Space charge behaviours of PP-based nanocomposites for HVDC cable insulation varying with temperatures

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ABSTRACT

The space charge behaviour and DC breakdown strength are critical issues in the design of insulation for high voltage direct current (HVDC) extruded cables, which are greatly affected by the operating temperature for different load conditions. The space charge and DC breakdown characteristics of polypropylene (PP) based insulations at various temperatures are therefore investigated in this paper. It's indicated that, at different testing temperatures, the PP/ULDPE blends with a low content of 0.01 wt.% graphene nanoplatelets show a good performance of space charge and breakdown strength for potential HVDC cable insulation.

KEYWORDS

HVDC cable insulation; Space charge; Breakdown strength; High temperature; Polypropylene; ULDPE; Graphene nanoplatelets.

INTRODUCTION

PP, with excellent electrical insulation performance, superiority of non-crosslinking and recyclable property, has drawn much concern as potential high voltage direct current (HVDC) cable insulating materials [1-2]. Especially, the good thermostable performance of PP will be beneficial for a high capacity electric power cable transmission [3]. Although the inherent brittleness of PP could be a limitation for its further practical application, blending with thermoplastic elastomer (TPE), has been revealed as one of the most effective and convenient methods for PP toughening [4-5]. Among the TPEs, the ultralow density polyethylene (ULDPE), an effective impact modifier for rigid matrices, has shown a good thermal and mechanical performance in PP/ULDPE blends [6].

The operating temperature of HVDC cables are usually designed up to 90 ºC, which would vary with the load conditions for cables in operation [7]. The temperature variation along with the space charge and breakdown characteristic in insulation are believed to be the key issues for the successful design and application of HVDC cable insulation [8-10]. The high densities of space charge in the insulation, either in transit or trapped, can cause a distortion of electric field, accelerate the ageing of insulator, increase the rate of electrical tree formation and bring eventual breakdown failure [11-12]. Especially when it comes to a high temperature, such as 90 ºC, the space charge performance could be even worse and more complicated [13-15]. What's more, in a DC cable, the electrical resistivity usually determines the distribution of electric field in insulation, which varies with temperature gradient for different loading conditions. When the increasing temperature from the conductor to the sheath rises to an appreciably degree, the field distribution could be inverted, which would result in a seriously enhanced field or even a breakdown [7, 16]. In addition, since the physical property of polymer will change at different temperatures, the temperature dependence of breakdown strength is of prime importance for the polymer insulation performance [15–18]. Therefore, the effects of different temperatures on space charge behavior, DC breakdown strength of PP based polymer insulation has a great practical significance and research value for a new type cable insulation.

Much research work reveals that the introduction of nanoparticles can suppress the space charge accumulation and enhance the electrical properties of polymer insulation, which is attributed to the charge-limiting effects of interfacial regions between the nanofillers and polymer phases [14, 19-20]. Although, some research work about the dielectric properties of PP and its nanocomposites have been done, most of them were investigated at room temperatures [2, 5, 18]. Recent research found that a little addition of graphene nanoplatelet in the polymers would form numerous of interaction zones and bring a lot deep trap, for its specific structure and enormous surface area [19]. This will do well for investigating the further potentials of PP based nanodielectrics at different temperatures.

In this paper, the space charge behavior, DC breakdown strength of pure PP, PP/ULDPE blends and its nanocomposites with 0.01 and 0.05 wt.% contents of graphene nanoplatelets are performed at 30, 60 and 90 ºC. The temperature effects on charge injection and transit, dielectric properties of PP/ULDPE/graphene nanocomposites are discussed based on experimental results.

EXPERIMENTAL PROCEDURES

Preparation of specimens

The PP (F401) was supplied by Liaoning Huajin Chemical Engineering (Group) Co., Ltd., China, of which the density is 0.92 g/cm3. The ULDPE (ATTANE™ 4203) was supplied by Dow Chemical Company, of which the density is 0.905 g/cm3. The graphene nanoparticle with a diameter of 0.2~10 μm and a thickness of ~1 nm is from Tanfeng Tech. Inc, China.

The preparation of different specimens follows the process bellow. Certain proportions of PP, ULDPE, graphene nanoparticles were blended by two roll mill at 190 ºC, with the rotation speed of 45 rpm for 10 min. A moderate amount weight of these blends were put in the stainless steel mold at the temperature of 190 ºC and the pressure of 25 MPa for 10 min. Afterwards, they were cooled to 160 ºC under the same pressure. With different stainless steel molds, some composites were made into a square of 8 cm length, with