HIGH PERFORMANCE MV CABLE SEMI-CONDUCTING SHIELDS

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ABSTRACT

Many patents have been issued and over 175 papers have been published on water treeing and water tree additive technology. Fewer papers have been published on conductor screen technology. High performance screens often employ acetylene carbon black which gives a smooth and ionically pure compound. In this paper we demonstrate that formulation plays a dominant role in determining the performance of power cable screens when compared to simply assessing smoothness and cleanliness of the compound. Time to failure and retained breakdown strength data on model and full size MV cores are presented.

High performance conductor screens (shields) with improved cleanliness and smoothness were introduced in the early 1980's. High performance screens often employ acetylene carbon black which gives a smooth and ionically pure compound. Smoothness controls electrical stress enhancement at the screen-insulation interface (Mayoux). Ionic cleanliness is a concern in MV cables due to water trees, although ions in ground water may also play a role (Shaw). Steady advancements in smoothness and cleanliness in semi-conductive shields and insulation compounds have been reported (Gao and Burns).

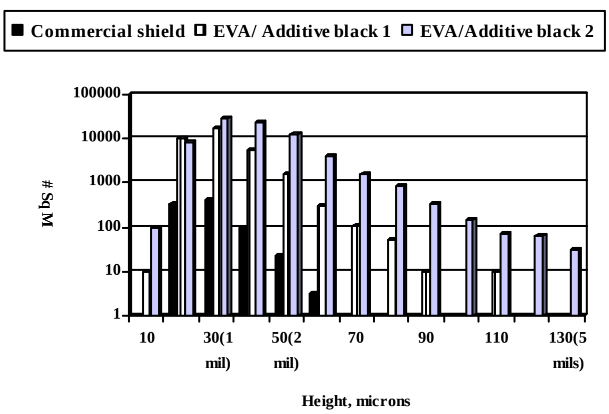
Extensive research has been done and over 175 papers have been written on water treeing in XLPE (Ross). TR-XLPE based on additive technology was introduced in the early 1980's in North America and was shown to be somewhat less sensitive to conductor shield cleanliness than earlier systems. Concurrently, co-polymer insulations were introduced in other regions of the world (primarily Europe) with similar success. Through the last two decades steady advancements in smoothness and cleanliness in semi-conductive screens and insulation compounds had been reported. Conductor screen formulation technology is usually not discussed however.

Several patents have been issued on conductor screen technology including patent #4,612,139 (use of polyethylene glycol, patent # 6,299,978B1 (polyolefin with ethylene vinyl acetate (vinyl alcohol) terpolymer), patent #6,291,772 (antioxidant that increases the accelerated test life of cable insulation), patent #6,491,849B1 (use of ethylene vinyl acetate and amide waxes) and patent #6,864,429 (carbon black with a specific range of properties). Formulation technology is usually not discussed as playing a major role. However, in this paper we demonstrate that in reality, formulation actually plays a key role in a conductor shields performance.

While there have been reports demonstrating better performance with clean furnace blacks compared to acetylene black, most published results still show a correlation between carbon black ionic and sulfur content or screen smoothness and performance. In this paper we demonstrate that formulation plays a dominant role in determining the performance of power cable screens when compared to simply assessing smoothness and cleanliness. Time to failure and retained breakdown strength data on model and full size MV cores are presented.

Figures 1 and **2** show the smoothness and ACLT performance of three experimental copolymer conductor screen compounds. 15KV XLPE cores were tandem extruded on a laboratory CV line and placed on test. Carbon black 2 had the highest sulfur level and Formula 2 which incorporated it had the least smooth surface yet it had over twice the life on test as the commercial low sulfur conductor screen compound. These formulas contained a unique antioxidant system (additive A) that may have protected the screen insulation interface. In addition it is believed the unique morphology of carbon black 2 changed the properties of the screen insulation interface. Earlier work suggested that formulation additives may modify or protect the interface (Gao). The last cable on figure 1 with an indicated life of 635 days also contained a unique base polymer. No samples failed after 635 days on test. The polymer was no longer available at that time so the test was discontinued.

Figure 1 Laser surface scan smoothness of conductor screen formulations



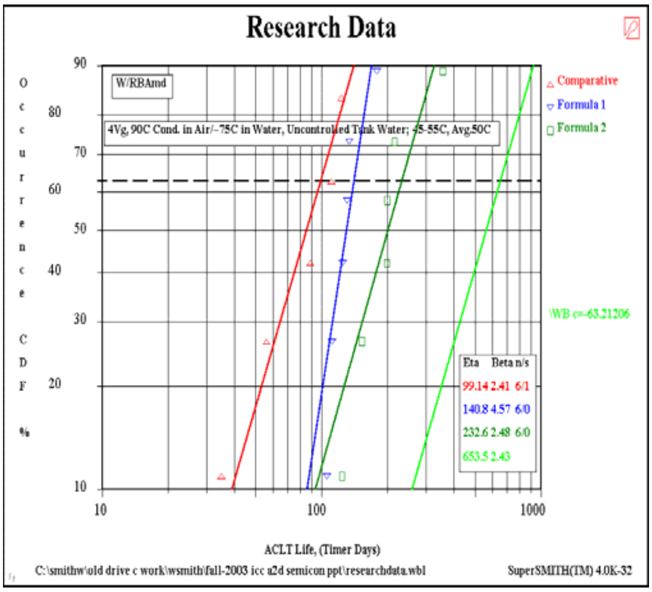


Figure 2 ACLT time to failure on 175 mil wall 15KV XLPE cables, furnace black conductor screens 4 Vg, 75C conductor temperature

The level of additive A also had a strong effect on the cable performance. 15KV XLPE cores with acetylene black based screen compounds containing 0.5% to 1.0% additive A were placed on test under the same conditions as those in Figure 2. A dramatic difference in performance was demonstrated between 0.5% and 1.0 % of the additive as shown in figure 3. The last cable on **figure 3** had a 1000 ppm sulfur furnace black and also contained an additional polymer (additive B). Although not nearly as smooth or ionically pure it had the best performance.

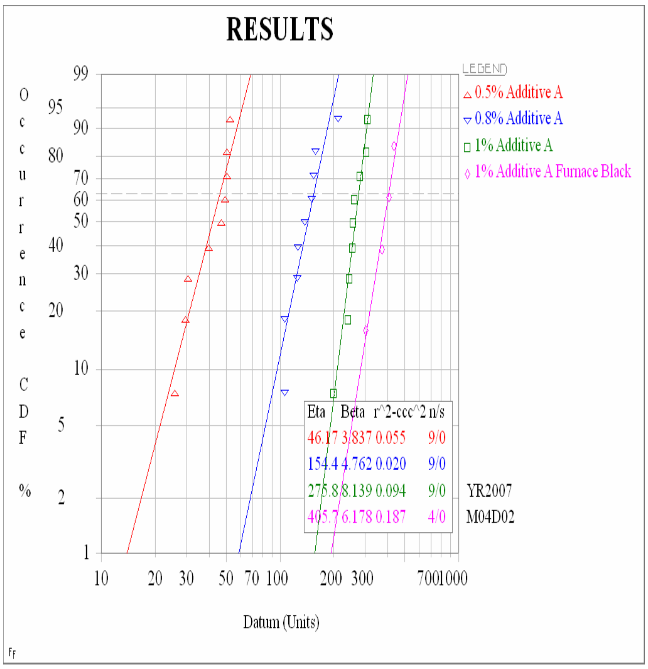


Figure 3 ACLT life of acetylene black based conductor shields with furnace black comparison

The acetylene black conduct screens were then tested with a commercially available TR-XLPE insulation (the predominate insulation used in North America). 60 mil wall model cables were produced to reduce time to failure. 1.2% additive B showed performance equivalent to other commercially available compounds and has been in use in North America for many years. Here again the level of additive B (additive A at 1.0%) proved to dramatically improve cable life. Another additive C was also found to greatly increase cable life. **Figure 4** shows how additive technology in the conductor screens tripled the life of cables on ACLT. Further research is being conducted on the most cost effective combination of screen, insulation and cable design for performance in the field. This research will be the subject of a future paper.

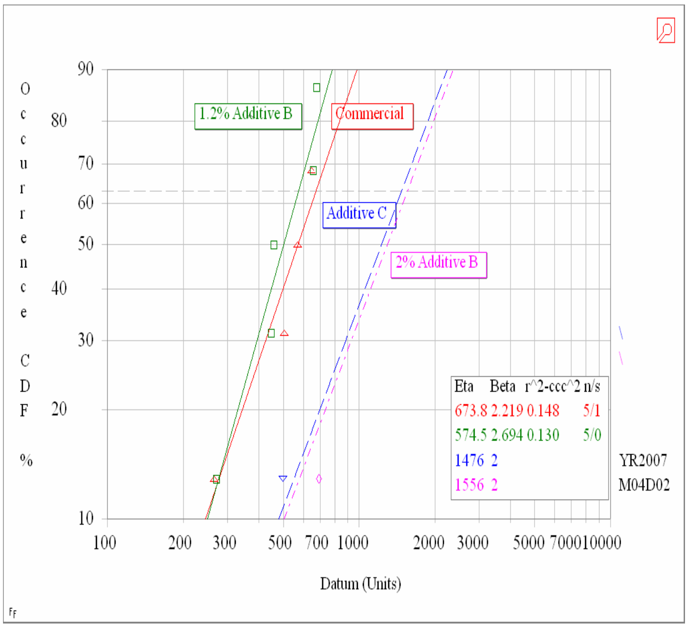


Figure 4 ACLT on 60 mil wall TRXLPE cables, acetylene black conductor screens 4 Vg; 75°C conductor temperature

As a final test of the new compositions AWTT testing on full size TRXLPE 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 mm^2) compressed, 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 45°C insulation shield temperature in water. Again, as shown in **Figure 5**, additives A and B greatly improved performance. The unique morphology furnace carbon black shown in Figure 1 had the best performance. No vented trees were observed in any cables on this test.

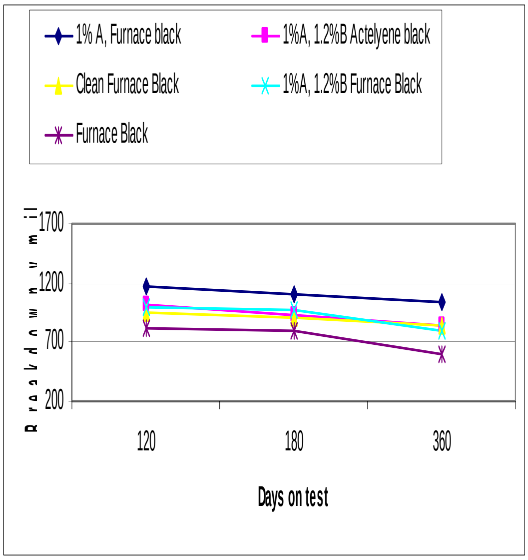


Figure 5 AEIC CS8-00 retained breakdown strength

CONCLUSION

Formulation of conductor shield can play a key role in cable performance and can pay a bigger role than the type of carbon black chosen. As a consequence, the performance of a final shield formulation on an accelerated life test is a more important consideration when specifying cable components rather than specifying individual ingredients in a formulation. Although this work shows that low quality carbon blacks can give good performance it is not intended to prove that ionic impurities and smoothness play no role. Most commercially available conductor screens contain high quality carbon blacks designed and produced for the application. This work does, however, give evidence that certain novel carbon blacks, in a formulation optimized for dispersion, purity and electrical performance can give exceptional performance.

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GLOSSARY

ACLT- Accelerated Cable Life Test

AEIC - Association of Edison Illuminating Companies

CV - Continuous Vulcanization

MV - Medium Voltage

TRXLPE -Tree Retardant Cross Linked Polyethylene

TMQ - 1, 2-dihydro-2-2-4, Trimethylquinoline

XLPE - Cross Linked Polyethylene