Electrical properties of flexible polypropylene based cable insulation materials

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DC resistivity and AC breakdown strength of flexible polypropylene (trade marked name Hifax) cable insulation materials have been measured at selected temperatures. The AC breakdown data has been analysed in terms of Weibull distribution. The results show that Hifax cable insulation has a higher AC breakdown strength than EPR (ethylene propylene rubber) and XLPE (crosslinked polyethylene), both of which are widely used for DC cable insulation. It is concluded that blending Hifax with ordinary polypropylene decreases the breakdown strength. The DC resistivity of Hifax is larger than that of XLPE and oil-impregnated paper insulations. It has been found that the electrical stress coefficient of resistivity of Hifax cable insulation increases with temperature, which may have important engineering implications. An anomalous drop in resistivity has been observed for Hifax at high electrical fields, suggesting charge trapping and detrapping processes are present in these cable insulations.

1. Introduction

Extensive research has been carried out to develop a feasible polymeric insulation material for DC applications [1–6]. As part of the assessment process, physical testing has been performed on potential insulation materials. Among them Hifax (Flexible Polypropylene) appears to be a promising candidate for the next generation of DC material. In particular, Hifax has a melting temperature of 142°C that is much higher than the normal working temperature of DC cables. Consequently, DC cables insulated with Hifax would not need to be crosslinked, removing the need for degassing. Previous studies have shown that the thermal conductivity of Hifax is similar to that for EPR and XLPE and its DC breakdown strength is higher than that of EPR [2]. Furthermore, DSC, TMA, hotset and tensile testing indicate that adding polypropylene to Hifax can raise the softening temperature even further. The resulting blend has a higher tensile strength. Since Hifax polymers are more expensive than polypropylene, it was suggested that polypropylene might be blended with the Hifax without adversely affecting its physical properties.

Initially, this work aims to investigate further the effect of blending Hifax with polypropylene on its electrical properties. AC breadown tests have been made on wire (model cable) samples insulated with Hifax blended with various percentages of polypropylene. The reason for using AC instead of DC breakdown strength to characterise the materials is that AC breakdown field of polymers is almost always less than DC breakdown field. The DC resistivity of these wire samples has also been measured as a function of electrical stress at selected temperatures. The temperature coefficient α and the stress coefficient β of resistivity have been calculated.

2. Experimental

2.1. Sample preparation

The details of the polypropylene blended Hifax samples are given in Table I. Ordinary polypropylene from three different industrial suppliers was used to prepare the insulation material. The melting flow rate (MFR) of polypropylene 1343 and 4553 is 9 g/10 min and 7.2 g/10 min respectively. Both of them are manufactured by Exxon Chemicals. Irganox 1010 and Chimasorb 944 are two types antioxidant additive normally included in XLPE cable insulations. The materials were mixed and extruded onto copper wires of 1mm diameter. The advantage of using wire samples is that it not only simulates the field distribution in real cable insulation but also eliminates the need for guard rings as in the high voltage test of plaque samples. For selected wire samples, a semiconducting polymeric screen was also extruded on the top of the insulation to act as an electrode.

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2.2. AC breakdown test

AC breakdown tests have been carried out using a modified BAUR dielectric strength test set. Wire samples, typically 1 metre long, were immersed in a glass water bath. The conductor of the wire acts as one electrode and the water as the other. The system is capable of supplying an AC voltage up to 75 kV with a 4 mA trigger-off AC current. To track any possible electrical ageing effects, the tests were repeated at three ramp rates: 0.5 kV/s, 2 kV/s and 5 kV/s.

On recording the breakdown voltage, care was taken to distinguish the real dielectric breakdown from the so called arc-cross in the surrounding air and the switch-off triggered by excess AC current. While it is possible to adjust the test configuration to avoid the low voltage arc-cross, the sample length has to be reduced to limit the AC current below the trigger off current. In both cases, the apparent voltage was recorded as "suspended" in the Weibull analysis.

2.3. The DC resistivity measurement

Ten meters of extruded wire were immersed in a glass jar filled with tap water. One end of the cable conductor was connected to a Glassman high voltage unit capable of generating DC voltages up to 15 kV. The other end was left free in the air. The water in the glass jar acted as another electrode. Since the resistivity of tap water is roughly 8 orders magnitude smaller than that of the cable insulation, the resistance of water can be ignored in data processing without losing much accuracy.

The glass jar, together with the sample, was placed in a Grant W14 oil bath, in which the sample temperature can be increased up to 150°C. A K-type thermocouple was immersed in the oil bath (not in the water, because the high DC voltage would cause the thermocouple to stop working properly) near the glass jar to measure the temperature to within an accuracy of ±1°C. The signal from the thermocouple was automatically recorded using a Keithley electrometer.

The high voltage output was controlled and monitored using the Keithley electrometer. To measure the DC current passing through the wire insulation, the water electrode was connected to earth through a 16 MΩ resistor. This was done with one end of the resistor immersed in the water in the glass jar and the other end connected to the earth. The voltage across this resistor was then measured using a multimeter, together with a high input impedance preamplifier, which makes the instrument extremely sensitive to electrostatic potentials. The DC current and subsequently the volume resistivity of the sample under test were calculated from the voltage across the resistor. Knowing the voltage V applied across the wire insulation and the DC current I in the material, the resistivity is given by

$$\rho = \frac{2\pi L}{\ln(r_2/r_1)} \frac{V}{I} \tag{1}$$

where L is the length of the wire, r_1 the conductor radius, r_2 the insulation radius.

After a DC test voltage is applied to the sample, the current normally decays to a steady or quasi-steady value. The time to reach the steady state depends on the electrical field and temperature of the insulating material. In the present work, current measurements were taken 60 and 180 s after a voltage step had been applied to the sample. Comparison of the two current values thus obtained showed that there was essentially no detectable difference between the two currents in the whole voltage and temperature ranges. Therefore, only the data taken 60 s after application of voltage will be presented and discussed in the following sections.

The whole testing system was controlled automatically by a computer program.

3. Results and discussion

3.1. AC breakdown strength of Hifax insulations

Electrical breakdown of polymeric insulating materials has a stochastic nature and the data are often best analysed in the frame of Weibull distribution [7, 8]. If apparently identical polymeric insulating systems are exposed to identical tests in which the voltage is linearly increased with time, a different breakdown voltage is often observed for each insulating specimen. The breakdown voltage so obtained may be characterised by a statistical distribution that describes the probability of breakdown as a function of voltage. According to Weibull's approach, the probability of failure $P_F(V)$ at voltage V during a progressive stress test with a ramp rate $\dot{V} = dV/dt$ (rate of voltage increase) is given by

$$p_F(V) = 1 - \exp\left[-\left(\frac{V}{V_c}\right)^{\beta}\right] \tag{2}$$

where V_C is the 63% failure voltage (scale) and β the gradient of the Weibull fitting (shape parameter). The shape parameter and characteristic breakdown voltage may be obtained by plotting the testing results on Weibull probability paper and this process has been realised by a computer program [7].

According to theory [3], the shape parameter β in Equation (2) is given by the sum of two constants:

$$\beta = a + b \tag{3}$$

and the characteristic breakdown voltage V_C is related to the ramp rate by

$$\dot{V} = \left(C \frac{a}{a+b}\right)^{1/a} V_C^{\frac{a+b}{a}} \tag{4}$$

where the constants a and b are the shape parameters of the Weibull function of time and voltage respectively, and

C is a new proportionality constant. The probability of failure under constant voltage conditions is given by

$$P_F(V,t) = 1 - \exp\left(-Ct^aV^b\right) = 1 - \exp\left[-\left(\frac{t}{\tau}\right)^a\right] \quad (5)$$

The characteristic time to failure at constant voltage V is

$$\tau = \frac{1}{C^{1/a}V^{b/a}} \quad (6)$$

If several progressive-stress tests are carried out at different rates of voltage increase, $\dot{V}$, a log-log plot of Equation (4) will result in a graph of slope $\frac{a+b}{a}$ and a constant $\frac{1}{a}\ln\left(\frac{Ca}{a+b}\right)$.

Notice that the value of $a+b$ is related to the shape parameter β that can be determined from Weibull plots of the testing data (Equations 2 and 3). The constant a, b and C can then be calculated and subsequently the time to failure for the insulation system can be obtained without recourse to constant-stress test.

To enable an accurate Weibull analysis, ten samples were tested at each of the three ramp rates (0.5 kV/s, 2 kV/s and 5 kV/s) for each Hifax insulation formula. The characteristic breakdown voltage and the shape parameter of Weibull analysis are shown in Table II. The characteristic breakdown stress E_c in the table is simply the average field defined as the voltage divided by the thickness of the wire insulation. For some of the pure Hifax insulation (without polypropylene but still with anti-oxidants), breakdown did not occur even at the highest voltage available. In these cases the suspended voltages were used in the Weibull analysis and the data are shown highlighted in the table.

In general, there is an electrical ageing effect for most of the samples: the breakdown voltage/stress tends to be higher for high ramp rates, consistent with Eq. 4. Slower ramp rate means the sample must withstand voltages for a longer period of time and breakdown may occur at a lower voltage. It can be seen from Table II that the shape parameter β has similar values for three different ramp rates. Thus average values of shape parameter were used in calculating the constants a, b and C. Fig. 1 shows the log-log plot of Eq. 4 for selected Hifax insulated wire samples. The straight lines are the least square fits of the breakdown data. The fitting parameters and the calculated constants a, b and C, together with the calculated characteristic time to failure at a constant voltage of 10 kV, are given in Table III. Note samples S08 and S16 are excluded from Table III because suspended voltages have been used to obtain their characteristic breakdown strength at ramp rates 2 kV/s and 5 kV/s. It can be seen that pure Hifax samples have larger values of time to failure (compare sample S04 with S01, S02 and S03; sample S12 with S09, S10 and S11). Also thicker samples tend to have longer time to failure as expected.

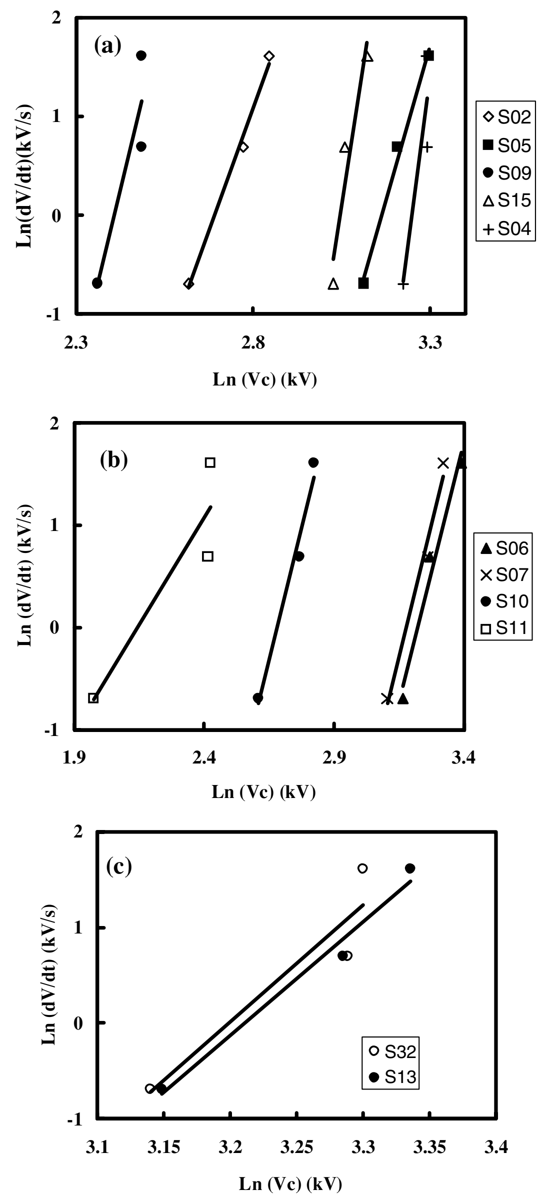

Figure 1 Log-log plot of ramp rate dV/dt versus 63% failure voltage V_c for Hifax cable insulation materials (a) S02, S04, S05, S09, S15; (b) S06, S07, S10, S11; (c) S12 and S13.

In real electrical applications, time to failure of polymeric insulation under constant voltage is of fundamental importance. However, time to failure test is normally time consuming. The analysis presented here enables us to estimate the time to failure of polymeric insulation using the data obtained in a progressive stress test that can be easily carried out within a short period of time. For most of the samples listed in Table III, the linear regression correlation coefficient R^2 is close to unity, with exceptions for samples S01, S03 and S14. These experimental results evidence a strong correlation between the breakdown voltage and the ramp rate and thus validate the theoretical model and the analytical procedures we are using. The small values of correlation coefficient R^2 for samples

TABLE I Details of Hifax insulated wire samples. The second and third columns give the weight percentages of Hifax and polypropylene respectively

Sample ID	Hifax (CA10) (%)	PP (%)	PP Type	Irganox 1010 (phr)	Chimasorb 944 (phr)	Wall thickness (mm)	Semicon screen
S01	38	62	1343	0.2	0.2	0.4	Yes
S02	38	62	4553	0.2	0.2	0.4	Yes
S03	38	62	PX405	0.2	0.2	0.4	Yes
S04	100	0	N/A	0.2	0.2	0.4	Yes
S05	38	62	1343	0.2	0.2	0.7	Yes
S06	38	62	4553	0.2	0.2	0.7	Yes
S07	38	62	PX405	0.2	0.2	0.7	Yes
S08	100	0	N/A	0.2	0.2	0.7	Yes
S09	38	62	1343	0.2	0.2	0.4	No
S10	38	62	4553	0.2	0.2	0.4	No
S11	38	62	PX405	0.2	0.2	0.4	No
S12	100	0	N/A	0.2	0.4	0.4	No
S13	38	62	1343	0.2	0.2	0.7	No
S14	38	62	4553	0.2	0.2	0.7	No
S15	38	62	PX405	0.2	0.2	0.7	No
S16	100	0	N/A	0.2	0.2	0.7	No

phr = parts per hundred base resin.

TABLE II Electrical breakdown strength of Hifax insulated wire samples measured at three ramp rates. Arcing or excess current switch-off occured in Samples S08 and S16 at voltage ramp rates 2 and 5 kV/s; the apparent voltage was recorded as "suspended" in the Weibull analysis and the corresponding results are highlighted

	0.5 kV/s			2 kV/s			5 kV/s		
Cable ID	V_C (kV)	β	E_C (kV/mm)	V_C (kV)	β	E_C (kV/mm)	V_C (kV)	β	E_C (kV/mm)
S01	10.5	1.5	26.3	11.3	1.9	28.3	10.5	1.8	26.3
S02	13.7	16.0	34.3	16.0	58.9	40.0	17.2	28.0	43.0
S03	15.2	5.5	38.0	12.9	3.0	32.3	18.5	4.9	46.3
S04	25.1	13.1	62.8	26.9	23.8	67.3	26.8	28.3	67.0
S05	22.5	13.6	32.1	24.7	16.4	35.3	27.0	11.4	38.6
S06	23.7	4.3	33.9	26.3	5.4	37.6	29.7	8.4	42.4
S07	22.3	11.6	31.9	26.1	7.2	37.3	27.7	8.9	39.6
S08	44.5	16.9	63.4	**42.8**	**81.4**	**61.1**	**41.7**	**77.8**	**59.6**
S09	10.6	9.6	26.5	12.0	5.7	30.0	12.0	5.0	30.0
S10	13.6	63.1	34.0	15.9	52.3	39.8	16.8	48.2	42.0
S11	7.2	1.0	18.0	11.2	1.4	28.0	11.3	1.9	28.3
S12	23.1	5.0	57.8	26.8	10.4	67.0	27.1	12.8	67.8
S13	23.3	5.0	33.3	26.7	18.1	38.1	28.1	20.9	40.1
S14	20.6	6.5	29.4	27.2	5.9	38.9	25.1	5.3	35.9
S15	20.6	6.7	29.4	21.3	6.6	30.4	22.7	12.2	32.4
S16	45.7	5.5	65.3	**38.9**	**141.3**	**55.6**	**37.6**	**111.3**	**53.7**

TABLE III Fitting parameters and calculated constants a, b and c for Hifax insulated wire samples. R^2 is the linear regression correlation coefficient. The last column shows the calculated characteristic time to failure at a constant voltage of 10 kV

Sample	R^2	$\frac{a+b}{a}$	$\frac{1}{a}Ln\left(\frac{aC}{a+b}\right)$	a	b	C	TTF at 10 kV(s)
S01	0.014	3±27	−7±65	0.5	1.2	7.0E−02	9.E−01
S02	0.992	9.9±0.9	−27±2	3.5	30.9	8.2E−40	2.E+02
S03	0.196	3±6	−7±16	1.6	2.9	3.3E−05	1.E+01
S04	0.808	27±13	−87±43	0.8	20.9	5.9E−30	2.E+10
S05	0.989	13±1	−40±4	1.1	12.7	1.4E−18	5.E+04
S06	0.974	10±2	−33±5	0.6	5.4	3.7E−08	2.E+03
S07	0.981	10±1	−33±5	0.9	8.3	1.9E−12	6.E+03
S09	0.844	15±6	−36±16	0.5	6.3	1.3E−06	1.E−01
S10	0.977	10±2	−28±4	5.2	49.3	3.3E−63	3.E+02
S11	0.856	4±2	−9±4	0.3	1.1	1.9E−01	8.E-02
S12	0.886	12±4	−39±14	0.8	8.6	1.1E−12	2.E+04
S13	0.981	12±2	−38±5	1.2	13.4	4.2E−20	6.E+04
S14	0.594	6±5	−19±16	0.9	5.0	7.2E−08	2.E+02
S15	0.915	22±7	−68±21	0.4	8.1	1.3E−10	5.E+04

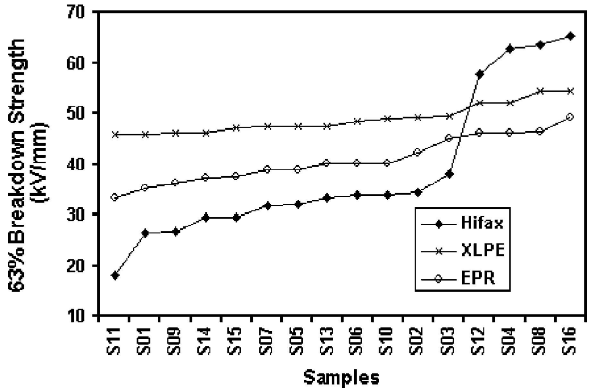

Figure 2 Electrical breakdown strength of round wire Hifax samples measured at a ramp rate of 0.5 kV/s. Data for XLPE and EPR wire samples are also presented for comparison [9].

S01, S03 and S14 might be ascribed to the fluctuations arising from the small size of the fitting data.

The most significant decrease in the breakdown strength (∼50%) occurs in the samples where Hifax has been blended with the three types of polypropylene. The 63% breakdown strength (measured at a ramp rate of 0.5 kV/s) is also shown graphically in Fig. 2, together with the results obtained on XLPE and EPR insulated wires for comparison [9]. It can be seen that pure Hifax insulation (samples S4, S8, S12 and S16) has a much higher AC breakdown strength than XLPE and EPR. Blending Hifax with 62% polypropylene decreases its breakdown strength to a level significantly less than that of EPR and XLPE. Fig. 2 suggests that to obtain insulation with electrical performance better than EPR, the amount of polypropylene has to be reduced to a level of 50% (or perhaps even lower). Physically, adding polypropylene raises the melting point and tensile strength of the resulting polymer but at the same time increases the brittleness and reduces the mechanical flexibility of the material. It is very likely that micro cracks would develop more readily on bending the wire insulation extruded with polypropylene additive, leading to a filamentary electromechanical breakdown [3].

3.2. Electrical stress and temperature dependence of DC resistivity for Hifax insulation

Due to the low AC breakdown strength of polypropylene blended Hifax insulation, DC resistivity tests have only been made on pure Hifax insulated wire samples. Fig. 3 shows the stress dependence of resistivity for Hifax insulated wire sample S16 at low stress values (the anomalous behaviour at higher stresses will be discussed later). It can be seen that the resistivity decreases exponentially with DC electrical stress within the stress range studied. Normally, the electrical stress/field (E) and temperature (T) dependence of resistivity (ρ) for an insulation material can be described by the equation [10]

$$\rho = \rho_0 \exp(-\beta E - \alpha T) \qquad (7)$$

The stress coefficient (β) and the temperature coefficient (α) of resistivity can be found by fitting the data measured at constant temperature and constant electrical field respectively to the exponential curve. The stress coefficient (β) for sample S08 and S16 at selected temperatures is given in Table IV, together with the resistivity of these materials measured at an electrical stress 7 kV/mm. The resistivity of oil-impregnated paper measured at 10 kV/mm and that of a XLPE sample measured at 7 kV/mm are also included for comparison [2, 11]. It can be seen that the DC resistivity of Hifax is larger than that of XLPE and oil-impregnated paper insulations. Compared with S16, the insulation of wire sample S08 has slightly larger resistivity but a smaller stress coefficient. Samples S16 and S08 are insulated with the same pure Hifax material of 0.7 mm thickness. The only difference between the two wire samples is that S08 has a semi-conductive core screen while S16 has not (Table I). The apparent resistivity difference of these two samples suggests that the resistivity of the semi-conductive screen may be comparable to that of the insulation and therefore may not be ignored when processing the data. The smaller stress coefficient of S08 (with semi-conductive screen) is consistent with the fact that semi-conductive screen would smooth the stress distribution on the surface of the insulation.

It should be noted that the stress coefficient β for both samples is strongly temperature dependent, consistent with the tests on plaque Hifax samples [2]. The data obtained here as well as those from plaque samples show clearly that the strong temperature dependence of the stress coefficient is an intrinsic feature of Hifax, not an artefact associated with the testing method. This variation of β with temperature has important engineering implications and should be taken into account in determining the electrical stress/field distribution across a DC cable insulation made of Hifax. Electrical studies of ethylene propylene rubber (EPR) and crosslinked polyethylene (XLPE) show that the electrical field coefficient β of resistivity for these two polymers also varies with temperature [9, 12]. The electrical field coefficient of EPR increases with temperature while for XLPE it decreases with temperature.

In Fig. 3, the data at high electrical stress have been ignored in order to calculate the stress coefficient. Fig. 4 shows the stress dependence of DC resistivity of S08, with the high voltage data included. For both samples S08 and S16, there is an anomalous resistivity drop at ∼12 kV/mm. Here the sharp decrease in resistivity occurs at low temperatures and tends to disappear above 80°C. The critical electrical field (or stress) at which the resistivity begins to drop sharply does not change with increasing temperature.

This anomalous resistivity change at high electrical stress may have important theoretical and engineering implications and has not been observed in the plaque samples. The phenomenon can be ascribed to the space charge limited conduction mechanism [3]. It is possible that the

TABLE IV Resistivity and stress coefficient of resistivity for Hifax cable insulation S08 and S16 (0.7 mm wall) at selected temperatures. The resistivity data were obtained at a constant electrical field 7 kV/mm. The resistivity of oil-impregnated paper measured at 10 kV/mm and that of a XLPE sample measured at 7 kV/mm are also included for comparison [2, 11]

	□ρ (ohm m)				β(mm/kV)	
T(°C)	S16	S08	Paper	XLPE	S16	S08
25	5.41E+14	1.28E+15	3.28E+14	3.08E+14	0.105	0.018
40	1.87E+14	2.61E+14	5.01E+13	6.91E+13	0.140	0.074
60	4.40E+13	7.72E+13	1.92E+13	9.52E+12	0.196	0.098
80	8.64E+12	1.77E+13	3.07E+12	1.373+12	0.314	0.175
100	1.37E+12	3.17E+12		1.87E+11	0.353	0.270

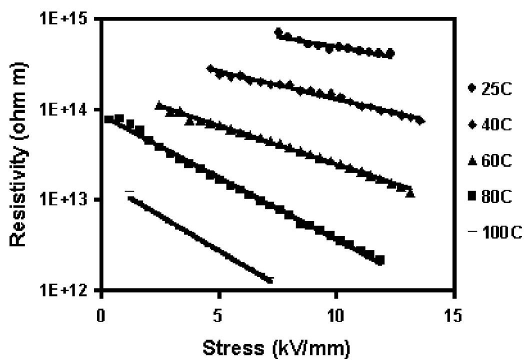

Figure 3 Electrical stress dependence of volume resistivity of Hifax insulated wire sample S16.

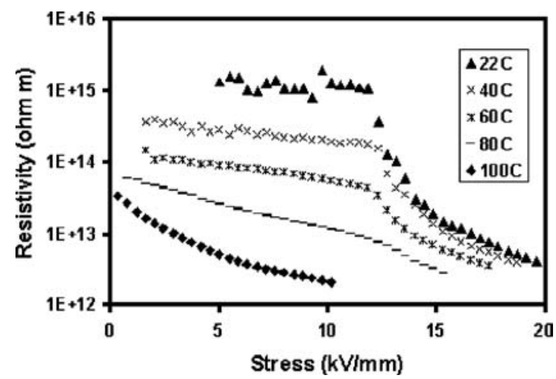

Figure 4 Electrical stress dependence of volume resistivity of Hifax insulated wire sample S08.

antioxidants in the wire insulation form some "traps". According to the Fermi-Dirac distribution and assuming all the traps are at the same energy level E_t with a number density N_t, the ratio of free charge carriers to those trapped is given by

$$\theta = \frac{n_c}{n_t} = \frac{N_{\text{eff}}}{N_t} \exp\left(-\frac{\Delta E_1}{kT}\right) \qquad (8)$$

where n_c is the number density of conduction band electrons and n_t the number density of occupied trap states, N_{eff} is the effective density of states for the conduction band, $\Delta E_t = E_c - E_t$ is the trap depth which is much smaller than the energy gap. At low stresses, most of the charge carriers injected from the electrode are trapped and contribute little to the conduction. The value of θ may be as small as 10^{-10}–10^{-6} and increases slowly with electrical stress. It is the charge trapping-detrapping process that is responsible for the low conduction of the material. The space charge limited current density J that flows for an applied voltage V can be given by the Mott and Gurney square law [3]

$$J = \frac{9\varepsilon_0\varepsilon_r m V^2}{8L^3} \qquad (9)$$

where L is sample thickness and m is carrier mobility. The current should vary as the square of the applied voltage. Fig. 5 shows the log DC current versus log DC voltage for Hifax insulated wire sample S08 at 40°C. It can be seen that Log current increases linearly with log voltage below a critical voltage, consistent with Eq. 9. However the slope of the curve at low voltages is 1.42 rather than 2 as predicted by the theory. This discrepancy may be an indication that the charge density in Hifax insulation is made of a small amount of free charges as well as injected charges. The observed slope of 1.42 is a consequence of both Ohmic (slope=1) and space charge limited (slope=2) current.

As the voltage is raised to a critical value the number density of charge-carrier being injected from the electrode is approximately equal to the number density of traps and the Fermi energy level will rise above the trap energy level. As this so called trap-filled limit is reached, the number

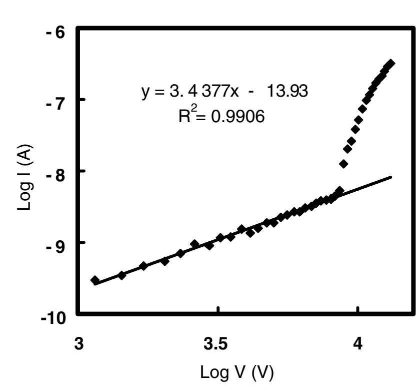

Figure 5 Log DC current versus log DC voltage for Hifax insulated wire sample S08 at 40°C.

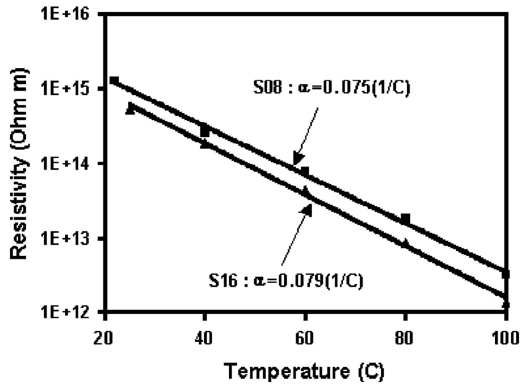

Figure 6 Temperature dependence of volume resistivity for Hifax cable insulation at 7.2 kV/mm.

density of the conduction band increases rapidly against the number density of the occupied trap states, resulting in an abrupt increase in conductivity or a decrease in resistivity. Using Poisson's equation the trap-filled limit voltage V_{TFL} can be calculated:

$$V_{TFL} = \frac{eN_t s^2}{2\varepsilon_0 \varepsilon_r} \tag{10}$$

where s is the thickness of the sample. Eq. 10 indicates that the critical voltage/electrical stress is proportional to the number density of traps and is independent of temperature, consistent with the observation in Fig. 4. As temperature increases, the number of free charge carriers becomes larger. At sufficiently high temperatures, the ratio in Equation 8 tends to be a constant. That is why we cannot see the sharp drop in resistivity of Hifax above 80°C. From Fig. 5, V_{TFL} has been determined as 8629 volt. Knowing the thickness $s = 0.7$ mm and taking $\varepsilon_r = 2.5$, the number density of traps can be estimated to be 5×10^{18} m^{-3}. Further work is in progress to establish the correlation between the concentration of additives and the number density of traps in the polymer. The critical electrical field obtained in this work indicates an upper limit for the DC cable stress design of this flexible polypropylene.

Temperature dependence of resistivity of Hifax cable insulation measured at a stress level of 7.2 kV/mm is shown in Fig. 6. The straight lines are the least square fits to the data. For both samples, the resistivity decreases exponentially with increasing temperature according to Eq. 7, with a temperature coefficient $\alpha \sim 0.08$ (1/°C) which is slightly less than that of EPR and XLPE [12].

4. Conclusions

(1) Hifax cable insulation has a higher AC breakdown strength than EPR and XLPE. Blending Hifax with ordinary polypropylene decreases the breakdown strength significantly.

(2) Hifax has a higher DC resistivity than XLPE and oil-impregnated paper insulations. Its relatively small temperature coefficient α of resistivity makes it particularly suitable for high temperature DC design.

(3) The electrical stress coefficient of resistivity of Hifax wire insulation increases with temperature. This strong temperature dependence of stress coefficient may have important engineering implications and needs to be taken into account when calculating the stress distribution across a DC cable insulation.

(4) The observation of an anomalous change in resistivity at high stress suggests that the trap-filled-limit is reached around 8.6 kV in Hifax wire insulation. The experimental data also indicate an upper stress limit of 12 kV/mm for DC cable applications of this insulating material.

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