Space charge behaviours of PP/PER/ZnO nanocomposites for recyclable HVDC cable

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ABSTRACT

This paper intends to reveal the mechanism of space charge suppression mechanism in PP/PER/ZnO ternary nanocomposites. Space charge distribution and crystalline form analysis were carried out by pulsed electro-acoustic (PEA) and X-Ray Diffraction (XRD), respectively. The PER doping can lead to the accumulation of the hetero-space charge, but the introduction of ZnO nanoparticles can suppress the accumulation of hetero-space charge effectivity. The reduction of space charge in nanocoposites can be explained as the result of the dissipation of charges through boundary regions of smaller spherulites due to the transformation of α-β crystal structure.

KEYWORDS

Polypropylene, propylene ethylene rubber, ZnO, HVDC cable, recyclable, morphology, space charge, spherulite.

INTRODUCTION

EXTRUDED cable with cross-linked polyethylene (XLPE) insulation for high voltage direct current (HVDC) transmission has been successfully applied in power systems, due to its favorable combination of superior mechanical, mechanical-thermal and electrical properties. Nevertheless, XLPE is not easy to be recycled because of the thermosetting properties when the cable reaches the end of their life. Therefore, they have to be burnt, which results in great damage to environment. Minimizing the environmental destruction of the XLPE is significant important. The difficulty for the recyclable insulation of power cable is combining the mechanical properties at ambient temperature and thermal-mechanical properties at the operating temperature.

Recently, some works have been done on novel thermoplastic alternatives as electrical insulation of extruded cable. The replacements for XLPE for next generation of extruded cable can be divided into ethylene and propylene system. For the ethylene system, high density polyethylene (LDPE) and its blends [1], high density polyethylene (HDPE) and its blends [2], and LDPE/HDPE blends [3] were investigated. It was found that LDPE and HDPE have lower operating temperature than that of polypropylene and meanwhile HDPE is rigid for cable to install and have to be blended with elastomer. Another potential material system for cable is polypropylene (PP) due to the fact that PP has higher melting temperature point resulting in high mechanical performance. However, a series of experiments on isotactic polypropylene (iPP) described that iPP was a stiff material and lack suitable flexibility at room temperature for incorporation into the cable. To solve this, researchers studied propylene-based co-polymers [4] and alloys [5]. The addition of the elastomer into PP is an effective way to toughen PP. Vistamaxx is a novel Propylene ethylene rubber (PER), in which propylene content is over 70%. It has excellent elastomeric properties, is easy to process and is more compatible with PP than other ethylene-based elastomers.

On the other hand, the accumulation of space charge in HVDC cables is the most tough problem bringing an insulation to failure [6]. Many researchers reported that the addition of nanometer oxides can improve the space charge distribution. Considering the fact that ZnO is a significant ultraviolet absorption and an important semiconductor material. Great interest is to be attributed to study the suppression effect and mechanism of space charge in PP/PER/ZnO nanocomposites.

In this study, PP/PER/ZnO ternary nanocomposites were prepared by mechanical blending. First, the dispersion and morphology of PP/PER/ZnO nanocomposites were observed by scanning electron microscopy (SEM). Furthermore, differential scanning calorimetry (DSC) and dynamic mechanical thermal analyzer (DMA) were adopted to determine whether the nanocomposites were suitable for recyclable power cables. In addition, pulsed electro-acoustic (PEA) experiments were carried out to evaluate space charge distributions. Finally, X-ray diffraction (XRD) patterns were applied to reveal the microscopic mechanism of space charge suppression of PP/PER/ZnO nanocomposites.

EXPERIMENTS

MATERIALS

Commercial isotactic polypropylene T30s was a product of Maoming Petrochemical Company. It has a melt flow index of 3 g per 10 min and density of 0.9 g/cm^3. PER VISTAMAXX 6102 (Exxon Mobil Chemical Company) was used to toughen PP. ZnO nanoparticles with an average diameter of about 50 nm was supplied by Aladdin.

PREPARATION OF NANOCOMPOSITES

PP/PER/ZnO ternary composites were prepared by melt-blending in a Hapro mixer. The cavity temperatures were set at 453 K for 30 min and a rotor speed of 60 r/min was used. The concentration of the PER in all the PP/PER/ZnO blends was 40 wt% and the ZnO concentration was 0.5, 1, 3 and 5 phr, respectively. As references, PP/PER binary blends with the same POE mass fraction as those in ternary composites were prepared using the same mixer. Their compositions are listed in Table 1.