

## RECENT DEVELOPMENTS IN CURE CONTROL FOR CROSSLINKABLE POLYETHYLENE (XLPE) POWER CABLE INSULATION

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### ABSTRACT

*Insulated power cables typically employ crosslinkable polyethylene. The most common technologies for crosslinking are i) peroxide-initiated radical crosslinking and ii) hydrolysis and condensation of silane-containing ethylene polymers. Recent advances in crosslinking chemistries have enabled new levels of performance in the rate of crosslinking and the resistance to scorch. Advances in peroxide-initiated crosslinking have demonstrated up to a two-fold increase in a characteristic scorch-time while preserving the ultimate cure potential. Advances in the silane-cure technology space have enabled crosslinking without the need for external heat or moisture. These technology advances open up new opportunities in power cable materials development.*

### KEYWORDS

Crosslinking, polyethylene, XLPE, peroxide, silane

### INTRODUCTION

Polyethylene is widely utilized as an extruded insulation for transmission and distribution power cables due to an excellent balance of high dielectric breakdown strength, low dielectric losses, ease of extrusion, and good mechanical properties over a wide temperature range. In addition, polyethylene can be readily crosslinked to provide an increase in the thermomechanical properties, and thereby increase the ampacity rating of a power cable with a maximum conductor temperature of 90°C rather than 70°C for thermoplastic polyethylene insulation.

Crosslinking of polyethylene is most commonly achieved by a free-radical crosslinking process with initiation via thermal homolysis of organic peroxide (most commonly dicumyl peroxide). A common alternative crosslinking chemistry involves the incorporation of silane functionality into the polyethylene, which can undergo hydrolysis and condensation to form siloxane crosslinks. Each of these approaches holds technical challenges.

Within the framework of radical-initiated crosslinking, a continuous extrusion and vulcanization process for cable manufacturing requires a balance between rapid crosslinking in the high temperature vulcanization process and yet a resistance to premature crosslinking (scorch) at extrusion temperatures. Such a balance provides a means to optimize cable manufacturing productivity while maintaining a high degree of quality, which can be negatively impacted if crosslinked and degraded material from the extruder is introduced into the cable.

Various approaches have been taken to address the cure-scorch balance within radical-crosslinking of polyethylene, including modifications to polymer structure and the introduction of functional additives to impact the efficiency and kinetics of polyethylene crosslinking. Here we will

compare various structural and chemical approaches, and highlight the result of breakthrough technology to yield a dramatic improvement in scorch retardancy of crosslinked polyethylene compounds.

Likewise, technology has advanced significantly in the realm of silane-crosslinked polyethylene. The technology has been inherently rate-limited by the diffusion of moisture into the cable insulation, which becomes more problematic as the thickness of the insulation is increased for higher application voltages. A brief review of previous work related to polymer structure and chemistries for silane-crosslinking of polyethylene is provided, and is used as a baseline to highlight the significant advancement of newly developed technology.

### EXPERIMENTAL METHODS

#### Characterization of Crosslinking with a Rotational Cure Meter

A moving die rheometer (MDR-2000) has been utilized for characterization of polyethylene crosslinking. Material samples are subjected to a 100 cycle per minute oscillation to 0.5 degree arc in a cone-and-plate cavity at the test temperature. The change in torque is monitored between an initial minimum and the ultimate torque level after crosslinking has been completed. Additionally, a scorch time (TS1) can be determined from the length of time required for a 1-unit rise in torque to take place at a test temperature.

#### Material sample preparation

##### **Materials for peroxide-initiated crosslinking**

Various polyethylenes have been evaluated without stabilizing additives. Incorporation of dicumyl peroxide into these pelleted materials is achieved through addition of molten peroxide into a jar of warm pellets, followed by several hours of soak time in an oven until the pellets surface has a dry appearance. Compositions including 6,6'-di-*t*-butyl-4,4'-thio-di-*m*-cresol (TBM-6) have been prepared via melt compounding with polyethylene in a Brabender mixer (250g) mixer at 170°C for 5min, followed by pelletization to yield a pelleted form for the soaking process as previously described. Cure coagents, when utilized, have been included in the soak process.

##### **Materials for in-Situ Water Generation in Silane-Containing PE**

The resin used is SI-LINK™ DFDA-6451 ethylene-silane reactor copolymer (1.5 weight percent vinyltrimethoxysilane (VTMS)). The latent catalyst is NACURE 1419 blocked sulfonic acid available from King Industries. The latent water source is  $\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,3-benzenedimethanol (BDM). The polymer compositions were formulated in a Brabender mixing bowl