NEW SEMICONDUCTIVE PRODUCTS PROVIDING HIGHER PERFORMANCE CABLES

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ABSTRACT

High voltage XLPE cables are typically produced using Superclean XLPE insulation combined with Supersmooth semiconductive shielding made using Acetylene carbon black, whereas cables for medium voltage employ semi-conductive shielding made from furnace carbon black.

Recent developments have resulted in a new class of semi-conductive shielding compounds, using improved furnace carbon black combined with novel polymer technology, which provide a number of improved properties of value to cable manufacturers and cable users.

The most significant improvements for the cable manufacturers are the ability to extrude cable up to 50% faster while also providing improved scorch resistance. This coupled with improved smoothness, resistance to conductor shield convolution, and reduced moisture sensitivity should result in improved final cable quality.

INTRODUCTION

The demand for cables is currently larger than the capacity of cable manufacturing. Production lines are run close to their maximum capacity, where the limit is often set by the potential scorch risk for one or more of the polymer compounds used.

Scorch will result in cable defects which, if undetected poses a risk for the cable performance. Such defects are most grave if they occur in the conductor screen where the resulting electrical stress concentration is highest and directly weakens the cables electrical breakdown resistance. Scorch resistance of a cable compound is a function of its thermal stability, type of peroxide used, the temperature at which it is processed, the maximum residence time in the extruder as well as the homogeneity of the compound itself.

Both the processing temperature and the maximum residence time can be modified by controlling the viscosity of the compound. There are however a number of factors to be considered when undertaking such a change. A lower compound viscosity, obtainable by reducing polymer molecular weight or the carbon black content, will provide the desired effect in the extruder as well as improved smoothness as result of easier filtering. Such a change must be balanced with the need for sufficiently high viscosity to avoid flow of the semicon compound into the conductor interstices, as well as a high enough carbon black content to assure percolation and desired conductivity.

The design latitude for such changes is very limited. The approach in this project was to optimize the rheology to obtain low extrusion viscosity at higher shear rates combined with high viscosity and melt elasticity at static conditions on the conductor.

Additionally the new formulation provides improved smoothness combined with reduced moisture pickup rates which combined with improved scorch resistance should result in improved quality of the semicon-insulation interface bringing about better cable quality.

Preliminary electrical testing on minicables confirms the projected improvements.

EXPERIMENTAL

Materials

The traditional semicons referred to as references are ethylene copolymer based products containing furnace black carbon black in the range of 30-40 % and high heat stabilization. The low viscosity semiconductive, as well as the new semicon formulation, uses novel polymer technology for the base resin resulting in improved rheology.

The insulation used in the cable trials where of the types HFDK-4201 EC XLPE homopolymer and HFDK-4202 TR-XLPE.

Test methods

Moving die rheometer (MDR): The scorch propensity of the semiconductive shield compounds was tested with an MDR instrument. The MDR conditions were ±0.5^{o} arc of oscillation amplitude and 100 cpm frequency (0.7 sec^{-1} shear rate). As the oscillation of the moving die continues at elevated temperature, a sinusoidal shear force (or torque) due to crosslinking increases until it reaches the equilibrium value. The time to reach 1 lb-inch torque (TS1) between 135 ^{o}C and 145 ^{o}C was measured to check scorch propensity.

Surface smoothness test: The semiconductive shield compounds are extruded into a tape through a die to maintain a constant thickness. An online protrusion detection device coupled with a computer data interface scans the extruded tape surface to scale the size and number of the protrusion as a defect.

Model cable test: Model cables with three extruded layers were utilized to test the influence of water on the aging behavior of cable system (semiconductive shields and insulation). The dielectric strength was determined after aging with AC stress and at elevated temperature for 1000 hrs. [1]

Rheological tests: Rheological characterization was based on Small Amplitude Oscillatory Shear, Creep and Capillary melt rheology. [2,3,4]
Small Amplitude Oscillatory Shear measurements were performed with the RDAII system of TA Instruments. A parallel plate setup with plate diameter of 25 mm was used under nitrogen in order to prevent oxidative degradation and crosslinking. Capillary melt rheometry is performed at 120°C with the Göttfert 6000 using a 20/1 flat die. Strands were visually observed for melt fracture.

Full scale extrusion trials: The evaluation of performance in real life was made on a state of the art Maillefer extrusion system consisting of three NXW extruders of 90,200 and 120 mm with a THX 35/75 triple extrusion head.
The semi conductive compound was tested as conductor screen using filtering and processing conditions common for traditional semiconductive shield compounds.

RESULTS

Melt Viscosity and Elasticity

Oscillatory measurements provide information about the viscosity and elasticity of a material. By definition, storage modulus (G') reflects energy stored, and loss modulus (G'') reflects energy dissipated. The ratio of G''/G' = tan δ is called a damping factor or a dissipation factor. Tan δ is a measure of the viscous versus elastic behaviour. The material is behaving more viscous when tan δ is greater than 1 and more elastic when tan δ is less than 1. As shown in Figure 1, the low viscosity semiconductive shield behaves more viscous while the new semiconductive shield is more elastic and will resist flow at low shear rates much better. More resistance to flow will result in more resistance to formation of conductor shield convolutions during cable manufacturing.

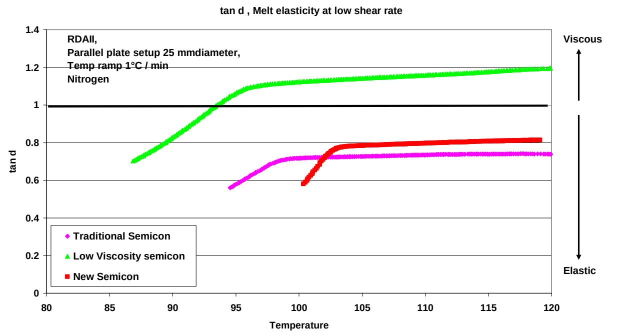

Figure 1 Dynamic rheological response of new semiconductive shield compound

Capillary melt rheology

Figure 2 is a plot of apparent viscosity versus apparent shear rate for the 3 compounds. Obviously, the traditional semicon has a higher viscosity compared to the Low Viscosity Semicon. The New Semicon shows an intermediate viscosity at low shear rate but the lowest viscosity at higher shear rate. The extrudate did not visually show melt fracture behaviour. The better shear thinning behaviour of the New Semicon gives opportunities in higher output, less shear heating (scorch), and less melt fracture behaviour.

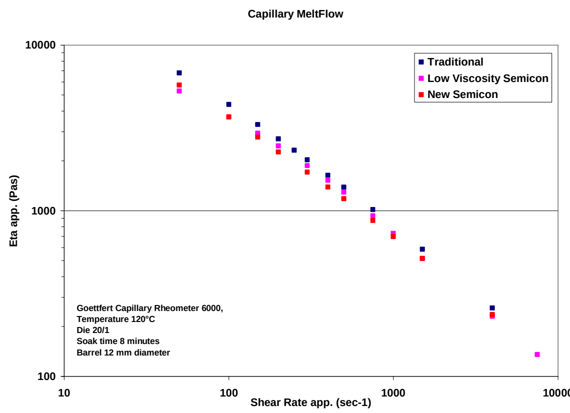

Figure 2, Capillary melt rheology of new semiconductive shield

Comparing the new and low viscosity semiconductive shield from high to low shear rate, a viscosity cross is observed where the new semiconductive shield shows higher viscosity compared to the low viscous semiconductive shield which is in line with the Creep data.

Scorch Resistance

Figure 3 shows the scorch propensity of the new semiconductive shield compound. The new semiconductive shield has a similar scorch retardation time (TS1) as the traditional reference semiconductive shields at typical extrusion temperature of 140 °C. However, the novel semiconductive shield formulation technology allows processing at 5 °C lower temperature, which helps to reduce scorch propensity further.

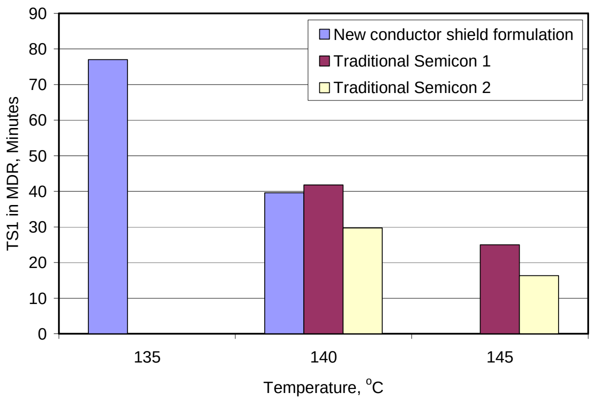

Figure 3 Scotch retardation time (TS1) of new semiconductive shield

Smoothness

The smoothness at interfaces between the insulation layer and semiconductive shields is very important to the long term electrical performance of power cables. The micro-protrusions from the semiconductive shields can result in localized electrical stress[5] and induce undesired treeing or electrical degradation.

Characterization of the smoothness of the new conductor shield formulation shows improved performance, as seen in Figure 4.

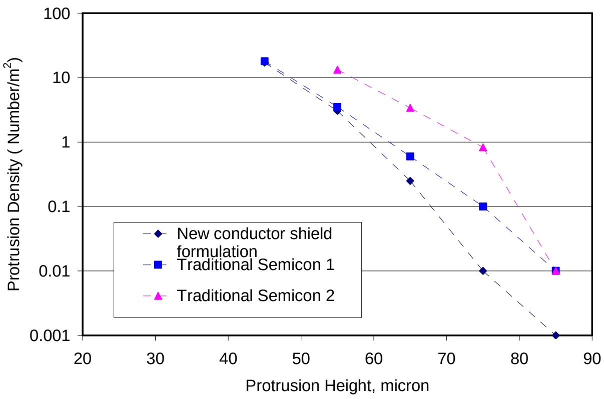

Figure 4 Smoothness of new conductor shield

Volume Resistivity

Industrial cable standards and specifications require the volume resistivity of semiconductive shields to be below 100,000 ohm-cm at 90 °C maximum continuous operation temperature. Figure 5 shows that the new conductor shield demonstrated volume resistivity well below the specification limit.

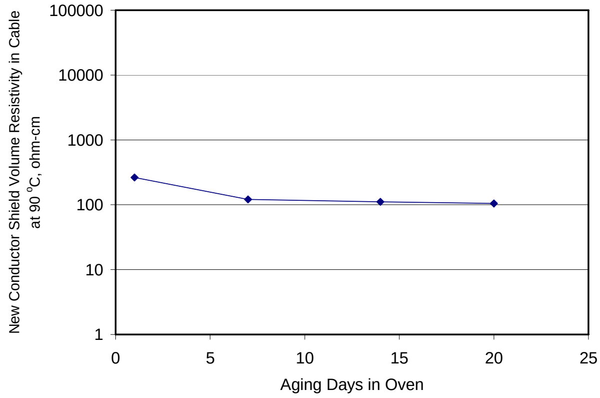

Figure 5 Volume resistivity of new conductor shield formulation in cable at 90 °C aging condition

Moisture content

The moisture sensitivity of semiconductive shields was tested by conditioning the semiconductive compounds in controlled humidity conditions at various time intervals. As shown in Figure 6, the new semiconductive shield is less prone to absorb moisture, which will help to reduce the drying time and improve cable manufacturing productivity.

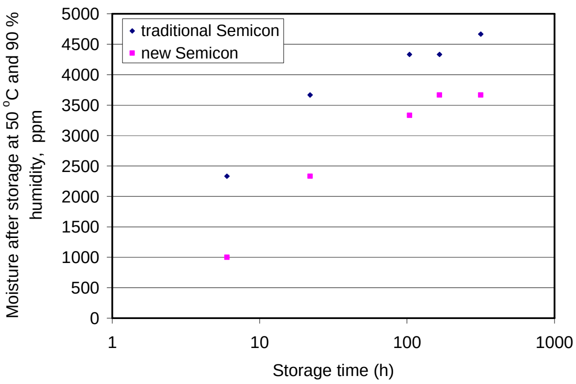

Figure 6 Moisture level in new semiconductive shield compounds after conditioning

Model cable test

A series of model cables have been tested to evaluate the absolute value of breakdown stress after aging for 1000 hours under the AC stress of 9 kV/mm at 50 Hz in water tanks. The temperature of bath is at 70 °C and the conductor temperature is at 85 °C due to electrical heating. Figure 7 shows the effect of different semiconductive shields on the residual AC strength of model cables. The cables with new semiconductive shield resulted in the highest breakdown strength among XLPE cables.

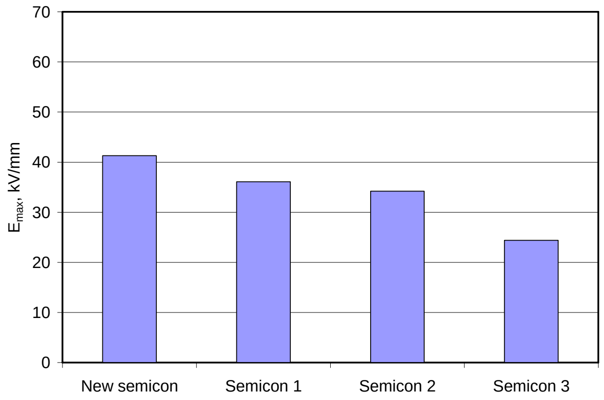

Figure 7 Model cable testing of cables with new semiconductive shield

Cable Extrusion Processability

One of the key requirements for semiconductive shields is extrusion processability. As the cable production rate increases, the semiconductive shields can pose a limitation in cable processability due to its higher viscosity, which can induce scorch in an extruder. The scorch build-up of semiconductive shield is a very important factor on the quality of cables because it can be embedded at the interface with insulation, resulting in protrusions and high electrical stress points. The new conventional shield formulation has been developed to address the issue of extrusion processability.

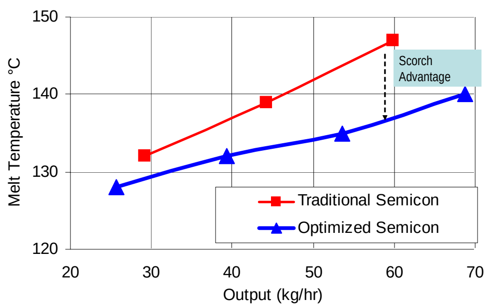

Figure 8 Melt temperature of new conductor shield during cable manufacturing

This advantage was applied in real life comparing the traditional semiconductive shield with the new semiconductive shield when making 11 kV cable on a line that was rate limited by the semicon extrusion. Processing the cable with a traditional semicon at maximum 140 °C melt temperature would have limited the output to 45 kg/hr as shown by the red line in Figure 8 while the new semicon allows as much as 69 kg/hr without scorch. Figure 9 shows the resulting line speed increase (from 16 to 25 m/min) as depicted by the intercept between the sloping line and the maximum output horizontal lines.

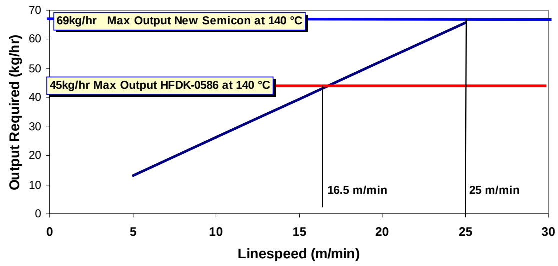

Figure 9 Line speed improvement projection of new semiconductive shield

CONCLUSIONS

We have demonstrated that a new conventional conductor shield based on novel formulation technology has several advantages over a traditional conductor shield, which provide a number of unique values to cable manufacturers and cable users. The processability of the new semiconductive shield is better than that of traditional conventional semiconductive shields, as a result of lower high shear viscosity and improved scorch resistance. It is resistant to conductor shield convolution. The volume resistivity of the new conductor shield with furnace black is well below the IEC specification and stable at 90 °C thermal aging condition. The new conductor shield is less prone to adsorb moisture and should require less drying time. The smoothness of the new conductor shield is better than those of traditional semiconductive shields. These attributes should result in better quality cable and improved service reliability.

ACKNOWLEDGMENTS

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REFERENCES

[1] H. G. Land, H. Schadlich, 1991, "Model Cable Test for Evaluating the Influence of Water on Insulating and Semiconducting Compounds for Medium Voltage Cables", *Jicable*.

[2] C.W. Macosko, 1994, "*Rheology: Principles, Measurements, and Applications*", VCH.

[3] J. D. Ferry, 1980, "*Viscoelastic Properties of Polymers*" 3rd Ed., Wiley.

[4] J. M. Dealy and K. F. Wissbrun, 1990, "*Melt Rheology and Its Role in Plastics Processing*", Wiley (1990).

[5] J. H. Mason, 1959, "*In Progress in Dielectrics*", vol. 1. J. S. Birks, and J. H. Shulman, editors, London: Heywood and Co.