Enhanced Performance Thermoplastic Insulation Systems

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ABSTRACT

Crosslinked polyethylene (XLPE), widely used as a solid insulation material for medium voltage and high voltage power cables, has improved thermo-mechanical properties compared with low density polyethylene. However, the softening temperature is low (80-90 °C) limiting emergency rating performance. New thermoplastic insulation systems were developed using PE and polypropylene (PP) blends. PE blends improved electrical performance at temperatures above 90 °C. The operational temperature was extended up to 150 °C using PP blends. In a parallel strategy hexagonal boron nitride (h-BN) introduction into these blends following chemical and thermal exfoliation provides a 25% increase in electrical breakdown strength at low filler levels.

KEYWORDS

Polypropylene, Polyethylene, Hexagonal Boron Nitride, Thermoplastic, Polymer blends, cables, insulation.

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INTRODUCTION

Historically, crosslinked polyethylene (XLPE) has been used as the insulation for medium voltage (MV) and high voltage (HV) cables. However, in recent times, the compositions used for fabricating electric power transmission cable layers need to satisfy more criteria, not only with regards to fabrication and utilization, but in terms of end of life options. In addition to this, the drive for improved insulation materials derives from the projected expansion in regional transmission networks and increased renewables connections world-wide, as well as to achieve milestones leading towards the Global Energy Interconnection vision that targets maximum global exploitation of renewable resources.

To this end new compositions are being developed to meet these needs and this work reflects the development of such, utilizing tailored thermoplastic blends, based on both polyethylene and polypropylene as well as the incorporation of hexagonal boron nitride (h-BN) into polyethylene to produce a composite with enhanced dielectric breakdown strength.

While high density PE (HDPE) has greater potential operating temperature headroom than either low density PE (LDPE) or XLPE, its stiffness is problematical for cable applications and its microstructure intrinsically contains electrically weak regions that adversely affect breakdown strength. Therefore, the fabrication of both PE and polypropylene (PP) blends and eventual end use requires intimate mixing of components, which can be difficult to achieve, especially in PP. Should this not occur, then phase separation may lead to heterogeneous zones at a microscopic scale with a resultant detrimental effect on the performance of the insulation.

Previous studies and literature highlighted the impact of h-BN loading at 10% weight fraction or above on electrical properties and thermal conductivity of thermosetting and thermoplastic resins [1-6]. Preliminary work by the authors revealed enhancements in breakdown strength and thermal conductivity of XLPE when loaded at 30 wt.% of h-BN. As a result, finding optimised h-BN polyolefin composites was a priority to deliver the balance of properties required to improve upon current polymeric cable insulation. Of further interest was the prospect of further enhancement of the insulation material property profile through surface treatment of the h-BN, as demonstrated for epoxy composites [6]. The insulation material currently deployed in the majority of new and existing solid-insulated cables is XLPE, so LDPE suitable for crosslinking was selected as one composite target class.

This paper details parallel strategies to deliver solutions for improved power cable insulation materials. A range of PE and PP blends and analogous h-BN composites have been produced targeting a balance of properties that can be tailored to the application requirements, and the resultant materials performance characterized by electrical, thermal and mechanical property measurements.

POLYETHYLENE BLENDS

It was found that there exists a crystallization temperature window of ~6 °C for the PE blend within which isothermal crystallization leads to enhanced electrical properties, it was decided to consider the viability of non-isothermal analogues. An initial estimate was obtained by comparing crystallization times for isothermal and non-isothermal crystallization. Samples of the blend, were analysed by DSC. Each sample was held at 200 ˚C for 2 min to erase its thermal history, before being crystallized to completion at a chosen isothermal temperature or subjected to the required non-isothermal temperature profile. The resulting crystallization exotherms were integrated with respect to time and compared in terms of their 10th, 50th and 90th percentiles; the data are summarised in Figure 1. From this analysis, a non-isothermal cooing rate range window of 0.5 - 10 °C min^{-1} was estimated to correspond to the isothermal temperature window of 113 – 119 °C. However, while this approach serves as a useful initial