The role of chain structure on enhancing the crosslinking efficiency for DC cable insulation material

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ABSTRACT

In this paper, the role of chain structure on enhancing the crosslinking efficiency has been elucidated by the comparison study between the properties of LLDPE (linear low density polyethylene) with 0.7 wt.% DCP contents and LDPE (low density polyethylene) with 2.0 wt.% DCP addition. Elongation test shows that low-crosslinked LLDPE has high-efficient crosslinking characteristics. DC conductivity of low-crosslinked LLDPE is 1~2 orders of magnitude lower than that of crosslinked LDPE, and the temperature stability of DC conductivity is better for cross-linked LLDPE. Furthermore, the electric field simulation suggests that the use of low-crosslinked LLDPE can effectively mitigate the 'inversion of electric field distribution' of DC cable insulation. This research provides a way to improve the performance of insulation materials for future HVDC cable system.

KEYWORDS

Low-crosslinked LLDPE; High-efficient crosslinking; DC conductivity; HVDC cable insulation.

INTRODUCTION

Voltage source converter high voltage direct current (VSC-HVDC) technology is widely used because of its advantages in long distance, large capacity, and low loss [1,2]. As the key equipment of flexible DC transmission technology, HVDC cable mainly uses crosslinked polyethylene (XLPE) for its cable insulation material [1,3]. XLPE cable is simple to manufacture, strong in transmission capacity, easy to install and maintain. It also has low cost of use, low environmental impact, and has been widely used all over the world [4].

In general, impurities are inevitably generated in XLPE insulation because the addition of antioxidants, peroxides, etc., which contributes to mechanical properties at high temperatures, resistance to deformation, long-term operation, etc., would generate impurities [5]. However, impurities such as crosslinking byproducts (acetophenone, α-methylstyrene, cumyl alcohol, etc.) are one of the most important factors of space charge formation [6]. Impurity ions in the bulk are often produced by the dissociation of additives and byproducts and can become traps for space charges when an electric field is applied, which can disrupt the uniformity of the local field, cause partial discharge and eventually lead to failure [2,6]. In addition, the conductivity of the insulation increases with the increase of byproducts, so a higher dicumyl peroxide (DCP) content means more energy costs, higher operating temperatures, and thus a greater probability of breakdown. Although degassing is applied after the three-layer coextrusion process of the cable, the byproducts in the insulation cannot be exhausted [7,8]. Ren et al. reported the uneven distribution of electric fields over the radial position of HVDC cable insulation and suggested that crosslinking byproducts as well as crosslinking and crystallinity may be attributed to this phenomenon [7]. They also reported degradation of space charge and conductance properties after 25 days of degassing [8]. Hussin et al. reported that byproducts increase the number of shallow traps in the sample and reduce the amount of charge trapped in deep traps [9].

One of the ways to reduce crosslinking byproducts is to reduce the addition of DCP content. However, traditional XLPE uses low-density polyethylene (LDPE) as the base material, its mechanical properties are highly dependent on the amount of DCP added, and the high-temperature mechanical properties of the material cannot meet the requirements at low crosslinking degree. In our previous research[10], we have proved that crosslinked linear low-density polyethylene (LLDPE) with a DCP mass fraction of 2.0% is superior to LDPE with the same DCP content in terms of resistivity and mechanical properties, as well as the temperature stability of conductance and DC breakdown in the temperature range of 30~90 ºC. Therefore, it is considered that a compromise between the high-temperature mechanical properties and conductivity of crosslinked LLDPE insulation materials could be achieved by using low-crosslinked LLDPE.

In this paper, the low-crosslinked LLDPE with a DCP mass fraction of 0.7 % is proposed as HVDC cable insulation, and LDPE with 2.0 wt.% DCP is prepared as a reference material. The mechanical properties of the materials were analyzed by the hot-set test and carbon-13 NMR spectroscopy (^{13}C nuclear magnetic resonance, ^{13}C NMR), the DC conductivity of the two materials was tested, and the relationship between the above characteristics and the microstructure of the samples was further discussed.

EXPERIMENTAL METHODS

Sample preparation

The LLDPE and LDPE used as basic resin for DC cables were selected, both with a density of 0.923g/cm^3 (25 ºC). Samples were made with 0 wt.%, 0.7 wt.%, 1.4 wt.% or 2.0 wt.% DCP and LLDPE or LDPE materials. For simplicity, their names are called LL-0, LL-0.7, LL-1.4, LL-2.0, L-0, L-0.7, L-1.4 and L-2.0.