Morphological Analysis of Injection Molded PP-Alumina Composites

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Received 01.08.2023 **received in revised form** 06.11.2023, **accepted** 23.11.2023
DOI: 10.47904/IJSKIT.13.2.2023.60-64

ABSTRACT- **The technique of material morphological analysis offers a comprehensive examination of the crystalline and amorphous characteristics of materials, along with valuable insights into their surface properties. The utilization of Scanning Electron Microscopy (SEM) as an imaging technique is highly advantageous for the examination and interpretation of the surface-topography of solid materials at significant levels of magnification. Similar to this, atomic force microscopy (AFM) is a scientific technique used to look at the surface properties of materials at the micro- and nanoscale levels. In this work, SEM and AFM methods are used to analyze injection-molded Polypropylene (PP)- Alumina composites**.

Keywords- **SEM, AFM, Morphological Investigation, Composites, Alumina**

1. INTRODUCTION

A polymer matrix that is reinforced with fillers or reinforcements makes up a particular family of composite materials known as polymer composites. The reinforcements, which frequently come in the form of fibers or particles, are adhered to by the polymer matrix, which acts as a persistent phase [1]. In compared to the constituent materials, the composite material produced by the combination of the reinforcements and the polymer matrix demonstrates better properties [2].

The primary component of the composite material is the polymer matrix, which also gives the reinforcement phase cohesion and support [3]. Epoxy, polyester/polyurethane, and thermoplastic polymers are examples of polymer resins that are often used in a variety of applications. Based on the required mechanical, thermal, electrical, or chemical characteristics of the composite, the choice of the matrix material can be made. Plastic injection molding (PIM) is a prevalent manufacturing technique employed for the mass production of plastic components[4]. The technique is recognized for its exceptional efficiency and economical nature, enabling the large-scale manufacturing of intricate and complex plastic components with remarkable precision and consistency. Plastic injection molding is a widely utilized manufacturing process across diverse industries such as automotive, electronics, consumer goods, medical devices, and other sectors[5]. Now a days, most commonly used ceramics material; Alumina is used in the fabrication of polymer composites, which is verified to include notable behavior at high temperatures, high hardness, outstanding thermal-conductivity and better-wearing resistance[6].

Alumina composites, specifically those belonging to the PPA-series, were fabricated using the injection molding technique, as shown in Figure 1. The fillers were incorporated into the composites at weight percentages of 5, 10, 15, and 20, in combination with Polypropylene (PP), as shown in Table-1. The novelty of this study is that investigation of the microstructure of injection-molded composites at a high resolution has been discussed. This is essential for understanding how the individual components of the compounds with filler particles are distributed within the PP- matrix, their alignment and the overall morphology of the material. This information is crucial for optimizing the manufacturing process and predicting material properties. Defect detection and interface analysis can be done with the help of this study like voids, inclusions, or cracks. It shows the interaction between the polymer matrix and reinforcing components which significantly influences the material's mechanical properties.

Similarly, in this study, the Nanoscale characterization has been exhibited with AFM, which is capable of providing extremely high-resolution images and topographical information at the nanoscale of the composites. This is especially valuable for studying the fine details of the compound's surface and interface morphology. Surface roughness is critical in many applications, which can affect properties like adhesion, friction, and aesthetics of produced parts.

2. MATERIALS AND METHODS

Scanning electron microscopy (SEM) is utilised in order to examine the morphology of composites, including the dispersion of reinforcements, and to analyse the mechanisms of failure on the fractured surfaces of polymer composites[7]. In order to examine the surface morphology of the synthesised compounds, the Bruker-Nova Nano SEM-450 model was employed to capture scanning electron microscopy (SEM) images of the samples (Figure 2). The specimens utilised for microscopic examination were obtained by cutting from the section of the specimens that experienced failure. Subsequently, these samples were meticulously polished with fine abrasive-wheel.

AFM (Atomic Force Microscopy) is a highly effective method employed for the examination and analysis of material surface characteristics at the nanoscale.

Scanning probe microscopy is a technique that offers high-resolution imaging and comprehensive characterization of the topographical, mechanical, and magnetic attributes of diverse samples, encompassing solids, liquids, and biological materials[8]. Atomic Force Microscopy (AFM) is extensively employed in various academic disciplines such as research, nanotechnology, materials science, and biology[9].

The purpose of conducting AFM investigation is to examine the material surface functionalization of fine Al_2O_3 particles and assess the dispersion quality of these particles within the PP matrix.

The imaging of a fractured surface is achieved by utilizing the tapping mode technique with an Atomic Force Microscope (AFM), specifically the Bruker Nanoscope V model, manufactured in the United States, (Figure 3) on more than 5 samples for each composite.

Figure 1 Fabricated PP- Alumina composites

Table -1 Detail composition of Al_2O_3 filled PP-composite.

Designation	Composite
PP	PP + 0 wt% Alumina
PPA- 5	PP + 5 wt% Alumina
PPA- 10	PP + 10 wt% Alumina
PPA- 15	PP + 15 wt% Alumina
PPA- 20	PP + 20 wt% Alumina

Figure 2: Scanning Electron Microscopy (SEM)

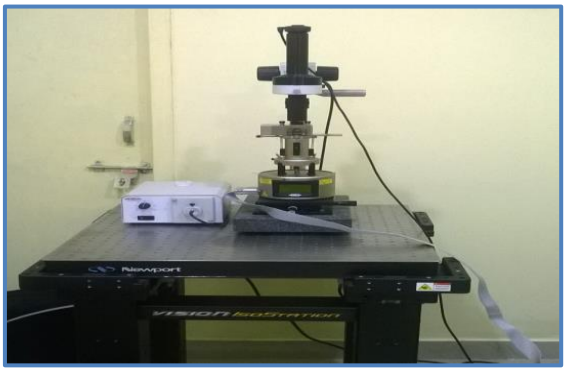


Figure 3: Atomic Force Microscopy (AFM)

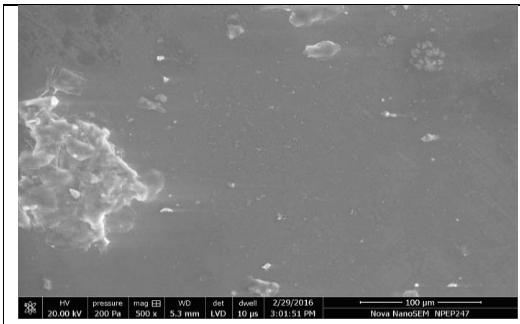
3. RESULTS

3.1 SEM of PP-Al_2O_3 compounds

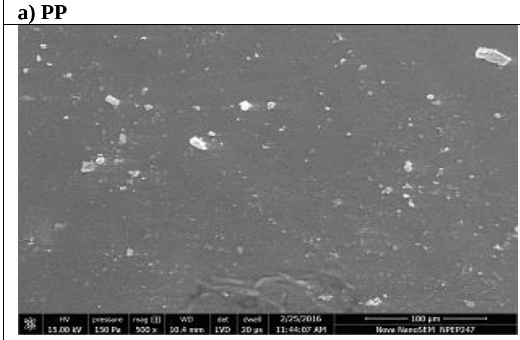
The morphology of composites containing PP-Al_2O_3 was investigated through the utilisation of scanning electron microscopy (SEM) analysis. The scanning electron microscope (SEM) was utilised to capture images of flexural fractured specimens, which were subsequently subjected to analysis. These images are presented in Figure 4. The descriptions provided indicate a strong adhesion between the polypropylene (PP) structure and the aluminium oxide (Al_2O_3) micro particles. As shown in Figure 4, virgin polypropylene (PP) exhibits a surface that is relatively smooth and does not display any indications of plastic deformation. The dispersion of Al_2O_3 in the PP-alumina composite was observed to be satisfactory, indicating that the alumina particles were evenly distributed throughout the composite material. Aluminates, in general, possess a higher surface energy, which suggests a relatively strong interaction between the PP matrix and the filler material. Tang et al. [10] assert that the flexural strength of composites is significantly influenced by the quality of the interface. The examination and characterization of the intermolecular interactions between the polymer matrix and nanotubes are conducted with meticulousness using various techniques, including spectroscopy, microscopy, and other analytical methods.

In conjunction with interfacial stiffness, static adhesion strength serves as a primary factor in enhancing filler reinforcement. However, Hajare et al. [11] suggest that the decrease in impact -strength may be attributed to the cluster phenomenon of larger filler particles, leading to stress concentration along the edges and subsequently initiating cracks within the polymer matrix. Certain aggregates can be discerned within these composites. With the presence of filler particles in composites leads to formation of agglomerates, resulting in the creation of voids within the composite material. These voids are likely to have a detrimental effect on the storage modulus, potentially causing a decrease in its strength.

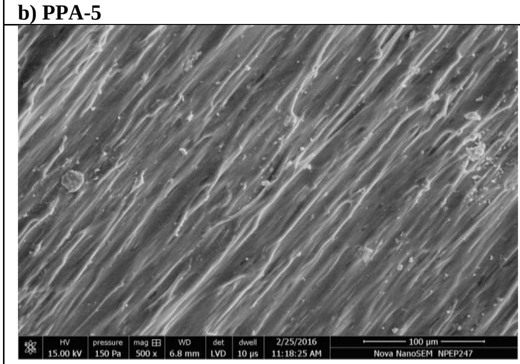
The study conducted by M. Abu-Okail et al. [12] examines the morphology and dispersion characteristics of ALPHA-Alumina nanoparticles within the LDPE matrix. The achievement of appropriate dispersion is of utmost importance, as it has a substantial influence on the ultimate characteristics of the nanocomposite material.



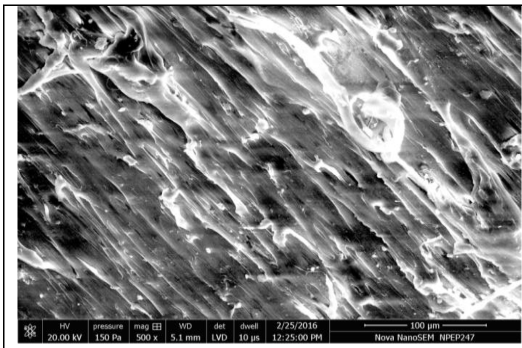
a) PP



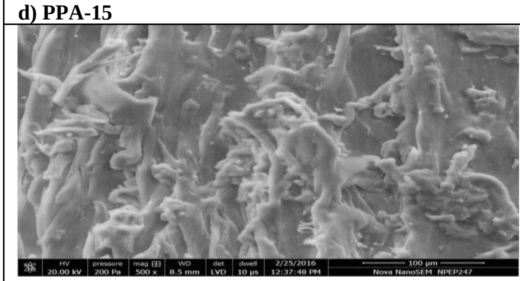
b) PPA-5



c) PPA-10



d) PPA-15



e) PPA-20

Figure 4: SEM images of PP-Alumina composites

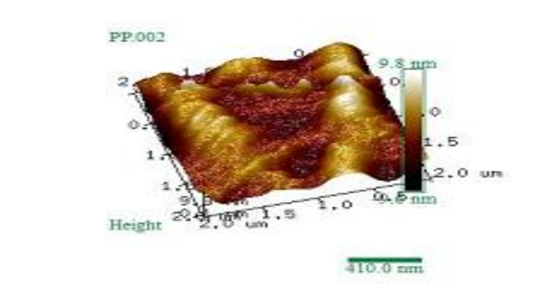
Methods such as microscopy and imaging are employed to assess the spatial arrangement and clustering of nanoparticles. In the study conducted by M. Abu-Okail et al. [12], it was noted that the inter phase's contributions to the storage modulus are comparatively lower at lower temp. This can be attributed to the rising modulus of the PP matrix, resulting in a higher storage modulus for the polymer matrix in comparison to the composites. In addition, the fracture surface exhibits certain micro-scale humps and cavities, it may be ascribed to the presence of the rubber phase in the PP-polymer, as noted by Pedrazzoli et al. [13].

Accrding to Vallack et al. [14] scanning electron microscopy remarks of the fabricated PP-Alumina composites revealed that the fracture surface exhibited an increased roughness as the filler loading was augmented. The thermal stability of composites is enhanced by the presence of spherical nodules that contain a high concentration of aluminium and oxygen. These nodules exhibit well-dispersed alumina particles, as observed by wang et al.[15].

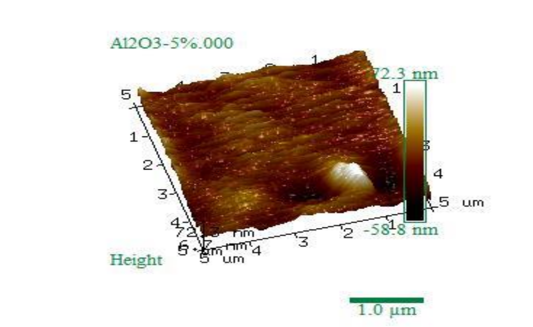
3.2 AFM of PP-Alumina compounds

Figure 5 displays the surface morphology of various PP- Al_2O_3 composites, all presented at a consistent scale of 1×1 μm^2. The alumina particles exhibit clear visibility, with an average size of approximately 0.6 µm. The results suggest that PP- Al_2O_3 composites exhibit a higher specific area compared to the as-received Al_2O_3. Similar to other porous ceramic particles, this results in an increased volume fraction/weight of the fabricated composite in the polypropylene-matrix. The presence of Al_2O_3

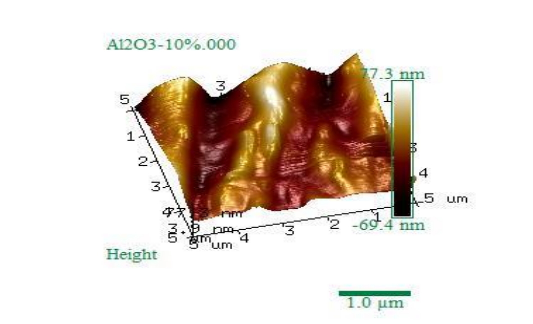
particles within the continuous PP phase has been observed by Kumar et al. [16]. The microstructure and dispersion of Al_2O_3 nanoparticles within the HDPE matrix were investigated by employing microscopy techniques. The importance of achieving adequate dispersion in nanocomposites for optimal mechanical and thermal properties has been noted.
The Atomic Force Microscopy results reveal that the morphology of Al_2O_3 within polymer matrix exhibits a chainlike-branched structure. It was observed that the polypropylene (PP) appears to adhere or envelop the alumina particles, as observed in the studies conducted by Pötschke, P. et al., [17]. The primary objective of this study is to investigate the dispersion and distribution patterns of multiwalled carbon nanotubes within the polyethylene matrix. Achieving uniform dispersion is crucial in order to optimise load transfer and reinforcement within the composite material. This study investigates the arrangement of multiwalled carbon nanotubes within the polyethylene matrix, as the orientation of these nanotubes has a substantial influence on the mechanical and electrical characteristics of the composite materials.



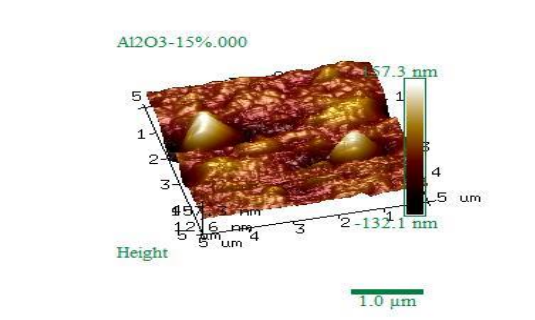
a) PP



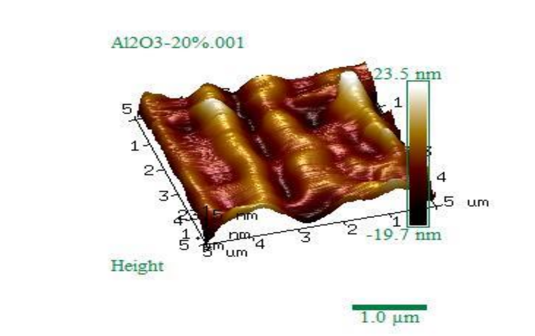
b) PPA- 5



c) PPA- 10



d) PPA- 15



e) PPA- 20

Figure 5: AFM images of PP-Alumina composites

4. CONCLUSIONS

- This research paper presents an investigation into the morphological characteristics of polypropylene (PP) alumina composites.
- The filler particles of alumina have been effectively dispersed with polypropylene. Scanning electron microscopy investigation of the PP-Alumina composites indicate that the fracture surface exhibited increased roughness as the filler loading was increased. The composites exhibit enhanced thermal stability due to the presence of well-dispersed individual alumina particles within spherical nodules that are abundant in aluminium and oxygen.
- Furthermore, it was noted that the presence of large alumina particles in the PP-Al_2O_3 composite leads to the formation of stress concentration. The average size of alumina particles was approximately 0.6 µm.
- The future research directions for fabricated composites made from polypropylene (PP) and alumina (Al_2O_3) in injection molding may include various areas of investigation and development to improve their properties with the newer applications. It explores innovative ways to improve the dispersion and alignment of alumina nanoparticles or fibers within the PP matrix for better mechanical and thermal properties. Nano-structuring will investigate the incorporation of nanoscale alumina fillers to create nano-composites. This will lead to unique properties, such as increased strength and enhanced thermal

and electrical conductivity. Similarly, research ways to make these composites more sustainable by using recycled or bio-based PP and exploring more ecofriendly processing methods, as reducing the environmental footprint of composites production is an essential future direction.

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