Fabrication and Performance Study of the Alumina-filled polypropylene Matrix Composites

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Abstract. Using the Polypropylene (PP) as the continuous phase matrix and the Alumina (Al_2O_3) as functional filler, the Al_2O_3-filled PP matrix composites were fabricated after the surface modification of Al_2O_3 by silane coupling agent KH-570. The effects of Al_2O_3 with different particle sizes and different filling amounts on the mechanical properties, thermal stability, dielectric properties and melting crystallization behavior of the composites were studied. The research results show that as the particle size of Al_2O_3 increases, the impact strength of composites gradually rises. With the increase of Al_2O_3 filling amount, the tensile modulus and bending modulus of the composite material gradually increase, as well as the thermal decomposition temperature. In addition, the crystallization temperature and the dielectric constant of the composite material enhance as the increase of Al_2O_3 filling amount, but the melting temperature does not change much.

Keywords: Polypropylene (PP); Alumina (Al_2O_3); Composite Material; Mechanical Properties.

1. Introduction

Polypropylene (PP) is one of the most promising general-purpose engineering plastics. It features good chemical stability, corrosion resistance, scale inhibition, light weight, low cost, fatigue resistance, and easy processing, within the temperature range of -10°C to 125°C [1-2]. However, the low thermal conductivity, low rigidity and easy thermal deformation of PP have limited its application in high-end fields. Composite modification with inorganic fillers is an effective way to upgrade its performance. Among them, alumina (Al_2O_3) is regarded as one of the ideal reinforcing fillers due to its high hardness, excellent thermal conductivity, good insulation and low cost [3-4]. The Al_2O_3 filled PP matrix composites, as high-performance engineering plastics developed in recent years, are widely used in electronics and electrical appliances, automobiles, mechanical equipment, household appliances, etc [5-6]. At present, the research mainly focuses on filler modification and performance optimization of composite systems. However, reports on the systematic study of the synergistic influence of different particle sizes and a wide range of filling amounts are still insufficient.

In this paper, the Al_2O_3-filled PP matrix composites were fabricated by using PP as the continuous phase matrix and the Al_2O_3 as the functional filler. The tensile properties, bending properties, impact properties, dielectric properties, and thermal performance of these composites were analyzed and studied. The effects of different particle sizes and filling amounts of Al_2O_3 on the various properties of composite materials were investigated, providing data support and theoretical explanations for the preparation of high-filled and high-performance Al_2O_3/PP composite materials.

2. Experiment

2.1 Materials

Polypropylene (PP230) was provided by Maoming Shihua Dongcheng Chemical Co., Alumina (Al_2O_3) was supplied by Jiupeng New Materials Co., Silane coupling agent (KH-570) was supplied by Nanjing Shuguang Chemical Group Co., Ultra-dry Dichloromethane was supported by Sigma Aldrich (Shanghai) Trading Co., Antioxidant 1010, Antioxidant PLM-168, and Zinc stearate were provided by Shanghai Aladdin Biochemical Technology Co., Anhydrous ethanol was provided by Tianjin Yongda Chemical Reagent Co.

2.2 Fabrication of Al_2O_3/PP Composite Materials

The weighed silane coupling agent KH-570 was dissolved in anhydrous ethanol. With equivalent Al_2O_3 was mixed evenly and dried at 120°C. Next, the mixture was added to a high-speed mixer with a certain amount of PP, antioxidant, and zinc stearate. After that, the mixture was extruded, granulated and dried. Finally, the Al_2O_3/ PP composite materials were fabricated by injection molding.

2.3 Characterization

The tensile properties of the Al_2O_3/PP composite materials were conducted in accordance with GB/ T1040.1-2006, with a tensile speed of 2mm/min. The bending properties of the Al_2O_3/PP composite materials were conducted in accordance with GB/T9341-2008, with a bending speed of 2mm/min. The impact performance was tested by GB/T1843-2008. The thermal stability was determined using a TGA-Q50 thermogravimetric analyzer under the following conditions: nitrogen atmosphere, heating rate: 20°C/min, and test range: 25-800°C. The T_g was determined by using a DSC214 differential thermal scanning calorimeter under the following conditions: nitrogen atmosphere, heating rate: 20°C/min, and test range: 20-250°C. The permittivity performance was tested at the frequency of 5~20GHz.

3. Results and Discussion

3.1 The Influence of Al_2O_3 Particle Size

The four particle sizes of Al_2O_3 (5μm, 10μm, 30μm and 50μm) with a filling amount of 50%, were selected to fabricated the Al_2O_3/PP composite materials. The influence of the particle size of Al_2O_3 on the mechanical properties was investigated, which were shown in Figures 1 and 2.

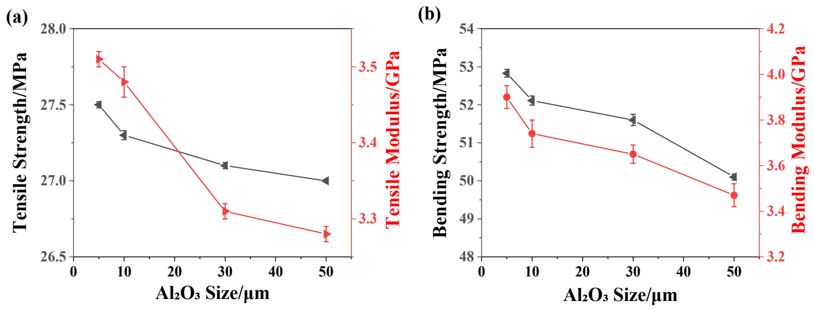

Figure 1. The effect of Al_2O_3 particle size on the tensile properties and bending properties of Al_2O_3/PP composite materials.

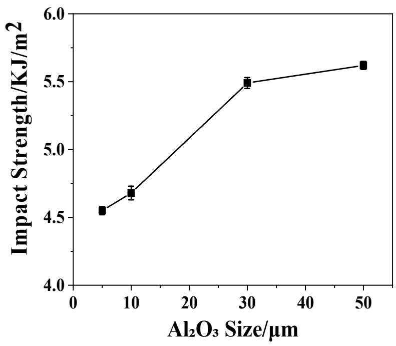

Figure 2. The effect of Al_2O_3 particle size on the impact strength of Al_2O_3/PP composite materials.

As shown in Figures 1 and 2, the tensile strength, tensile modulus, bending strength, and bending modulus of the Al_2O_3/PP composite materials gradually decreased with the increase of Al_2O_3 particle size, and the decrease was not significant. The Al_2O_3 with smaller particle size had a larger surface area and a greater bonding strength with the PP interface. As a result, the PP molecular chain could more fully wrap and entangle with the small-sized Al_2O_3. During the molding process, the internal stress generated by temperature rise and fall wa relatively small. When the mixture was subjected to tensile or bending stress, the stress was efficiently transferred to the small-sized Al_2O_3. The impact strength of the Al_2O_3/PP composite materials gradually increased with the increase of Al_2O_3 particle size in the Figure. 2. The reason was that the inorganic filler Al_2O_3 could cause silver streaking and shear yield in the PP matrix, absorbing a large amount of energy and enhancing the impact strength of the Al_2O_3/PP composite materials. The larger-sized Al_2O_3 particles had the larger volume, causing a more extensive silver stripe area around them. The larger-sized Al_2O_3 particles could more effectively block the progress of the crack, thus consuming more energy, resulting in an increase in the impact strength of the material.

3.2 The Influence of Al_2O_3 Filling Amount

The filling amounts of Al_2O_3 were selected in 30%, 40%, 50%, 60%, and 70% to fabricated the Al_2O_3/PP composite materials, respectively, with a particle size of 5μm. The influence of the filling amount of Al_2O_3 on the mechanical properties was investigated, which were shown in Figures 3 and 4.

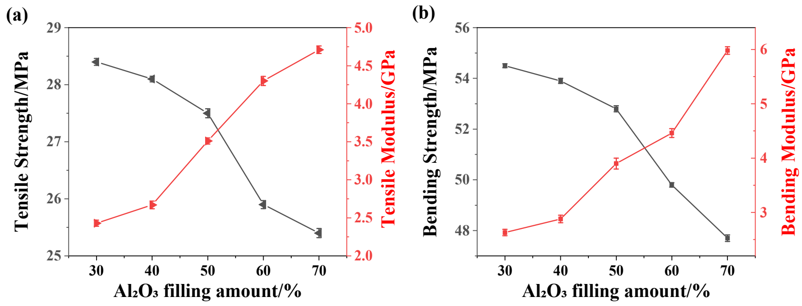

Figure 3. The effect of Al_2O_3 filling amount on the tensile properties and bending properties of Al_2O_3/PP composite materials.

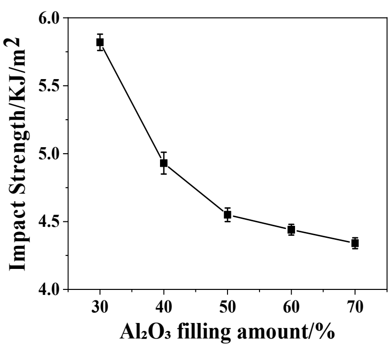

Figure 4. The effect of Al_2O_3 filling amount on the impact strength of Al_2O_3/PP composite materials.

As seen in Figures 3 and 4, the tensile strength, bending strength and impact strength of the Al_2O_3/PP composite materials gradually decreased with the increase of Al_2O_3 filling amount, while the tensile modulus and bending modulus gradually increased. The interfacial bonding between Al_2O_3 and PP could not be perfect, and the interface would undergo debonding, forming holes or cracks. Moreover, the Al_2O_3 particles were more prone to agglomeration with a high filling amount, forming larger defects. When the filling amount of Al_2O_3 was 30%, the impact strength was 5.82KJ/m^2. When the filling amount of Al_2O_3 was 70%, the impact strength was 4.34KJ/m^2. The internal structure of the Al_2O_3/PP composite materials gradually shifted from being dominated by the tough PP matrix to being dominated by the rigid Al_2O_3 networ as the filling amount of Al_2O_3 increased from 30% to 70%. The interface defects, stress concentration, and internal pores of the material were systematically increased and magnified.

3.3 Thermal Performances Analysis

Al_2O_3 with a particle size of 5μm was selected as the inorganic filler, and the filling amounts of Al_2O_3 were 30%, 40%, 50%, 60%, and 70% respectively to prepare the Al_2O_3/PP composite materials. The thermogravimetric analysis was presented in Figure 5(a), as well as the crystallization curve (in Figure 5(b)) and melting curve (in Figure 5(c)).

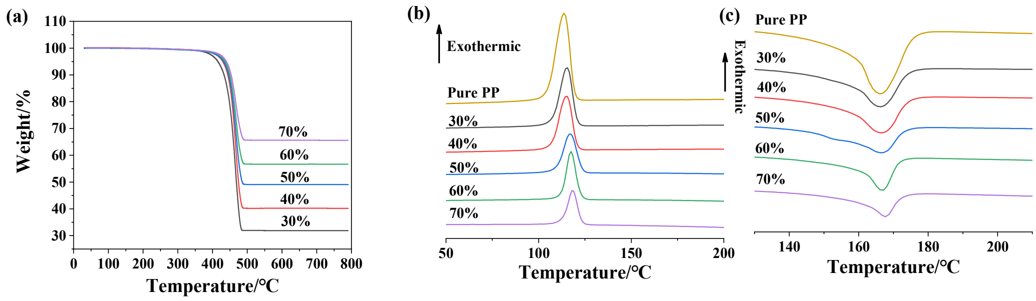

Figure 5. DSC curves of PCL/AA-PEAs fiber membranes.

As shown in Figure 5(a), with the increase of Al_2O_3 filling amount, the thermal decomposition temperature of Al_2O_3/PP composite materials was significantly improved. When the Al_2O_3 filling amount was 70%, the thermal decomposition temperature of the composite material at 5% could reach as high as 439.8°C. Figure 5(b) exhibited that the crystallization temperature of pure PP was 113.6° C. When Al_2O_3 filler was added, the crystallization temperature of the Al_2O_3/PP composite materials increased with the increase of Al_2O_3 filling amount. The crystallization temperature of the composite material reached 118.0°C in the 70% Al_2O_3 filling amount. Probably because the addition of Al_2O_3 particles provided a large number of ready-made nucleation points for the attachment and ordered arrangement of PP molecular chains, acting as seed crystals and making it easier for PP molecular chains to be arranged into crystals. As seen from Figure 5(c), the melting point of the Al_2O_3/PP composite materials changed little overall with the increase of the Al_2O_3 filling amount.

3.4 Dielectric Constant Analysis

The influence of Al_2O_3 filling amount on the dielectric constant of Al_2O_3/PP composite materials was also investigated. The result was presented in Figure 6. The dielectric constant of the Al_2O_3/PP composite materials increased with the increase of Al_2O_3 filling amount. When the Al_2O_3 filling amount was 70%, the dielectric constant of the composite material reached 3.71. Probably due to the sites for interface within the composite materials increased significantly. When the Al_2O_3 filling amount was higher, the particles approached each other, forming a connected and complete filler network, resulting in the increase of dielectric constant.

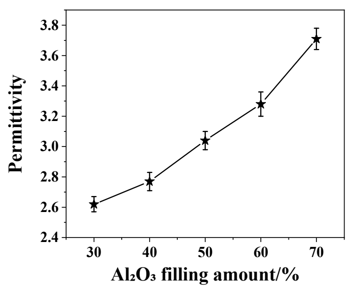

Figure 6. The effect of Al_2O_3 filling amount on the dielectric constant of Al_2O_3/PP composite materials.

4. Conclusion

The Al_2O_3-filled PP matrix composites were successfully fabricated using the polypropylene (PP) as the continuous phase matrix and the alumina (Al_2O_3) as functional filler. The tensile strength, tensile modulus, bending strength and bending modulus of the Al_2O_3/PP composite materials gradually decreased as the particle size of Al_2O_3 increased. But the impact strength gradually increased. As the filling amount of Al_2O_3 increased, the tensile strength, bending strength and impact strength of the Al_2O_3/PP composite materials gradually decreased, while the tensile modulus and bending modulus gradually increased. The thermal decomposition temperature and the crystallization temperature of the Al_2O_3/PP composite materials improved as the filling amount of Al_2O_3 increased. The dielectric constant of the composite material gradually increased as well. While the change of the melting temperature was not significant.

Acknowledgments

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