Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10404

New Crosslinking Technologies for Polyethylene Insulated Power Cables

Paul CARONIA, Timothy PERSON, Jeffrey COGEN, Roshan AARONS, Caroline GRAND, Yabin SUN

Dow Chemical, United States of America

Motivation

- Peroxide-mediated crosslinking presents cable manufacturing challenges
  - propensity for some decomposition of the peroxide in the cable manufacturing extruder which can result in premature crosslinking or scorch.
  - peroxide-mediated crosslinking generates byproducts that need to be removed from the cable in a degassing process

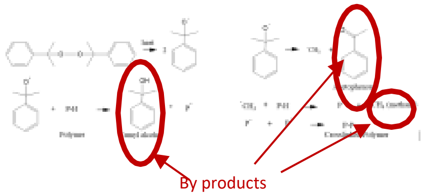
Method/Approach

- Our hypothesis is that the challenges with peroxide crosslinking can be addressed with novel chemistry while achieving the mechanical and electrical performance expected for crosslinked polyethylene insulation.

Objects of investigation

- Novel organic peroxides, crosslinking coagents and scorch retardants as well as byproduct scavengers have been studied

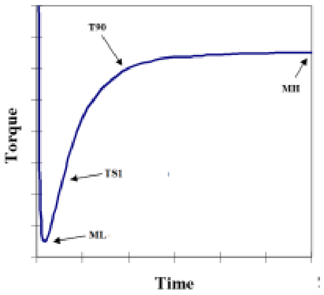
Peroxide Crosslinking Process



Experimental setup & test results

- Crosslinking Performance was characterized using a moving die rheometer

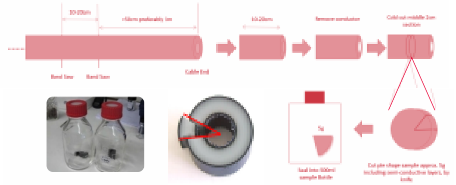
Typical Moving Die Rheometer Curve



TS1 ~ scorch Time
T90~ cure time
ML ~thermoplastic viscosity
MH ~ maximum cure level

- Degassing performance was characterized using TGA and gas chromatography-mass spectrometry

Preparation of Cable Samples for Head Space Gas Chromatography- Mass Spec



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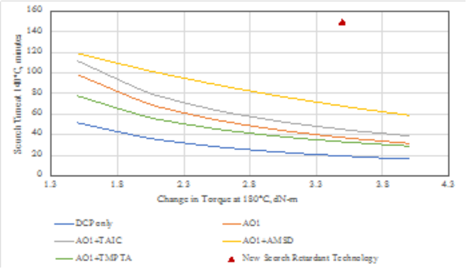
(continued)

Discussion

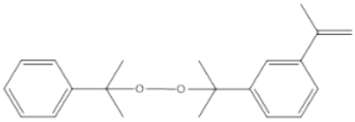
- A unique combination of organic peroxide, antioxidant, crosslinking coagents and scorch retardants have been identified

- This unique combination has been used to develop a novel crosslinked polyethylene insulation with:
  - Improved resistance to premature crosslinking
  - Significantly reduced byproducts to enable faster cable degassing
  - Maintains excellent electrical performance

Novel Additive Technology Advances Crosslinking-Scorch Balance Beyond Conventional Additive Approaches



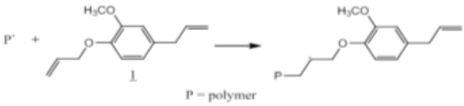
Novel Isopropenyl Dicumyl Peroxide Improves Degassing Performance



- 67% increase in rheometer scorch time
- Isopropenyl groups grafted to polymer to reduce amount of volatile byproducts

New Scorch Retardant Identified

2-methoxy-4-allylphenyl allyl ether



DCP (wt%)	MAPAE (wt%)	AMSD (wt%)	MDR MH @ 182°C (dN-m)	MDR TS2 @ 149°C (minutes)
1.61	0.00	0.00	5.7	17.8
1.38	0.10	0.00	5.7	23.5
1.42	0.20	0.00	5.7	28.0
1.52	0.40	0.00	5.7	32.8
1.34	0.00	0.33	5.7	28.1
1.46	0.00	0.60	5.7	31.4
1.55	0.00	0.80	5.7	32.4

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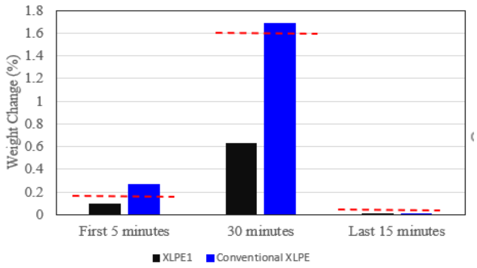
(continued)

Conclusion

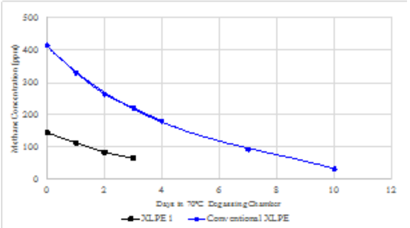
- A new cross-linkable polyethylene insulation has been developed:
    - Provides a high level of scorch retardance
    - Generates significantly lower level of peroxide decomposition byproducts
    - Has low electrical loss performance
- Expected to lead to improved cable manufacturing efficiency with improved cable quality

Novel XLPE Insulation has Faster Degassing Performance than Conventional XLPE

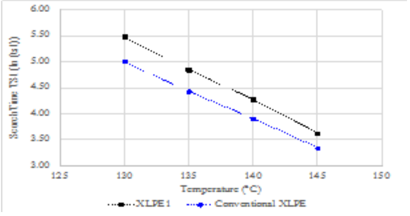
TGA measurements on XLPE Cables "Fresh" off the CV Line



Methane measurements with GC-MS on cable samples after degassing at 70 °C



Novel XLPE Insulation Has Longer Scorch Time



Novel XLPE Insulation has Low Electrical Loss

Insulation	XLPE 1	XLPE 1	XLPE 1	XLPE 1	Conventional XLPE
Cable Temperature	24°C	61°C	99°C	128°C	128°C
Electrical Stress (kV/mm)	tan δ (X10-4)	tan δ (X10-4)	tan δ (X10-4)	tan δ (X10-4)	tan δ (X10-4)
2.8	0.7	<0.1	<0.1	0.8	0.9
5.5	0.6	<0.1	<0.1	0.9	1.4
10.0	0.6	<0.1	<0.1	1.3	2.6
16.0	0.6	<0.1	<0.1	2.3	5.4
20.0	0.6	<0.1	0.1	3.2	8.4
25.0	0.6	<0.1	0.1	4.5	

Novel XLPE Insulation Achieves Cure and Mechanical Properties expected for XLPE Insulation

Tests		Conventional XLPE	XLPE 1
Cure performance	Hot set (%) (20 N.cm², 200°C)	77 ± 7	81 ± 9
	MH (dN-m) 182°C	2.8 ± 0.1	2.5 ± 0.1
	T90 (min) 182 °C	3.7	3.7
Mechanical properties	Tensile strength (MPa)	20.3 ± 1.4	19.1 ± 1.4
	Elongation (%)	547 ± 27	516 ± 31
	Retention (%) after 14 days at 150 °C	≥ 98	≥ 85