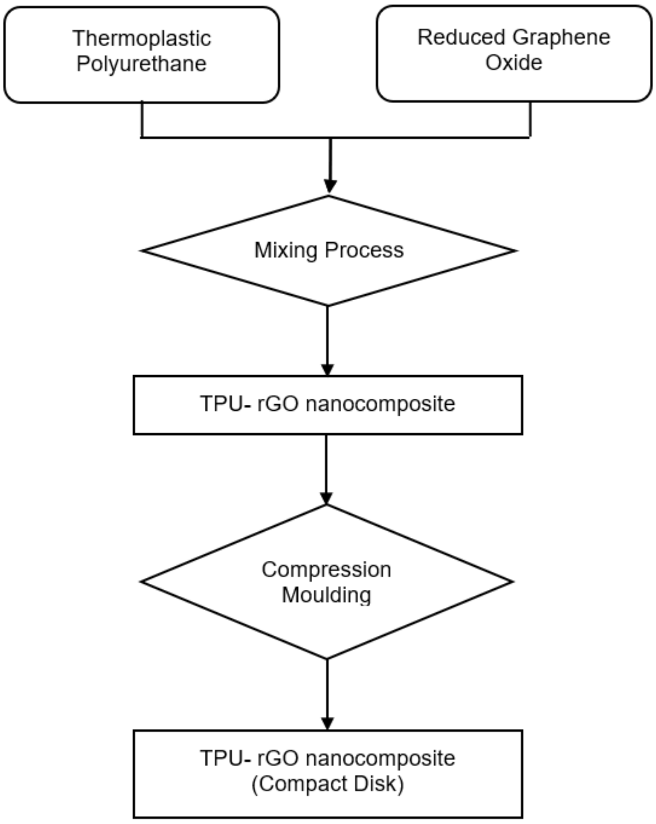


Figure 1. A Schematic illustration of the dry (mechanical) mixing process of TPU/RGO nano-composite followed by compression molding.

Comparing the interface between the size of TPU particles and rGO nanoparticles in the two mixing methods was interesting. The fast rotational speed of the container during the dry mixing process allowed for the homogeneity of the TPU/rGO combination, resulting in good characteristics. It also saves time, money, and is more hygienic and dust-free. Conversely, when the solvent was evaporating, the Graphene oxide nanoparticles in the mixture tended to clump together and disperse unevenly. This suggests that the solvent effect is to blame for the polymer breakdown. Prolonged stirring exposure causes flaws in graphene sheets that are harmful to the characteristics of the nanocomposite. Agglomeration happens when a high concentration of Graphene oxide is slowly evaporated in a solvent, which causes an uneven distribution of Graphene oxide in the TPU matrix [13].

The compressive strength results of the mechanical testing done on TPU/RGO nanocomposite samples were encouraging. For the mechanically mixed samples, additional characterisation methods such as resistivity testing, TGA, and MFI were used.In order to assess the flow of the polymer, melt flow index (MFI) test was done to reveal the link between wt. % G and its effects on the viscosity of the TPU/RGO nanocomposite. The dispersion of the G particles inside the TPU matrix may also be lessened by an increase in viscosity. Furthermore, G improved the TPU's thermal stability, according to TGA testing. In order to learn more about how increasing the weight percentage of G affects the mechanical behavior of the resulting TPU/RGO nanocomposites and to look into the distribution of G inside the TPU matrix, the morphology of the mechanical mixed samples was examined using a scanning electron microscope. Using Image-J software, the particle size distribution was calculated in order to corroborate the results of the SEM analyses.

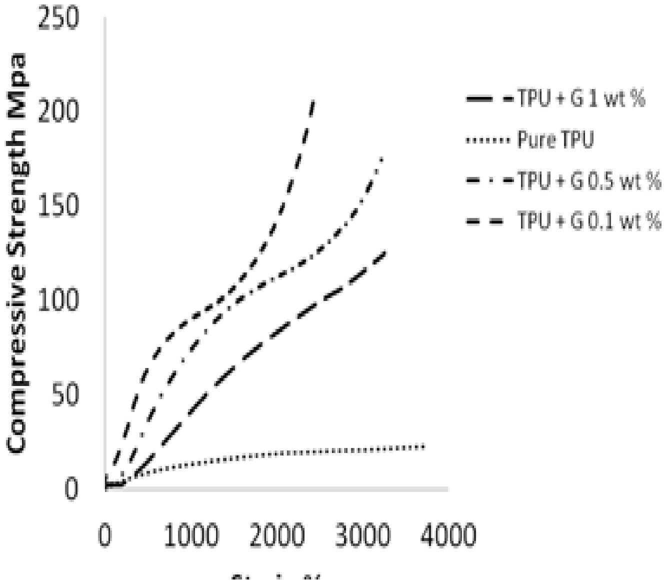


Figure 2. Compressive strength of Pure TPU and different wt % of G. (e.g. 0.1, 0.5, 1 wt. %) in TPU/RGO Nano composite prepared by dry (mechanical) mixing

The curve in Fig. 2 represented the compressive strength that resulted from the reinforcement of G into the TPU. In comparison to a pure TPU specimen with a compressive strength of 25 MPa, the compressive strength of 0.1 weight percent G reached 200 MPa, indicating a significant increase. Additionally, the compressive strength is only increased to 170 MPa by adding 0.5 weight percent G. Additionally, the compressive strength rises to 130 MPa with an addition of 1 weight percent of G. The lowest improvement of 1 weight percent was made, which is still quite encouraging. The diameter size of G nanoparticles tends to increase as the G weight percentage rises.

The large carbon network in its structure is responsible for the rise in compressive strength that occurs with the addition of G at increasing weight percentages. Because G is imbedded through both the soft and hard TPU chains, the interfacial bond between G nanoparticles and TPU chains is stronger than pure TPU interactions. It is recommended that during the compression moulding process, G be mechanically distributed throughout the TPU. According to a recent study, shear stresses during melt mixing cause the G aggregates to get dispersed throughout the TPU matrix [22]. The interfacial bond between the phases that separates the TPU chains and G behaves as holes or Nano-structure flaws, which as a result induces local stress concentrations and reduces the transfer between the TPU matrix and G, is another possible explanation for the decrease in compressive strength upon increasing weight percentage G [23]. Compressive strength decreases at 1 weight percent G because G nanoparticles begin to aggregate and crack [24].

As seen in Figs. 3(A, B) and 4A, respectively, pure TPU and pure G lack aggregated features. In contrast, the TPU / 0.1 weight percent G has an uneven shape and may form clusters that strengthen the links between TPU and G nanoparticles. It was anticipated that increasing the weight percentage of G (0.5 and 1 weight percent) in the mechanically mixed samples will raise the compressive strength above 200 MPa. However, as was previously shown, the compressive strength dropped to 130 MPa. It was discovered that, as shown in Figs. 4B and C, respectively, adding l weight percent G to the TPU matrix led to bigger agglomerations than adding 0.5 weight percent G. The lack of a uniform distribution of G due to clustering may account for the observed drop in compressive strength. This change in the role of G nanoparticles from reinforcing filler to inclusions with less cohesiveness at the TPU-G interfaces is explained. which led to the occurrence of induced cracking linked to early failure.

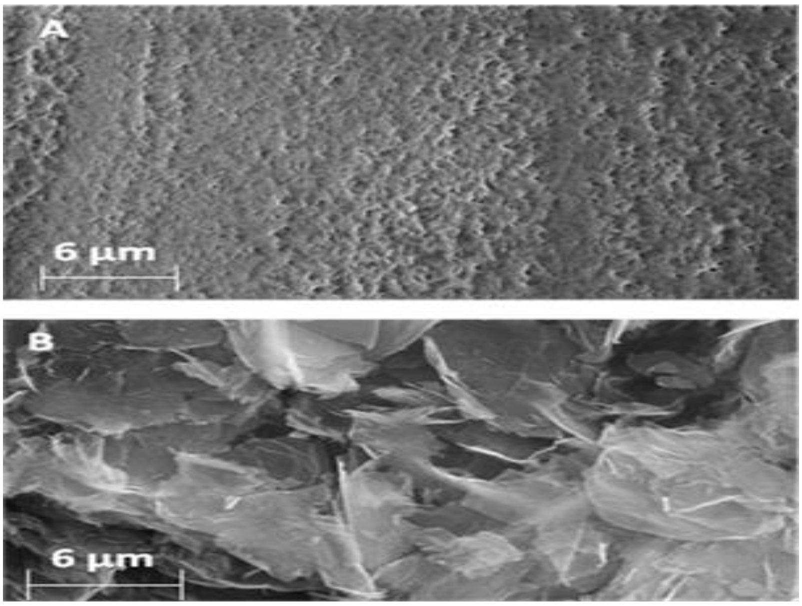


Figure 3. Scanning electron microscope images of (A) Pure TPU, (B) Pure reduced Graphene oxide

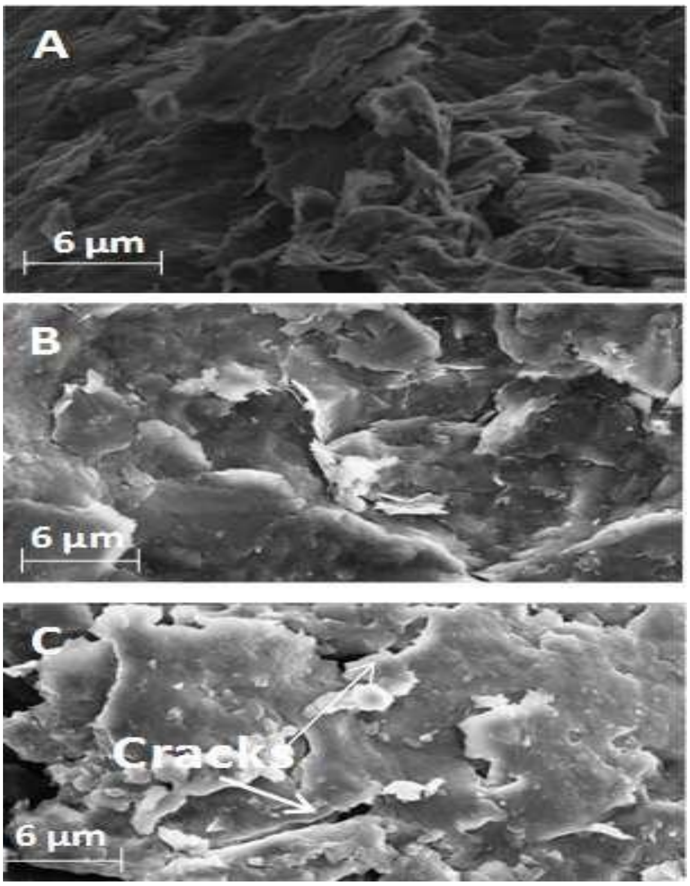


Figure 4. Scanning electron microscope images of TPU/rGO nanocomposite with different wt % of rGO :(A) 0.1 wt. % rGO (B) 0.5 wt. % rGO (C) 1 wt. % rGO

Nonetheless, as seen in Fig. 5A, the modest size distribution at 0.1% TPU/rGO supports homogeneous dispersions of reduced Graphene oxide. The measured reduced Graphene oxide particle sizes are 0.105, 0.48, and 1.78 µm for the 0.1, 0.5, and 1.0 G weight percentages, in that order. Figures 5B and 5C make it clear that the diameter size grows as the reduced Graphene oxide weight percentage increases.

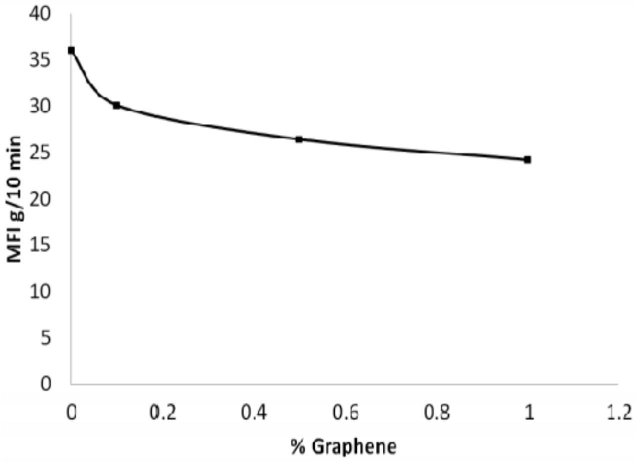


Figure 6. Melt flow index of different wt % of TPU/ Graphene Oxide nanocomposite prepared by dry (mechanical) mixing

Improving the nanocomposite's thermal deterioration for use in applications requiring a greater level of thermal stability is a fascinating project. The TGA results, as illustrated in Fig. 7, revealed that temperature increased as reduced Graphene oxide content increased, suggesting an improvement in thermal stability as reduced Graphene oxide content increased. G's addition to the TPU matrix accelerated the breakdown.

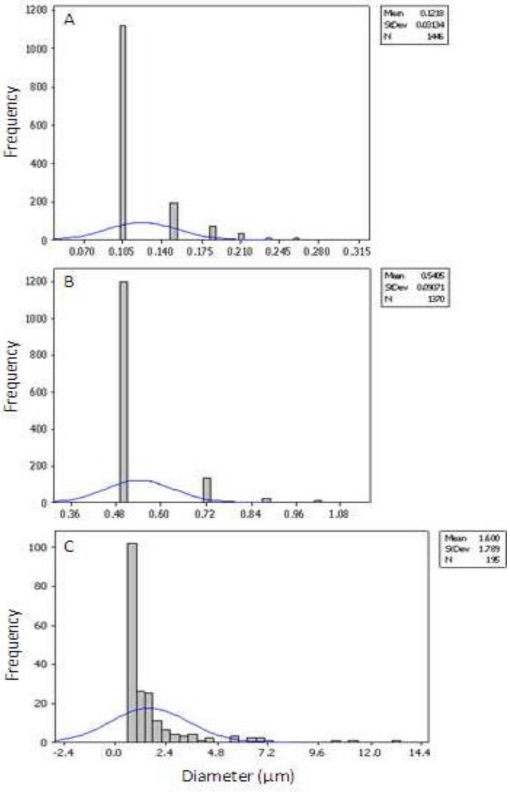


Figure 5. Size distribution of TPU/rGO nanocomposite with different wt % of rGO: (A) 0.1 wt % rGO (B) 0.5 wt % rGO (C) 1 wt % rGO

The TPU/rGO nanocomposite's thermal stability was improved due to the interfacial contacts that were created between reduced Graphene oxide and TPU. Along with mechanical characteristics, thermal stability studies expand the potential uses of polymer nano composites [27, 28].

Moving to the composite physical qualities, not only reduced Graphene oxide plays a vital function to improve the mechanical properties but also the 0.1 wt.% reduced Graphene oxide reduces the viscosity of TPU melt significantly and makes the processing easier. The results showed that the 0.1 weight percent reduced Graphene oxide exhibits a greater melt flow index (lower viscosity) than the 0.5 weight percent and 1 weight percent reduced Graphene oxide. As seen in Fig. 6, a rise in rGO% results in a decrease in the MFI. Any polymer nanocomposites' mechanical performance is determined by how well the load is transferred between the reinforcement and the matrix. Higher shear force required between reduced Graphene oxide nanoparticles and TPU can be due to lower melt flow indices, or higher viscosity.

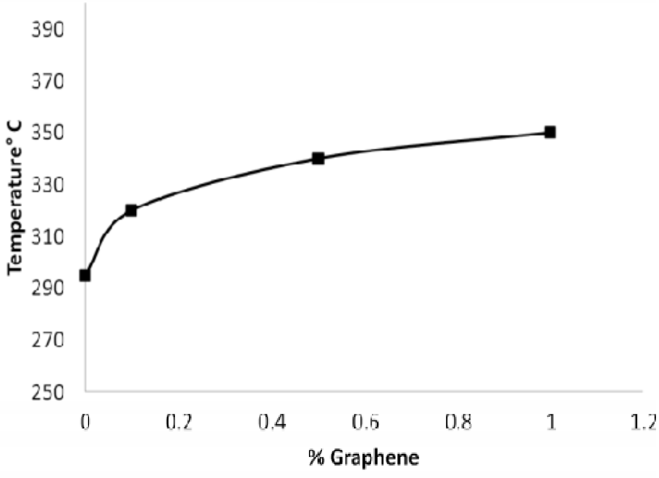


Figure 7. Thermogravimetric analysis of different wt % of TPU/ rGO nano- composite prepared by dry (mechanical) mixing

The disc's better electrical conductivity and increased thermal stability expand the disc's potential applications. As shown in Fig. 8, it was observed that electrical resistivity values rose as reduced Graphene oxide content increased. When comparing the high surface area of TPU/rGO to pureforcement, there is a noticeable change in the increase from the specimen with the lowest rein and pure TPU, which is thought of be an insulator. Next, there is an unexpected rise in the TPU [25]. The load transmission improves with decreasing weight percentage of reduced Graphene oxide (lower viscosity) added to the TPU, validating the earlier compressive strength findings. With an increase in reduced Graphene oxide weight percentage, all of the TPU/rGO samples became more viscous.

This represents the addition of 0.5% and 1% rGO. The findings of the various characterisation methods applied to the TPU/rGO nanocomposite using both mixing processes are compiled in Table 1. For every TPU/rGO nanocomposite sample, three specimens underwent testing, and an average value was noted

Table 1. Average values of mechanical properties for different wt % of reduced Graphene oxide

rGO Wt. %	0	0.1	0.5	1.0
Diameter size (µm)	0	0.105	0.48	1.72
Compressive strength (MPA)	25	200	170	130
MFI (g/10 min)	55	53	51	50.1
Dry Mixed	295	320	340	350

TGA (°C)				
Compressive strength (MPA) *MFI (g/10 min)*	25 36	115 30	100 26	70 24
Solvent mixed *TGA (°C)*	300	300	320	330

in TPU matrix. The interfacial adhesion between the phases weakens and the nanofillers take on the characteristics of holes or nanostructured defects, causing localized stress concentrations and decreasing the transfer between the filler and the matrix. Furthermore, because of its high production costs and low yield, wet mixing is not the best method for manufacturing in the sector.

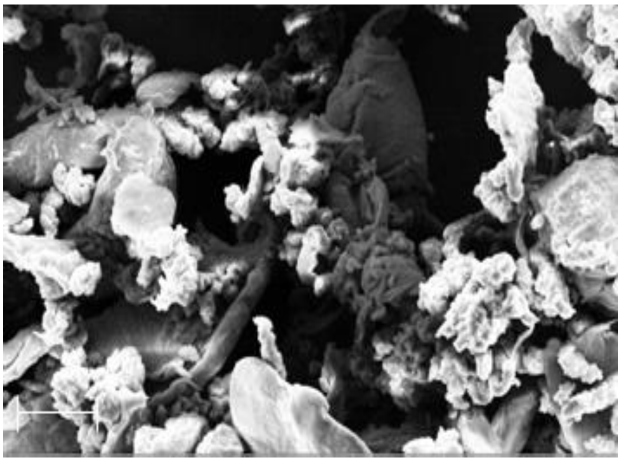


Figure 9. Scanning electron microscope images of TPU/rGO nanocomposite with 1 wt % of reduced Graphene oxide (wet mixing)

For this reason, there is still a great need for dry mixing-based fabrication methods. Since the product is mixed in separate containers of varying sizes, the dry mixing production method is dust-free and hygienic. No pollution, emissions, or additional cleaning is present. The quick and easy mounting of the container makes the process efficient in terms of time. It is proposed that during the dry mixing process, the particle surfaces become active and disordered, improving the mechanical properties as indicated in Table 1. When compared to wet mixing, the compressive strength at 0.1 weight percent increased by 85 MPA. By 23 g/10 min, the melt flow index increased considerably. As a result, the mixture's viscosity decreased, facilitating easy processing.

Due to the production of various crystallization forms raising the transition temperature, there is a 20-degree improvement in thermal stability in dry mixing. In the end, the electrical resistivity increased by a factor of ten because it allowed an electron to go farther before being obstructed by scattered light [30].

Conclusion

There were many issues with the wet mixing procedure during processing. Processing methods for graphene include mechanical mixing, compression molding, and wet mixing. Graphene has an inclination to aggregate. As demonstrated in Fig. 9, the great homogenous dispersion that can occur during evaporation leading to low surface energy and decreased mechanical properties due to the action of solvent might cause dry mixing results to exhibit an overall increase in mechanical characteristics when compared to wet technique. Defects in graphene nanoparticles caused by prolonged stirring exposure are harmful to the composite's properties. Agglomeration happened during the sluggish solvent evaporation process, and the combination's inhomogeneous graphene distribution was the outcome of the interplay between rotation and agglomeration. At 0.1 weight percent reduced Graphene oxide, a startling change in compressive strength was seen.

When compared to pure TPU, the strength rose seven times. At 0.1 weight percent reduced Graphene oxide, the lowest viscosity (maximum MFI) was attained, making it simpler to mix and process the TPU/rGO nanocomposite. Furthermore, at the lowest reinforcement concentration (0.1 weight percent reduced Graphene oxide), there was a noticeable shift in temperature and an increase that was gradual but constant as the rGO-content rose. Adding 0.1 weight percent reduced Graphene oxide and 0.5 and one weight percent reduced Graphene oxide respectively improved and increased electrical conductivity. Depending on the application, 0.5,1% weight percent reduced Graphene oxide will be appropriate if compressive strength is compromised in favor of electrical conductivity and thermal stability.

reduced Graphene oxide 's potential uses as a nano-filler have created new opportunities for the manufacture of inexpensive, lightweight solar cells, packaging films, vehicle parts, and biological products including medical implants.

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