

EVA-EPDM Blends as Cable Insulant

I. RAY and D. KHASTGIR*

Rubber Technology Centre, Indian Institute of Technology, Kharagpur-721302, India

SYNOPSIS

Base materials for heat-resistant cable insulant have been developed from blends of ethylene vinyl acetate (EVA) copolymer containing 28% VA and ethylene propylene diene (EPDM) rubber. Different electrical, mechanical, and thermal properties of these blends have been studied extensively. Aging under different conditions has also been studied. The chemical and mechanical stability of these compositions has been assessed at the actual temperature range of application. Dielectric properties have been determined against varying temperature. These blends may be used as insulating materials having a temperature rating around 90–130°C, which is above the temperature rating (85–90°C) of heat-resistant insulation based on EPDM. © 1994 John Wiley & Sons, Inc.

INTRODUCTION

Synthetic polymers have found extensive application as electrical insulators, especially for extruded cables. They have a wide application area, ranging from power and control to apparatus cables. Cross-linking of thermoplastic polymers with organic peroxides and/or other curing agents leads to a three-dimensional network structure having adequate thermal endurance properties coupled with good electrical and mechanical properties. A good combination of flexibility and strength is an essential requirement of cable insulant. A continuous effort is being made to improve mechanical and thermal endurance properties of cable insulant without much sacrifice of electrical properties.

The selection of polymeric insulating material for cable application depends on various factors.¹⁻⁴ Different thermal, electrical, and fire testing techniques are applied for quality checkups of various cable materials.⁵⁻⁷ For special application areas, e.g., for oil resistance and flame- and fire-retardant cables, requirements are also very specific.^{3,4,8-11}

The development of cable insulant for low-to-medium voltage power and control cable based on blends of ethylene vinyl acetate (EVA) (28% VA)

and ethylene propylene diene (EPDM) rubber are discussed in the present article. Different thermoset blends of these two polymers are characterized with respect to electrical, mechanical, and thermal endurance properties.

This blend shows partial miscibility in the amorphous region of EVA with EPDM, as evidenced from the DSC and DMA plots.¹² In the DSC curve, the discontinuity in the variation of heat flow vs. temperature is due to the transition. This transition temperature changes with the blend composition. This reveals partial miscibility of the system, whereas the melting temperature of EVA retains its integrity, leading to the conclusion that the crystalline phase of EVA remains unaffected on blending. It has been found that cross-linking leads to technical compatibility between two completely dissimilar polymers like nitrile and EPDM.¹³ The curing characteristics and mechanical properties of the system reveals the possibility of interfacial cross-linking between the two constituent polymers of the blends. The compatibility of these blends has been detailed elsewhere.¹²

EXPERIMENTAL

Materials

Materials used in the experiment have the following characteristics:

* To whom correspondence should be addressed.

	Trade Name	Characteristics	Producer
EVA	Pilene 2806	VA content = 28% MFI = 6 g/10 min $d = 0.95$ g/cc	PIL, India
EPDM	Royalene 521	ML ₁₊₄ at 100°C = 45	Uniroyal, USA

Preparation of the Blend Compounds

Blending of two polymers and the subsequent compounding operation were carried out in a Brabender Plasticorder (Model PLE 330) with a cam-type rotor. The temperature of the chamber was set at 100°C, and rotor speed, at 60 rpm. Formulation of the compounds are given in Table I.

Processability

Brabender Viscosity

During blending and mixing in a Brabender Plasticorder, a continuous record of mixing torque against time was made. The attainment of equilibrium torque (torque nonvariant with time) was taken as the condition of homogeneous blending. Final equilibrium torque (Brabender viscosity) was taken as the characteristic viscosity of the material for further processing such as extrusion and calendaring.

Curing Characteristics

The curing behavior of the compounds was studied by a Monsanto rheometer (R-100) at the cure temperature of 170°C. The optimum cure time was calculated from the rheometric torque-time curve.

Molding and Curing

All the materials were subjected to compression molding at the temperature of 170°C for optimum cure time. Test specimens were punched out of these compression-molded sheets.

Table I Formulation of the Compounds

	EP ₀	EP ₃₀	EP ₅₀	EP ₇₀	EP ₁₀₀
EVA	100	70	50	30	0
EPDM	0	30	50	70	100
Antioxidant	2	2	2	2	2
Peroxide-based curative system	2.5	2.5	2.5	2.5	2.5

Mechanical Properties

Hardness

On the compression-molded sample, hardness was measured according to ASTM standard D 2240-86 at 28°C.

Tensile Properties

Tensile properties were measured according to ASTM standard D 412-87 at 28°C using a Zwick universal testing machine (UTM 1445).

Electrical Properties

Volume Resistivity

The volume resistivity of the molded samples was measured according to ASTM D 257-83 using a Hewlett-Packard 4329A high-resistance meter and resistivity cell at room temperature (27°C).

Dielectric Strength

The dielectric strength of the molded samples was measured according to ASTM standard D 149-87 with the help of a Siemens breakdown voltage set up at 50 Hz. The test voltage was applied across the thickness of the samples of approximately 0.3 mm.

Dielectric Constant and Loss

The dielectric constant and loss factor were measured on thin samples (thickness ranging between 0.25 and 0.35 mm) over the temperature range 30–150°C at the frequency of 50 Hz using a dielectric analyzer DEA-2970 interfaced with a controller 2000. ac conductivity (dielectric specific conductivity) values were also obtained from this instrument.

Thermogravimetric analysis (TGA):

The thermogravimetric analysis of different blends and pure components were carried out using a DuPont 951 thermogravimetric analyzer in a nitrogen atmosphere at the heating rate of 20°C min⁻¹.

About 10 mg of the sample was used for each experiment.

Thermal Aging Behavior

Air-oven Aging

The effect of thermal aging on the tensile properties of compression-molded samples was measured as per ASTM standard D 573-88 at 28°C. Samples were subjected to aging at the temperature of 135°C for 7 days.

Air-bomb Aging

The effect of simultaneous oxidative and thermal aging on the tensile properties of different compositions, under the accelerated conditions of compressed air and temperature, was measured according to ASTM standard D 454-88 at 28°C. The samples were aged at 127°C under an air pressure of 0.55 MPa for 42 h duration.

Ozone Resistance

The effect of ozone on the tensile properties of the molded samples was studied. Ozone concentration was maintained at 0.03% by volume (300 ppm) and the samples were kept for 30 h at 27°C in the ozone chamber.

Dynamic Mechanical Thermal Analysis (DMTA)

Dynamic mechanical analysis was carried out using the PL-DMTA instrument (Polymer Labs). Tests were performed in the shear mode from -50 to 250°C at a frequency of 30 Hz with a double-strain amplitude of 64 μm and at a programmed heating rate of +2°C.

RESULTS AND DISCUSSION

Processability

The change in Brabender viscosity (mixing torque) against time for different blend compositions is presented in Figure 1(A). The torque at any point of time is dependent on the blend composition. Both initial and final (equilibrium) torque increase with increase in the EPDM concentration of the blend. The area under the torque-time curve represents the mechanical energy consumed during blending. The energy required for blending decreases with increase in EVA concentration. A lower value for final viscosity (equilibrium torque) implies better processability with lower energy consumption during further processing such as extrusion and calender-

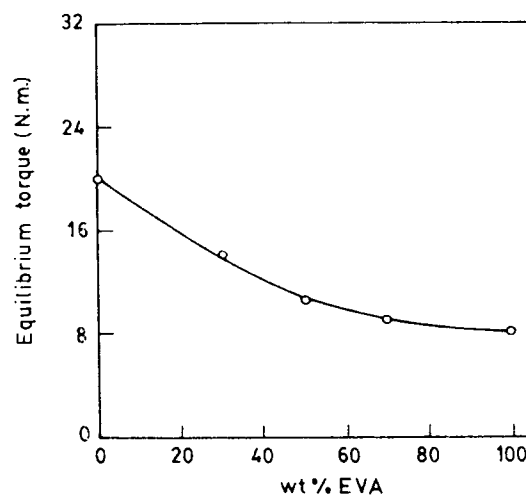
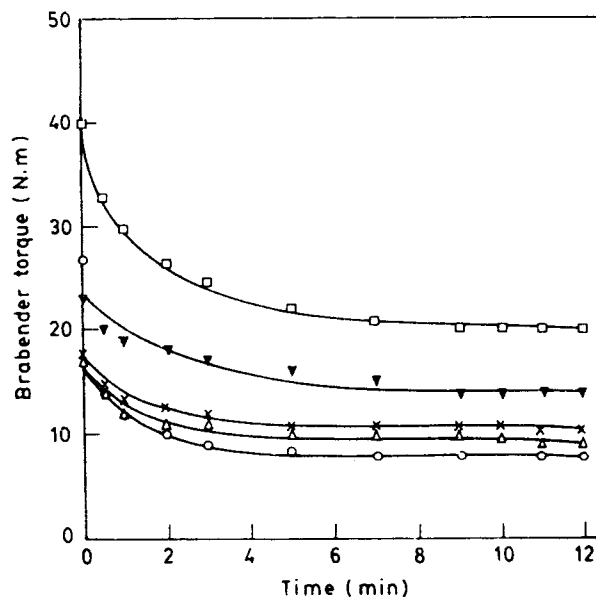


Figure 1 (A) Brabender torque of different EVA-EPDM blend compositions vs. time. For details of the blends, see Table I. (—○—) EP₀; (—△—) EP₃₀; (—×—) EP₅₀; (—▼—) EP₇₀; (—□—) EP₁₀₀. (B) Equilibrium Brabender torque of different EVA-EPDM blends.

ing. The equilibrium torque is plotted against compositions in Figure 1(B). The equilibrium torque varies nonlinearly against composition, and a negative deviation from linearity is observed.

Curing Characteristics

To increase the thermal stability of polymeric cable insulants, they are often converted from the state

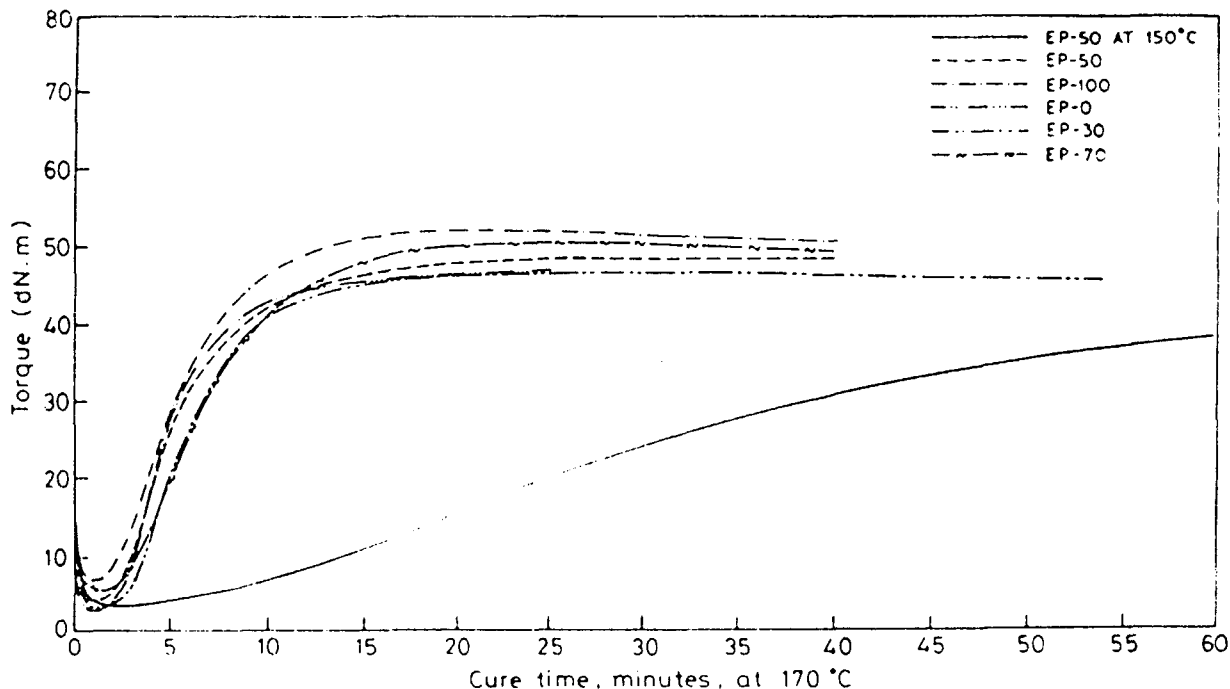


Figure 2 Rheometric torque of different EVA-EPDM blends.

of thermoplastic to thermoset through introduction of a sufficient number of interchain cross-links, and curing or vulcanization is an essential step for this conversion. The curing characteristics of different blends are presented in Figure 2. The following observations are worth mentioning:

1. The cure rate was found to be too slow at 150 and 160°C.
2. At the temperature of 170°C, the cure rate is substantially high, so that the process can be completed within a reasonable time period.
3. A flat curing without any tendency of reversion indicates good thermal stability of all blend compositions at elevated temperature.

The matching of cure time and cure rate of pure EVA and EPDM indicates the possibility of co-curing and interfacial cross-linking of the two components in their blends.

Physicomechanical Properties

The assessment of a cable insulant may be made in terms of the following physicomechanical properties:

- (i) Hardness;
- (ii) Tensile strength;
- (iii) Elongation at break;
- (iv) Modulus;
- (v) Retention of these properties after accelerated aging at different specified conditions.

The hardness of the blends increases with the increase in EVA content. The variation is nearly linear until 70% EVA concentration in the blend, beyond which the rate of increase decreases slightly. Shore A hardness of these systems ranges from 40 for pure EPDM to 85 for pure EVA (Fig. 3).

Tensile strength, modulus, and elongation at break for different blend compositions are shown in Figure 4. Tensile strength and modulus increase steadily with increasing EVA concentration in the blend. However, all EVA-containing compositions show almost the same elongation at break.

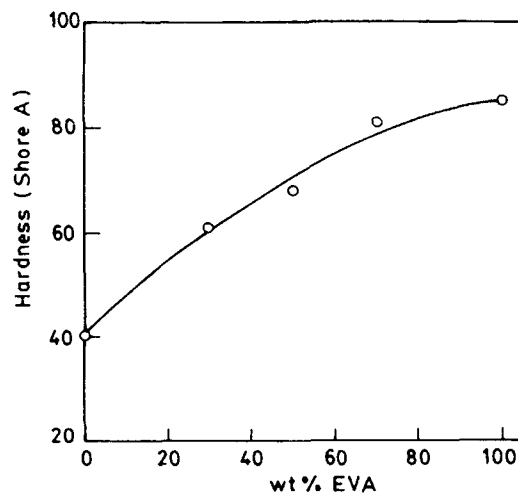


Figure 3 Hardness of different EVA-EPDM blends.

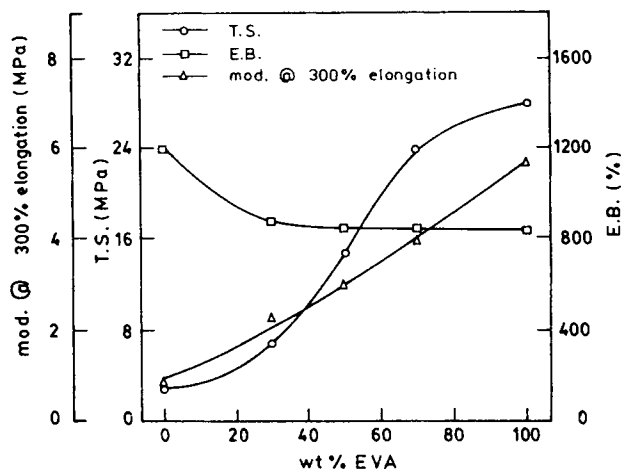


Figure 4 (○) Tensile strength, (□) elongation at break, and (Δ) modulus at 300% elongation values of different EVA-EPDM blends.

The variation of strength properties like tensile strength and elongation at break against composition for original and aged samples are given in Figures 5 and 6. Little reduction in the properties is observed for samples subjected to air aging and air-bomb aging compared to the original ones. It is interesting to note that all EVA-containing compositions retain more than 80% of their original tensile strength. For pure EPDM, it is between 60-70% of the original strength. A very similar observation is made for the elongation-at-break values. However, the trend in the composition-dependent variation of these two properties is similar for both aged and unaged samples.

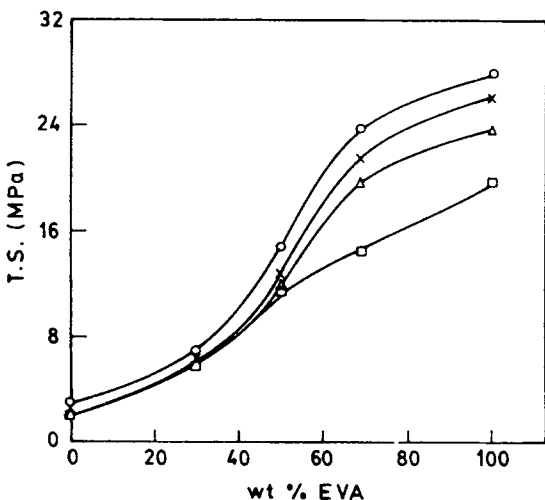


Figure 5 Effect of aging on tensile strength of different EVA-EPDM blends: (○) unaged; (Δ) air-bomb-aged; (×) air-oven-aged; (□) ozone-aged.

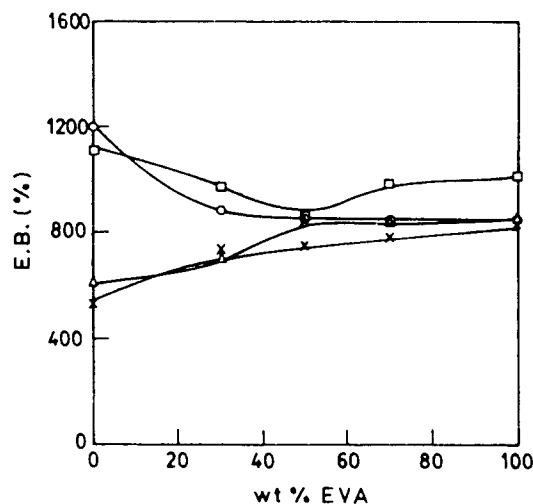


Figure 6 Effect of aging on elongation at break of different EVA-EPDM blends: (○) unaged; (Δ) air-bomb-aged; (×) air-oven-aged; (□) ozone-aged.

Electrical Properties

The selection of material for cable insulant primarily depends on the following electrical properties:

- (i) Dielectric constant (permittivity);
- (ii) Loss factor (loss tangent);
- (iii) ac conductivity;
- (iv) dc conductivity;
- (v) Dielectric strength (breakdown voltage).

Permittivity (ϵ') and loss factor (ϵ'') of different EVA-EPDM blends at ambient temperature (30°C)

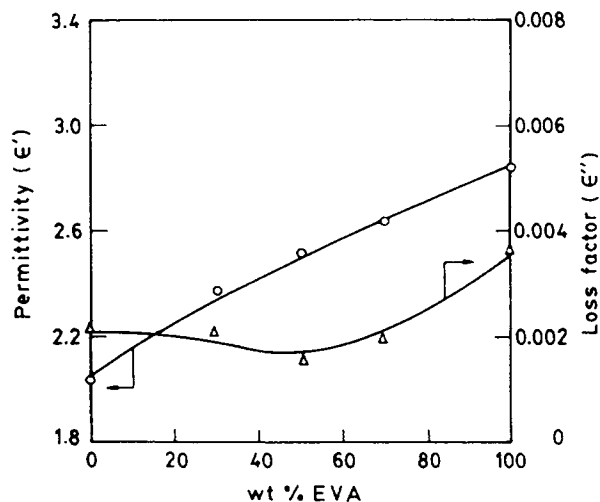


Figure 7 Permittivity and dielectric loss factor of different EVA-EPDM blend compositions at ambient temperature.

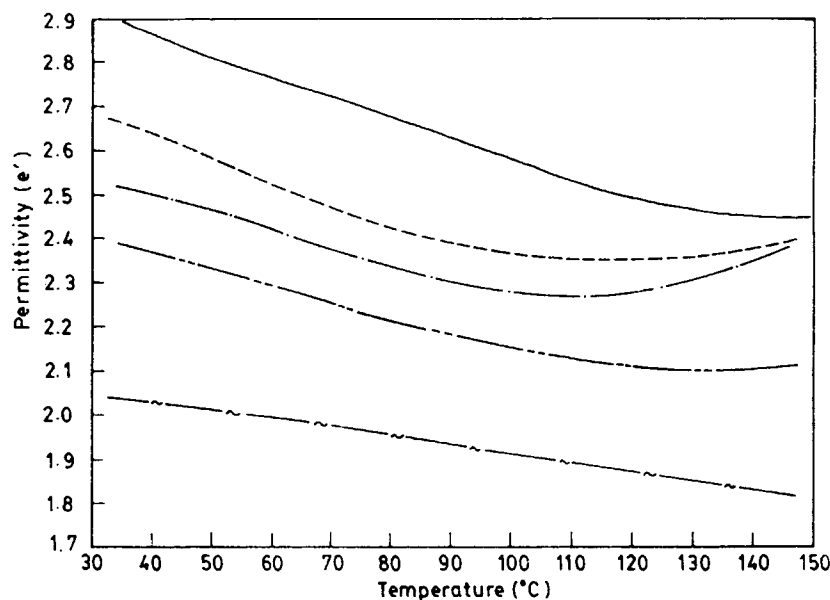


Figure 8 Permittivity of different EVA-EPDM blends vs. temperature: (—) EP₀; (---) EP₃₀; (-·-) EP₅₀; (----) EP₇₀; (-~-) EP₁₀₀.

are presented in Figure 7. The dielectric constant increases with increase in EVA concentration in the blend. This is mainly because EVA is polar, whereas EPDM is nonpolar in nature. However, the variation of the dielectric loss factor against composition does not follow exactly the same trend as that of permittivity. The loss factor remains almost constant for all compositions except in pure EVA; a somewhat higher loss value is observed for pure EVA compared to other compositions. The variations of dielectric

constant of different compositions against temperature are presented in Figure 8. The dielectric constant (ϵ') decreases gradually with increasing temperature for pure EPDM. For EVA-containing compositions, ϵ' decreases with temperature, but after a certain point, the change is marginal. In fact, for EVA-rich compositions, a tendency of reversion is observed beyond $\sim 105^\circ\text{C}$.

Dielectric losses against temperature for different blends are presented in Figure 9. For all composi-

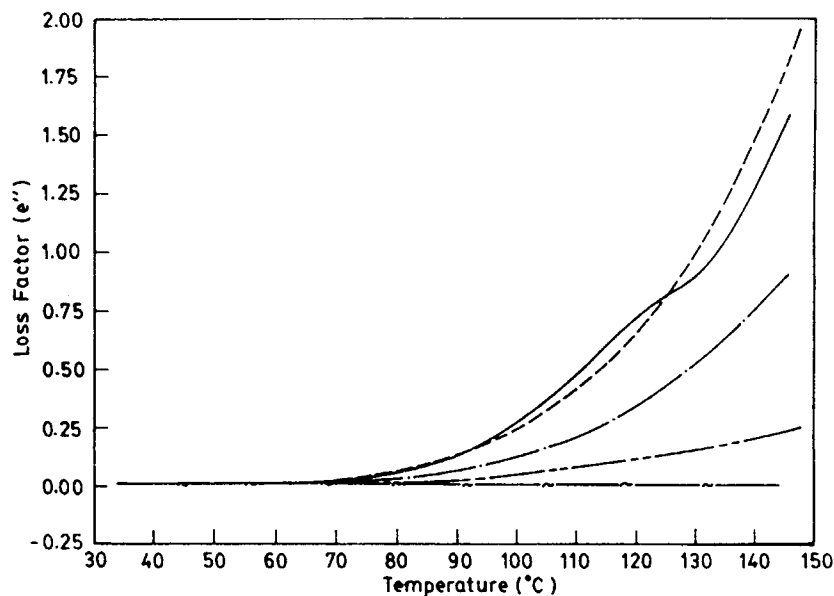


Figure 9 Loss factor of different EVA-EPDM blends vs. temperature: (—) EP₀; (---) EP₃₀; (-·-) EP₅₀; (----) EP₇₀; (-~-) EP₁₀₀.

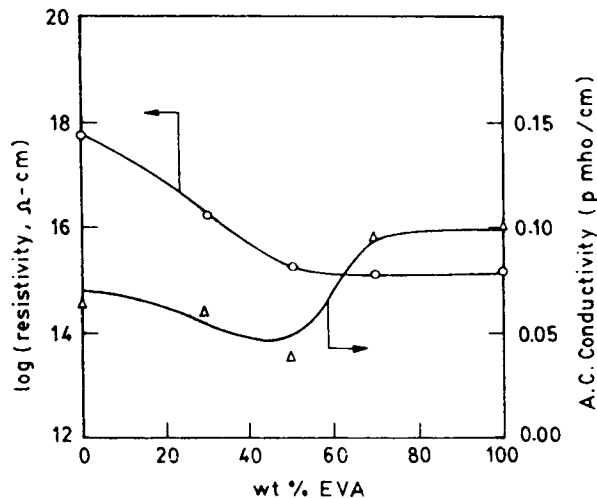


Figure 10 dc volume resistivity and ac conductivity plots of different EVA-EPDM blends at ambient temperature.

tions, there is hardly any change in loss factor up to around 60°C; beyond that, the loss factor increases sharply with temperature except for pure EPDM. The changes become more pronounced as the EVA concentration increases in the blend. This reflects that the compositions containing polar EVA become more and more lossy as the temperature increases.

The variation of dc resistivity and ac conductivity (ionic conductivity) at ambient temperature and 50 Hz against composition is presented in Figure 10.

dc resistivity decreases with increase in EVA concentration in the blend up to 50 wt %; beyond that, the change in dc resistivity is marginal. The ac conductivity value shows a slight decrease against EVA concentration up to 50 wt %; beyond that, some increase in conductivity is observed.

The variation of ac conductivity against temperature for pure components and blends is presented in Figure 11. The trend in the variation of conductivity against temperature has some similarity to that of the loss factor vs. temperature. The change in ac conductivity with temperature is marginal up to ~ 60°C; thereafter, a sharp rise in conductivity against temperature is observed for all systems. The rate of change of conductivity with temperature is higher for higher EVA-containing compositions. The dielectric strength of blends is presented in Figure 12. The dielectric strength decreases marginally with increase in EVA concentration in the blend, and the dielectric strength of samples subjected to immersion in water for a specified period (14 days) is found to decrease slightly compared to original strength for all compositions. The lower the dielectric constant and loss factor, the better is the dielectric for cable insulant. Lower values of these two properties reveal lower transmission loss due to the insulant and a lesser tendency to heat up the insulant under a high-voltage gradient, whereas higher dc resistivity and dielectric strength of the insulant are desirable for safe operation of the cable. Moreover, these properties should not vary much with experimental conditions.

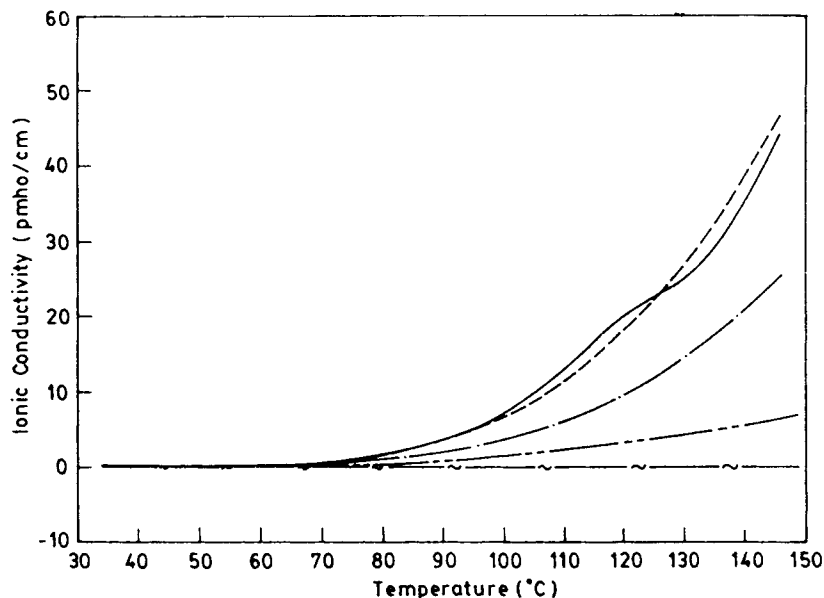


Figure 11 ac conductivity of different EVA-EPDM blends vs. temperature: (—) EP₀; (---) EP₃₀; (- · -) EP₅₀; (- - -) EP₇₀; (- ~ -) EP₁₀₀.

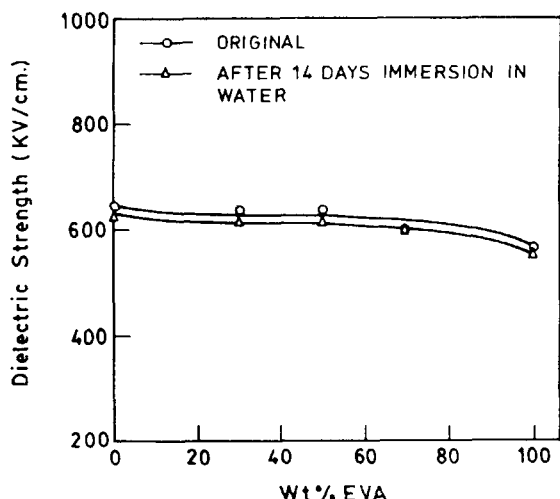


Figure 12 Dielectric strength of different EVA-EPDM blend compositions.

Thermal Endurance Properties

Thermal endurance properties such as the (a) thermal decomposition behavior of the insulant and (b) chemical and mechanical stability at high temperature are very important considerations for a cable

insulant, especially for high-temperature and high-voltage application.

Thermal Stability

With polymers being organic bodies, they have limited thermal stability. In the event of fire, due to a short circuit or other faults, the temperature of the cable system may go very high. So, the thermal stability of the polymeric material is an important consideration for its selection as a cable insulant. TGA analysis gives an idea of the thermal decomposition characteristics of different blends at elevated temperature. TGA plots for different blends are shown in Figure 13. Two-stage decomposition is the characteristic of EVA and its blends, whereas pure EPDM undergoes single-stage decomposition. The first-stage decomposition of EVA starts at around 340°C. The initiation of second-stage decomposition of EVA-containing blends ranges from 440 to 460°C.

Characteristic Temperatures of Cable

A cable insulant is designated by two important temperatures: (1) allowable maximum conductor temperature for continuous use (temperature rat-

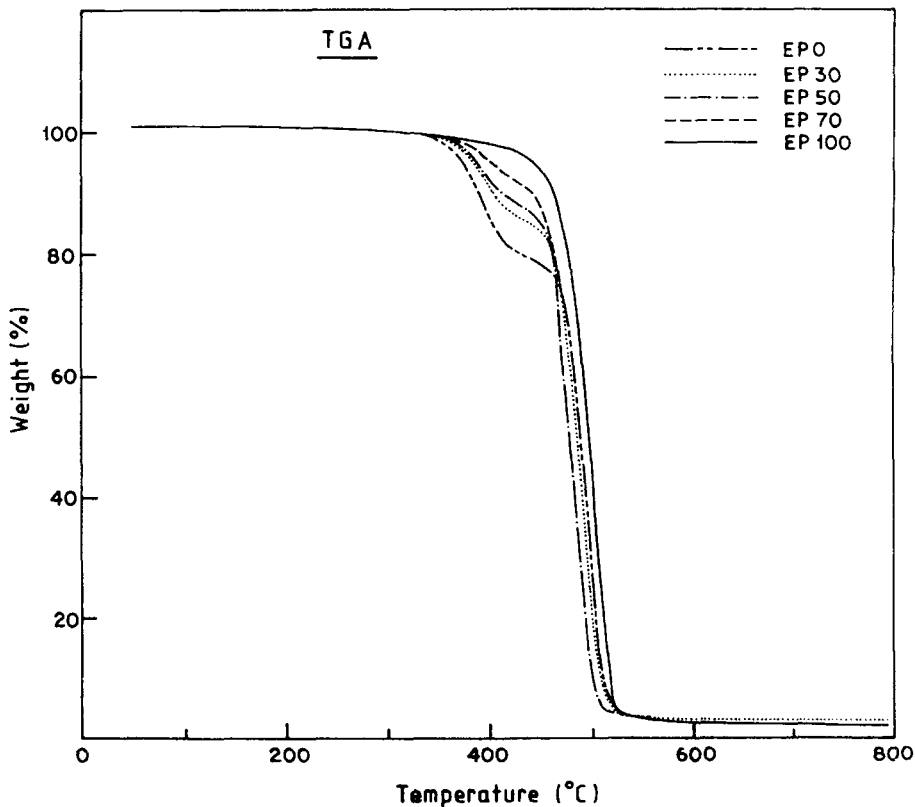


Figure 13 TGA plot of different EVA-EPDM blends.

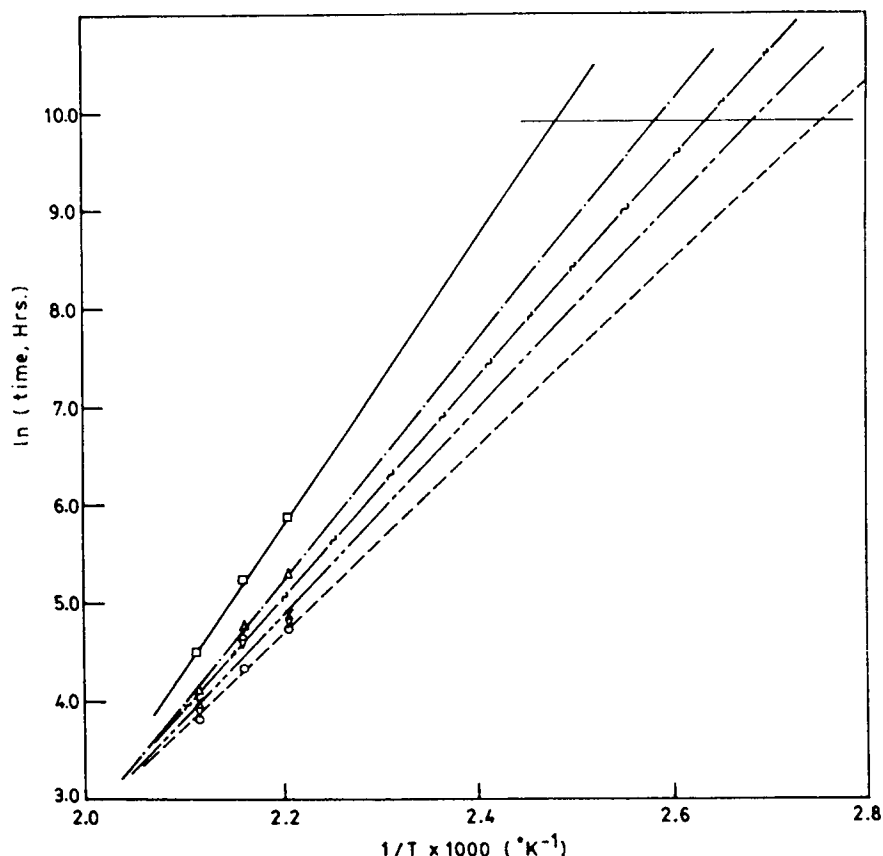


Figure 14 Time required to attain 50% residual elongation at different temperatures vs. inverse of temperature plot of different EVA-EPDM blends: (—) EP₀; (- - -) EP₃₀; (- · -) EP₅₀; (- - - -) EP₇₀; (- - -) EP₁₀₀.

ing/temperature index) and (2) allowable maximum conductor temperature during a short circuit.¹⁴⁻¹⁶

Maximum Conductor Temperature for Continuous Operation

Due to passage of current through the conductor, conductor temperature is high. The actual conductor temperature depends on the current rating (amount of amperage), operating voltage, conductor size, and specific resistance of the material used as the conductor and also the ambient temperature. In fact, final temperature (T_f) of the conductor is equal to $\Delta T + T_a$, where ΔT is the increase of temperature due to passage of current and T_a is the ambient temperature. Estimation of service life and the study of electrotechnical aging are subjects of interest for cable insulant and sheathing materials.¹⁷⁻²⁰

According to DIN VDE 0304, under the designation of the temperature index, TI indicates that it is the temperature for continuous use of the cable insulant for a service life of 20,000 h, with the criteria of attainment of 50% residual elongation; e.g., TI 150 signifies that the material for which it is quoted

remains serviceable for 20,000 h under thermal stress of 150°C with a residual elongation of 50%.

TI of different blends are calculated based on the plots of t_{50} (time required for 50% residual elongation) vs. the reciprocal of temperature in the absolute scale ($1/T$) (Fig. 14). The TI of the different blends thus calculated are given in Table II.

Maximum Conductor Temperature During Short Circuit

It is possible to heat the cable above the permissible limit by an operational overcurrent as well as by

Table II TI of the Different Blends

Blend Compositions	Temperature Index (TI) (°C)
EP ₀	129
EP ₃₀	114
EP ₅₀	107
EP ₇₀	100
EP ₁₀₀	90

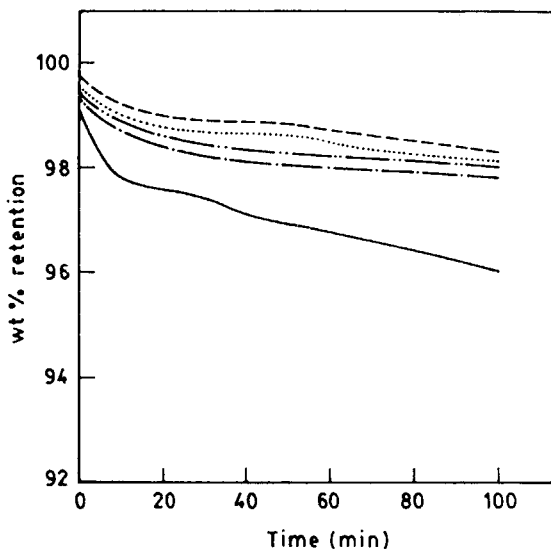


Figure 15 Retention of weight of different EVA-EPDM blends on isothermal heating at 250°C for 100 min in nitrogen atmosphere: (—) EP₀; (---) EP₃₀; (-·-·-) EP₅₀; (·····) EP₇₀; (- - -) EP₁₀₀.

short-circuit current. During the short circuit, a heavy rush of current flows through the conductor. Consequently, there is an appreciable increase of

temperature in the conductor. Although the short circuit duration is very short, only a few seconds, the insulation in contact with the conductor must withstand that temperature and should not undergo appreciable chemical decomposition with a loss of mechanical properties. So, it is necessary to test the mechanical and chemical stability of the insulant at elevated temperature.

In fact, there is no well-defined procedure for determining the short-circuit temperatures for polymeric insulants. Different cable manufacturers set their own methods to specify the short-circuit temperature of cable insulant. The short-circuit temperature assigned to XLPE-based insulant is 250°C. So, it is necessary to check both the mechanical and chemical stability of these insulants at this temperature.

To understand the chemical stability of blends at the short-circuit temperature, the materials are subjected to isothermal heating at 250°C for 100 min. It is found that all the blends show very good chemical stability with a maximum loss in weight less than 5% (Fig. 15). However, EPDM-rich blends exhibit somewhat better resistance to thermal degradation. The materials are subjected to this high temperature for a prolonged period (100 min),

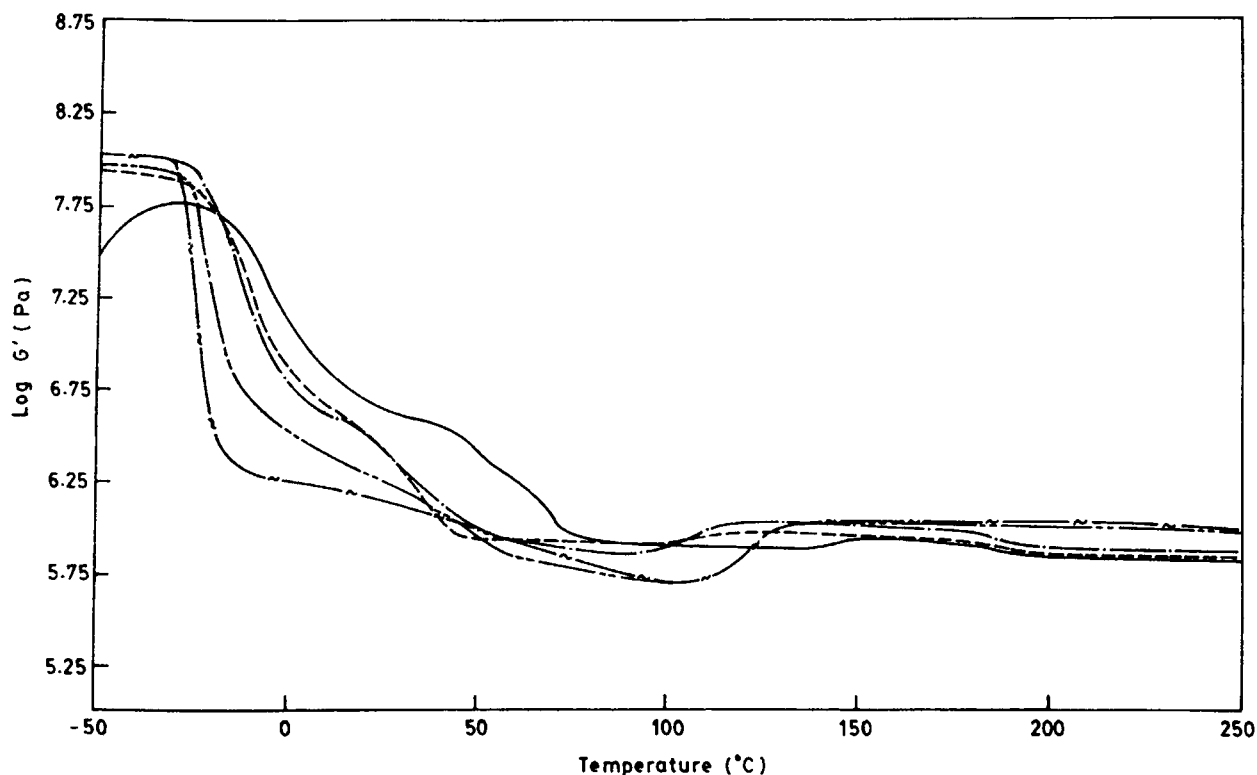


Figure 16 DMA plot of shear modulus (G') vs. temperature of different EVA/EPDM blends at 30 Hz: (—) EP₀; (---) EP₃₀; (-·-·-) EP₅₀; (- - -) EP₇₀; (- · - ·) EP₁₀₀.

whereas the maximum specified duration for the short circuit is only 5 s.^{15,16} So, it can be concluded that the materials will show enough chemical stability at this temperature. The mechanical stability of the systems was assessed through the determination of the low strain shear storage modulus at elevated temperatures. All the compositions show a stable value of shear modulus at 250°C (Fig. 16). The temperature is kept constant at 250°C for 15 min and no fall in modulus is observed. This shows that all the blends have adequate mechanical and chemical stability at 250°C, which is generally considered as the short-circuit temperature for polyethylene-based thermosetting cable insulant.^{15,16}

CONCLUSION

The tensile strength of different EVA/EPDM blends increases with increase in EVA concentration. The retention of strength properties of EVA-containing blends after aging are excellent. Dielectric properties, e.g., dielectric constant, loss factor, and resistivity, deteriorate with increase in the EVA concentration of the composition. The highest operating temperature is achieved for pure EVA and this temperature decreases with increasing EPDM content of the blend.

This blend system is expected to exhibit better processability when compared with XLPE and clay-filled EPDM insulants. This is mainly because of the thermoplastic nature of EVA, which melts around 70°C. When extruded above 70°C, EVA acts as a processing aid for the blend and also controls the die swell. It shows better flexibility compared to XLPE and much better mechanical properties than those of clay-filled EPDM. Better retention of properties on aging of these blends over XLPE is also noteworthy.

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