Eco-friendly nanodielectrics with enhanced thermal and electrical properties for HVDC cable insulation

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ABSTRACT

Recently, HVDC cable power transmission has attracted great attention but the crosslinked polyethylene (XLPE) as the most common HVDC cable insulation material is difficult to be recycled due to its thermoset nature. In this paper, surface modified magnesium oxide (MgO) nanoparticles were introduced into polypropylene/ polyolefin elastomer (PP/POE) blends to develop novel eco-friendly insulation material for HVDC cables. The thermal, mechanical and electrical properties of the nanocomposites were examined. It is shown that the introduction of MgO nanoparticles could enhance the electrical properties of PP/POE blends due to suppressed space charge accumulation and the excellent thermal properties of PP remain. The results indicate potential applications of MgO/PP/POE nanodielectrics for HVDC power cable insulation.

KEYWORDS

Nanocomposite, polypropylene, MgO nanoparticle, eco-friendly insulation material, space charge, HVDC cable

INTRODUCTION

With the development of power system, some problems have occurred in HVAC transmission system, it is required to develop a new power transmission mode with large transmission capacity and long transmission distance. HVDC power transmission, especially HVDC cable transmission, will be popular in the future for low construction cost, low power loss, large capacity, easy to control and less impact on the environment. For most modern extruded HVDC cables, crosslinked polyethylene (XLPE) is used as their insulation material, but XLPE is very difficult to be recycled at the end of its lifetime and also the tolerance temperature of XLPE is not very high which limits the operating temperature and transmission capacity. As environmental protection and sustainable development is becoming much more important than ever, it is urgent to develop new type of eco-friendly HVDC cable insulation material.

As cable insulation material, the thermal, mechanical, thermo-mechanical and electrical properties must be taken into account. In particular the space charge accumulation which has large influence on the degradation and breakdown of the insulation material under DC electric field should be considered [1]. Polypropylene (PP) is a good base material for cable insulation because of its excellent thermal and electrical properties and thermoplastic nature which make it very easy to be recycled, but the mechanical properties of PP are very poor and easy to fracture. In our previous study [2], polyolefin elastomer (POE) was used to improve the mechanical properties of PP by melt blending. It has shown that PP/POE blends have good thermal and mechanical properties compared with XLPE but the space charge accumulation is still a problem, which is very unfavorable for HVDC cable insulation.

Recent researches in nanodielectrics have shown that the introduction of small amount of nanoparticles like MgO, Al_2O_3, SiO_2, and TiO_2 [3], in polymer matrix have great effect on improving the electrical properties of the nanocomposite, such as increasing breakdown strength, dielectric polarization, volume resistivity and suppressing space charge accumulation [3]. The excellent behavior of nanodielectrics should be attributed to the large nanoparticle-polymer interfacial areas [4]. Although the mechanism of suppressing space charge by nanoparticles is still not very clear, nanodielectrics have attracted great attention in both industry and academic.

Based on our previous study of PP/POE blends [2], in this investigation we use MgO nanoparticles to suppress the space charge accumulation and further improve the electrical properties of PP/POE blends to make it more applicable. The MgO nanoparticles were surface modified by silane coupling agent to improve the compatibility between the nanoparticles and the polymer matrix. We have studied the thermal, mechanical and electrical properties of the MgO/PP/POE nanocomposites. It is shown that the introduction of 3 phr of MgO nanoparticles could enhance the electrical properties of PP/POE blends due to suppressed space charge accumulation and the thermal properties are still good enough.

EXPERIMENTAL SECTION

Material: The PP (F401) was purchased from Panjin Ethylene Co. Ltd., which is additive free, isotacticity 97%, density 0.910 g/cm^3, melt flow index 1.7-3.1 g/10 min. The POE (8150) was purchased from DuPont Dow, which is a kind of ethylene-octene copolymer with an octene comonomer content of 25 wt%, melt flow index 0.5 g/10 min, density 0.868 g/cm^3. MgO nanoparticles (average particle size 50 nm, specific surface area 70 ± 15 m^2/g) were supplied by Aladdin Industrial Inc.. (3-Aminopropyl) triethoxy-silane (APTES, code name KH550) from Sinopharm Chemical Reagent Co. Ltd. was used as the coupling agent for surface modification.

Sample Preparation: The nanoparticles were vacuum dried at 100 °C for 12 hours before surface modification. Briefly, the surface modification was carried out as follows, the dried MgO nanoparticles were dispersed in ethanol by sonication, and then the coupling agent was added into MgO/ethanol mixture. After that the mixture was refluxed and magnetically stirred at 70 °C for 12 hours and the nanoparticles were centrifuged from the mixture and washed with fresh ethanol for 3 times. Finally, the modified nanoparticles were dried in vacuum drier at 60 °C for 12 hours.