

NEW HIGH PERFORMANCE, ENVIRONMENTALLY FRIENDLY MV POWER CABLE INSULATIONS



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ABSTRACT

New polymers based on metallocene catalyst technology are now being offered in the marketplace. These polymers include new elastomers that could compete with traditional EP and EPDM materials used in cable making. These new polymers offer great promise because along with being produced in a more environmentally friendly process they have much lower catalyst residues-hence promising potential advantages in electrical and thermal performance. These new polymers have not fully lived up to their promise to date however.

A new elastomer insulation based on metallocene resins with a number of improvements in environmental impact and use possibilities is presented in this work. This new insulation shows much improved performance over current insulations. The paper will provide small sample and cable test data in comparison to traditional EP formulations available today.

KEYWORDS

Power Cable, Catalyst, EAM, Filled Insulation, HALS

INTRODUCTION

Traditionally, medium volt power cable producers had two choices for insulation. These broad categories are XLPE and EP, and include all variations such as TR-XLPE, EPR, and EPDM. Rubber insulation for cables date back to the Gutta Purcha used on Samuel Morse's telegraph lines. Synthetic EPR became available in the early 1960s with the invention of Ziegler Natta polymerization catalysts. Insulation compounds based on these synthetic EPRs soon became available (Ohm). These insulation types are approaching 40 years of reliable service. Rubber insulation is chosen for its proven service life, flexibility and performance in high temperature operation (Brown). Most rubber insulations produced today are based on EPR or EPDM polymers. Current EPR and EPDM insulations have been used successfully for many decades at all service voltages up to 138 kV.

Ziegler Natta catalyzed resins have been the dominant polymeric class of materials in wire and cable since their discovery in 1954 (Billmeyer). While many improvements in catalyst technology have been made since the first

Ziegler Natta catalysts, few have found service in wire and cable due to the demanding specification and long service life requirements. Metallocene catalyst technology, for instance, is now widely used to manufacture elastomeric polymers. The manufacture of metallocene polymers by single site catalysts is described by Gomez.

These materials include the traditional ethylene and propylene building blocks as well as other C2 to C8 Alfa Olefins. The most common new building blocks are butene, hexene and octene (four, six, or eight carbons respectively). Since these molecules all contain carbon to carbon double bonds, they fall under the general chemistry family called alkenes. ASTM D-1418, *Standard Practice for Rubber and Rubber Lattices - Nomenclature* gives eight classes of rubbers. The ethylene alkene polymers fall into class M, which are described as rubbers having a saturated chain of the polyethylene type. The standard indicates that the classification letter should be listed last preceded by the subsistent groups on the polymer chain-in this case EA for ethylene alkene which gives us the term EAM.

These new polymers offer potential promise in wire and cable because they have potential advantages in flexibility, thermal performance and have lower catalyst residues than traditional types (Kuttila). Catalyst ions can contribute to the degradation of cables by providing a path for metal ion catalyzed oxidation processes and as initiation sites for water-trees in dielectrics (Dissado). This modern route to polymer manufacture also produces polymers in a more environmentally friendly process requiring no solvents or large quantities of water to wash out excessive catalyst residue. Early work suggested good electrical properties and also suggested they might be able to be used in formulations without lead oxide stabilizer (Camillo). These new materials have not lived up to their promise to date, however. Some suffered higher dissipation factors, poorer thermal stability, and poor performance on accelerated cable life tests. They have found only limited use in power cable insulations.

Lead oxides have a long track record of use as stabilizers in EP insulations with great success. Lead oxide is necessary for thermal as well as electrical stability (Brown). It is well known that there are significant legislative pressures to discontinue use of lead as a stabilizer in manufactured products-one example is the European RoHS directive (European Parliament). Much work has been done to find a suitable alternative to lead oxide stabilizers for both traditional EP polymers and the newer metallocene materials. At the same time, North American cable users

and some European users including Iberdrola are demanding higher operating temperatures and reduced wall cables (higher electrical stresses).

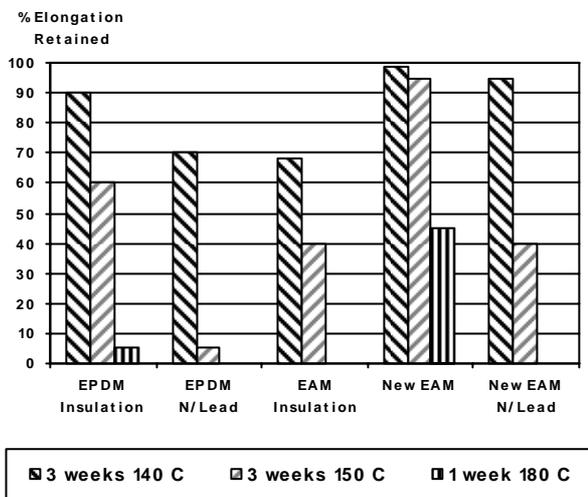
While traditional EPR and EPDM filled insulations have provided excellent service for many decades, the combined need to remove lead, increase operating temperature, and increase the operating electrical stress leads to the need for a new class of filled insulation.

RESEARCH

A wide variety of additives were screened to determine their effectiveness at stabilizing EAM cable grade formulations without lead. TMQ has long been used in filled cable insulations due to its good performance and low cost. A number of newer antioxidant systems were evaluated but none showed any improvement over TMQ. Hindered amine light stabilizers were then considered for two reasons: they are useful against thermal degradation and are known in unfilled insulations to provide electrical stability (Denisov).

HALS are known to provide initial thermal stabilization but also display a cyclic action; once consumed, they revert back to active nitroxyl radicals after an intermediate stage. (Denisov). **Figure 1** illustrates thermal stability data on pressed plaques of the trial formulations. Plaques were press cured at 350 °F (177 °C) and then subjected to thermal ageing. For aging experiments in the United States, an ASTM D 573 type II oven, having between 100 and 200 air exchanges an hour, is required. In comparison, European test requirements, described in IEC 60811-1-2, require no less than 8 and no more than 20 complete air exchanges per hour. This large difference in specifications makes air oven aging tests in the United States much more demanding than those performed in Europe. This is due to the increase in the amount of oxygen in the ovens from an order of magnitude more air exchanges.

Figure 1: Retained Elongation on Air Oven Aged Plaques



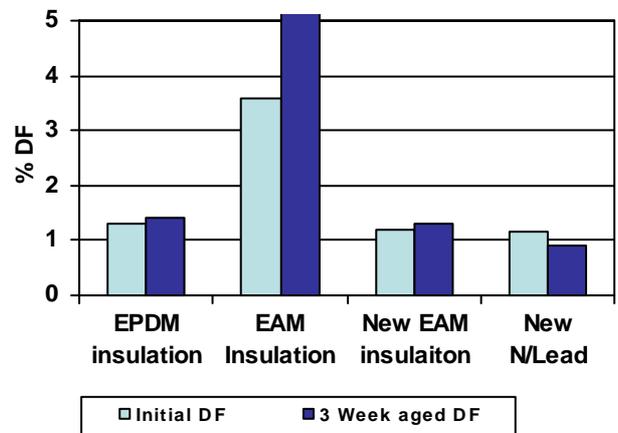
HALS proved to be a remarkably good thermal stabilizer for

elastomeric insulations. Although 221°F (105 °C) operating and 284 °F (140 °C) overload temperatures are the highest normally allowed by North American standards, the new no lead formulation would give a margin of safety for unavoidable overloads.

In terms of electrical degradation it is well known that HALS are useful additives for un-filled insulations. U.S. patent no 4,870,121 discloses an optically transparent polyethylene high voltage insulation formulation with a HALS. The HALS was thought to prevent electrical trees from light emitted by excited electrons. U.S. patent no. 5,719,218 discloses an optically transparent polyethylene medium voltage insulation formulation with a HALS in combination with a hydrolyzed ethylene vinyl acetate terpolymer. In fact, there are over 50 patents that propose solutions to water treeing in polyethylene medium voltage insulations but none that discuss degradation of filled elastomeric insulation. It should also be noted that all current MV polyethylene insulations are based on Ziegler Natta catalyzed polyethylene.

The dielectric properties of the new compounds were then investigated. Current North American specifications demand a stable DF for a cable core when subjected to the emergency overload temperature of 284 °F (140 °C) for 21 days. The new HALS based stabilization system was shown to dramatically improve the DF of EAM based insulations (as shown in Figure 2).

Figure 2: Plaque %DF

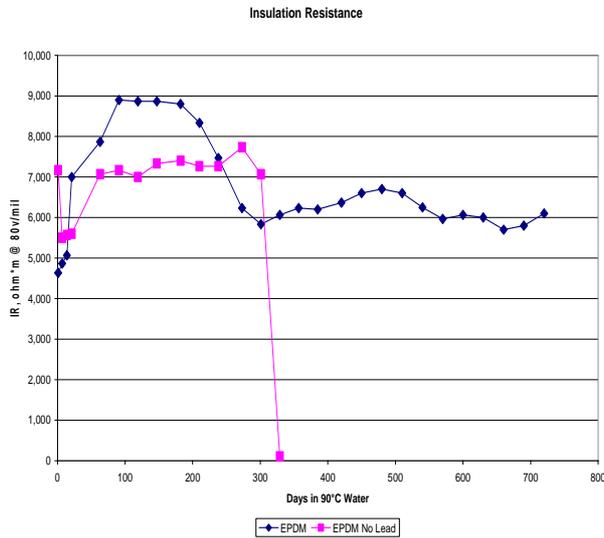


Low voltage and medium voltage cable designs that may utilize this new insulation are wet designs. Stability in the presence of moisture is required to demonstrate good service life. Round and square conductor Wires were extruded with the new formulations on a laboratory CCV line and subjected to long term wet testing to validate wet performance.

Efforts to simply remove lead from EPDM and EPR insulations have not been successful. 14 ga (2.5 mm) solid copper conductors with 45 mils of insulation were tested at 2200 VAC in tap water at 194 °F (90 °C). The test is based on the accelerated water absorption test in Underwriters Laboratories standard UL 44; Standard for safety for

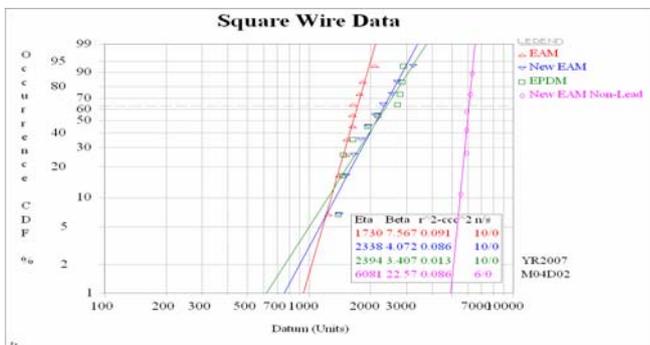
thermoset insulated wires and cables. EPDM insulations with out lead show dramatic reductions in insulation resistance after about 300 days.

Figure 3: Insulation Resistance



The square conductor wire test has shown to be a good method for screening insulation compounds (Bostrom). The test employs 14 AWG (2.5 mm) square conductor with 30 mils of insulation, energized to 7.5KV (250 v/mil) in 122 °F (50 °C) tap water. Time to failure (in hours) is recorded. The new HALS based stabilization system showed significant improvement in lead and non lead based filled insulation compounds. Remarkably in the EAM compounds the non lead system proved better than the lead system, unlike in the EPDM compounds. **Figure 4** shows, in fact, the non-lead HALS stabilized EAM showed the best performance in this test.

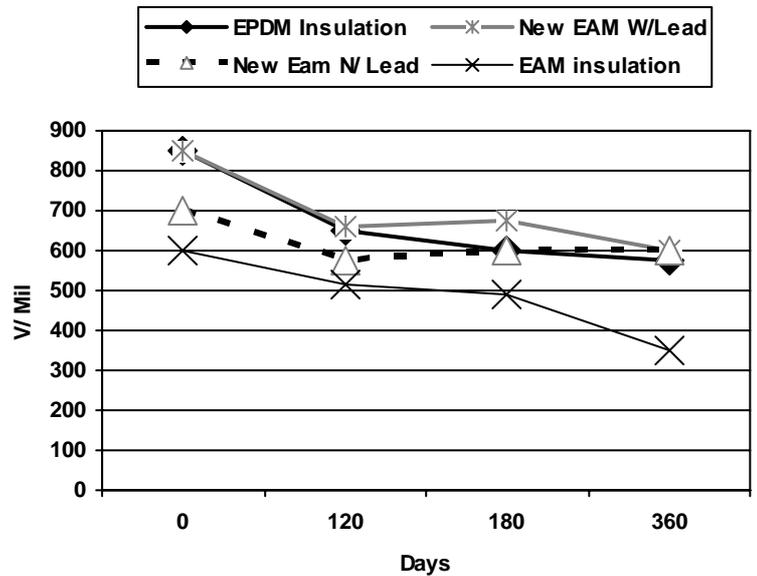
Figure 4: Square Wire Data Time to Failure Results



As a final test of the new compositions, AWTT testing on full size MV power cable cores was performed. Cable core samples were made and tested per section M.2 of AEIC CS8-2000. This consists of a 1/0 AWG (53.5 mm²)

compressed, class B unblocked stranded conductor (in this case aluminum) with conductor and insulation shields and approximately 4.45 mm (0.175 in.) thick insulation. These samples are aged 1 year at 3 times rated voltage and 113 °F (45 °C) insulation shield temperature in water. **Figure 5** indicates a good performance of the new EAM insulations. The new EAM formulations also used a new oligbeneric silane for clay treatment instead of traditional vinyl trimethoxy silane. These new silanes provide better performance and do not produce hazardous 2-methoxy ethanol as a condensation product. It must also be stated that it is known that wet aged breakdown strength of filled insulations decreases somewhat more than XLP but its impulse strength remains markedly higher (DiLorenzo).

Figure 5



The data clearly indicates that the new formulations display stability in long term wet testing on full size core when compared to the previous generation of EAM with out the new additive technology. This is further illustrated by observation of bow tie trees in the test samples (water trees are only very rarely observed in filled insulations (Noto). The new EAM compounds display a dramatic reduction in bow tie tree counts when compared to the traditional materials. **Figure 6** indicates that the growth and growth rate of bow tie trees are significantly reduced in the new insulations and both are superior to traditional EPDM insulations. It should also be noted here that conductor shields can play a role in this test. The EPDM and new EAM insulations shown used a proprietary EAM based conductor shield.

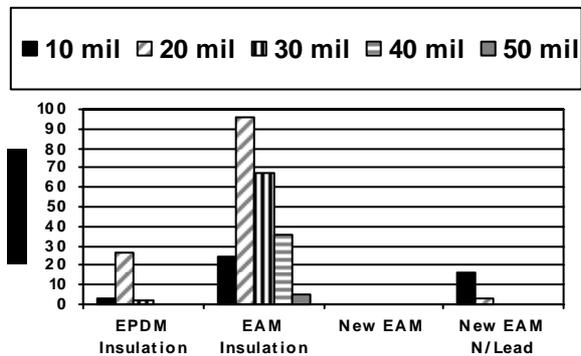


Figure 6: Bowtie Tree Count on AEIC Breakdown Samples

CONCLUSION

This research led to the discovery of improved filled insulation systems. It was discovered that lead, while a good stabilizer for Ziegler Natta catalyzed EPDM polymer, was not an effective stabilizer for EAM polymers. EAM resins formulated into traditional insulation systems show poor results on electrical and thermal stability. The new HALS based stabilizer system presented in this work proved to be a very effective electrical and thermal stabilizer for filled insulations.

The new EAM insulations also are much more environmentally benign to produce because they do not require solvents or contaminate water during polymerization, do not produce 2-methoxy ethanol, and do not contain lead. They also contain no naphthenic or paraffinic oils which might be damaging to the environment or lower electrical performance (Brown). EAMs are also produced in pellet form allowing for cleaner enclosed system handling. Since existing Ziegler Natta EPDM plants are nearing the end of their useful life and new plants will undoubtedly be built using new more economical and environmentally friendly catalyst systems, the authors believe EAMs will certainly be the polymers used in the filled insulations of the future.

ACKNOWLEDGEMENTS

The authors wish to thank IBERDROLA, a Spanish electrical company whose services are focused on the generation, the transport, the distribution and the sale of electricity. Due to their concern for a reliable service in energy supplying, the protection of the environment, and optimization of natural resources, IBERDROLA was one of the main drivers of this work.

REFERENCES

Billmeyer, Jr., Fred W. Textbook of Polymer Science. 3rd ed. Indianapolis: John Wiley & Sons, 1984.

Boggs, A. "Water Treeing: Filled Vs. Unfilled Cable Insulation." IEEE Electrical Insulation Magazine 17 (2001): 50-57.

Bostrom, J. O. Assessment of Cable Performance as Measured by a Variety of Accelerated Ageing Test Methods. Insulated Power Cable, 1993, Jicable. Paris: Jicable, 1993.

Brown, Morton. "Compounding of Ethylene Propylene Polymers for Electrical Applications." IEEE Electrical Insulation Magazine 10 (1994): 30-35.

Brown, Morton. "EPR Based URD Insulation: a Question of Confidence." IEEE Electrical Insulation Magazine 4 (1988).

Camillo, David. "EAM Insulation: Viable Alternative for Medium-Voltage Power Cable Applications." Transmission and Distribution Mar. 2004: 25-26.

Denisov, E. International Symposium on Degradation and Stabilization of Polymers, 1974. Brussels, 1974.

DiLorenzo, T. IEEE Insulated Conductors Committee, Apr. 2002, IEEE. New York: IEEE, 2002.

Dissado, L. A., and J. C. Fothergill. Electrical Degradation and Breakdown in Polymers. New York: Institution of Electrical Engineers, 1992.

Donghee, Kang. Assessing the Electrical Properties of Alternate Wire and Cable Coatings: Metallocene EPDM. University of Massachusetts. Lowell: University of Massachusetts, 2004.

Parliament, European. "Official Journal of the European Union." Europa Online. 13 Feb. 2003. 12 Apr. 2007 <http://europa.eu/lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf>.

Gomez, R. "Mono-Eta-Cyclopentadienyl-Benzamid in Chloro Compounds of Titanium, Zirconium and Hafnium." Journal of Organometallic Chemistry 491 (1995): 153-158.

Kuttila, Hilka. EPE. Europolymer Congress, 27 June-July 2003, Europolymer Congress. Stockholm: Europolymer Congress, 2003.

Noto, F. "Research on Water Treeing in Polymeric Materials." IEEE Transmission E115 (1980): 251-258.

Ohm, Robert F., ed. Vanderbilt Rubber Handbook. 13th ed. New York: R.T. Vanderbilt Company, 1990.

GLOSSARY

AEIC: Association of Edison Illuminating Companies

ASTM: American Society for Testing of Materials

DF: Dissipation factor or loss tangent delta

EP: ethylene propylene rubber

EPDM: ethylene propylene diene rubber

HALS: Hindered Amine Light Stabilizer

IEC: International Electrical Committee

ROHS: Reduction of Hazardous Substance Act

TRXLPE: Tree retardant cross-linked polyethylene

TMQ: 1,2-dihydro-2,2,4, trimethylquinoline

XLPE: Cross linked polyethylene