

The Chemistry of Ethylene Propylene Insulation - Part II

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Introduction

Ethylene propylene rubber (EPR) is one of the primary extruded dielectrics used today in medium and high-voltage power cables. This second part of a two-part article on EPR discusses manufacturing and processing and performance characteristics. (*Part one appeared in the September/October issue.*)

Manufacture

EPM and EPDM are made in continuous flow-stirred tank reactors. Most manufacturers use a solution process in hexane. At least one uses a propylene slurry or bulk polymerization.

Hexane, ethylene, propylene, diene, and catalyst solution must all be pure and dry because of the sensitivity of the Ziegler-Natta catalyst system to water. These materials are fed continuously to the reactor in the correct proportion based on reactivity ratios. Unpolymerized monomers are recovered under reduced pressure and reused. Hexane solvent is flashed off with steam, recovered by decantation, dried, and reused. The polymer, now free of solvent, precipitates in the water as a crumb. Catalyst residues are removed as soluble salts by water-washing. The polymer in crumb form is dried with de-watering screens, mechanical presses, and drying ovens. Dried polymer is compressed into a large bale and wrapped in plastic for sale. If sufficiently crystalline, the polymer may be pelletized. There are about ten global suppliers of EPM and EPDM.

Applications

EPR has found use in the following diverse markets:

- Single ply roofing
- Automotive weatherstrip and coolant hose
- Steam hose
- Motor oil viscosity index improver
- Plastic impact modifier
- Electrical insulation

How EPR is compounded has a substantial effect on insulation performance. Among the various compound ingredients, the filler choice and amount are keys.

Excellent weathering and water resistance are key characteristics to the success of EPR in several of these applications. Although it has not been successful in replacing SBR in automotive tire tread or the basic tire carcass, EPR has found use in sidewalls because of its excellent ozone resistance.

Extensive use of EPR in wire and cable insulation is based on its superior electrical properties and water resistance. Key insulation uses are the following:

- Medium voltage power cable
- Low voltage power cable
- Flexible cords
- Control and instrument wire
- Automotive ignition wire
- Appliance wire
- Motor lead wire
- Mining cable
- Electrical connectors

Compounding

Extrusion of EPR polymer alone typically results in a rough extrudate surface because of melt fracture. Mechanical strength is low, particularly for amorphous EPR. Filler addition provides the smooth surface and mechanical strength desired for electrical applications [8]. Compounding involves the selection of the filler type and amount to be used with EPR. Mineral or non-black fillers, such as clay, talc, whiting, silica, and alumina, are used in electrical insulation. Carbon black typically is not used because it compromises electrical properties.

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The marked effect of the filler level on the mechanical and electrical properties of a medium voltage insulation compound based on a semicrystalline EPDM is shown in Table I. A minimum filler level optimizes electrical properties, but at the expense of mechanical strength. Compound A is impractical from an extrusion standpoint. The challenge in compounding is to achieve the proper balance among several requirements. The compound defines the electrical properties of the EPR, provides useful mechanical properties, and characterizes processing, both mixing and extrusion.

Other ingredients typically compounded with EPR are metal oxide, plasticizer, process aid, antioxidant, and curative. Silane coupling agents may be used to promote polymer/filler interaction to enhance mechanical properties. Some of the characteristics directly affected by compounding are processing, specific gravity (cost), tensile strength, elongation, low temperature flexibility, heat and abrasion resistance, moisture absorption, dielectric strength, insulation resistance, and power factor. Thus, the EPR along with the compound ingredients and amounts defines the performance that can be achieved. EPR is the key ingredient because it controls how the various ingredients can be compounded.

Curing

Curing, crosslinking, and vulcanization are synonymous terms that refer to the formation of chemical bonds between polymeric chains. Polymers such as EPR that can be crosslinked are called thermosets. On initial heating, EPR can be shaped as during extrusion, but once crosslinking occurs, the shape of the polymer is fixed and it cannot be reshaped. Formation of chemical crosslinks ties the polymer chains together and en-

hances mechanical properties such as tensile strength. Since crosslinking involves a chemical reaction, it is time/temperature dependent. The result is an elastic and resilient polymer that resists permanent deformation. Thermoplastic materials, on the other hand, do not crosslink and can be repeatedly shaped with heat. Physical properties are greatly reduced above a threshold temperature, generally the crystalline melting point of the polymer.

EPM copolymer is cured exclusively by a free radical mechanism with decomposition of peroxides. Electron beam radiation can be used to generate free radicals, also [9]. In either case, very stable carbon-carbon chemical bonds are formed between polymer chains. Free radical vulcanization is enhanced by polyfunctional coagents such as triallyl cyanurate and trimethylolpropane trimethacrylate. Coagents increase the crosslinking efficiency of the peroxide. The decomposition rate of the peroxide is a function of temperature and is not affected by the coagent. Acidic compound ingredients promote ionic breakdown of peroxide rather than free radical initiation and should be avoided.

Peroxides can be used to cure EPDM terpolymers. Since peroxide curing is more efficient with EPDM than EPM, coagents are normally not used with EPDM.

Sulfur can be used to cure EPDM but not EPM because an unsaturated site is required for this crosslinking chemistry. Peroxide-cured EPR has superior heat resistance, compression set resistance, and lower tension set than sulfur cures. Although the electrical properties of sulfur and peroxide-cured EPDM are comparable in dry service and initially in water, immersion longer-term in hot water shows the peroxide cure to be decidedly superior. Primarily for this reason, EPR used in electrical insulation is peroxide cured. On the negative side, peroxide cures are inhibited in air, require higher cure temperatures, have a higher material cost, and poorer tear strength than sulfur cures.

EPR is cured in steam, dry nitrogen, and pressurized salt. Radiation can be used also, as mentioned earlier. Most EPR-insulated wire is cured in continuous vulcanization (CV) catenary tubes with either steam or dry nitrogen. Steam provides a very efficient heat transfer media, but temperature is directly tied to steam pressure. With dry nitrogen greater latitude is possible in the choice of temperature, but heat transfer is not as efficient. A debate continues in the industry as to whether microvoids formed during steam cure result in a more rapid degradation of the insulation. Pressurized salt is a little-used cure method that has value in improved concentricity of large diameter cables.

EPR can be cured through grafted silane. These cures involve a reaction of vinyl silane-grafted EPR with water to form crosslinks through silane sites on two-

Table I
Effect of Increasing
Clay Filler Level in Semicrystalline EPDM

Compound	A	B	C	D
Parts Filler / 100 Parts EPDM	0	30	60	90
Density, g/cc	0.90	1.04	1.20	1.31
Tensile Strength, psi	750	1200	1500	1700
Elongation, %	450	400	320	260
Dielectric Constant	2.4	2.4	2.5	3.0
Power Factor, %	0.06	0.20	0.25	0.60
AC Breakdown, Volts/mil	850-1000	750-850	700-800	550-650
After 26 Weeks in 90 C° Water				
Dielectric Constant	2.4	2.5	2.75	3.1
Power Factor, %	0.40	0.65	0.80	1.5

polymer chains. The cable reel is typically submerged in warm water or placed in a steam autoclave for a few hours to complete the cure. This method eliminates capital investment in CV equipment but has suffered from cure variability in EPR systems.

Processing

EPR compounds are mixed on two-roll mills, in internal Banbury mixers, and in continuous screw mixers. Amorphous low viscosity polymers with broad MWD are best for mill mixing. Compounds based on semicrystalline EPR are very difficult to mix on two-roll mills, especially if also high viscosity. Most EPR compounds are mixed in a Banbury because internal mixers are fast and efficient with short cycle times. Semicrystalline types can present dispersion problems when used in a compact bale form. Use of either a pellet or friable bale form solves this problem. Friable bales are loosely compacted and break apart easily in the Banbury under the shearing action. Continuous screw mixers offer potential control advantages in dispersion and heat history. Compound ingredients must be in the form of pellets or powder for feeding purposes. Thus, compounds based on amorphous EPR are precluded.

Extrusion of the mixed compounds through fine mesh screens (0.1 mm opening) removes undispersed compound ingredients and hard contaminants and results in increased ac breakdown strength of the insulation. Preliminary evidence indicates that even finer mesh screening will further increase breakdown strengths, but pressure and through-put rate become limiting factors.

EPR compounds extrude rapidly and smoothly onto conductors with conventional extrusion equipment and crosshead pressure dies. Crosshead temperatures of 90 to 120°C soften the polymer to allow good flow and are below the peroxide decomposition temperature so that pressure or scorch is not a problem. Compounds based on amorphous EPR are best extruded with a rubber-type screw, while semicrystalline EPR runs best with a polyethylene-type screw. Amorphous EPR compounds are normally strip fed while semicrystalline types are fed as pellets or in diced form. Insulation compounds based on EPR with broader MWD appear to give better surface appearance with a wider process window available than do polymers with narrower distribution [5]. Most EPR-insulated wire is then cured in a CV. The reeled wire is either sold or used in later cabling operations.

Performance

How EPR is compounded has a substantial effect on insulation performance. Among the various compound

ingredients, the filler choice and amount are keys. A minimum level of filler is required by the cable manufacturer for acceptable processing during extrusion of the insulation on the conductor and by the end-user for acceptable mechanical properties. Compounds with low filler levels and no process oil provide optimum electrical properties, such as low dielectric constant and power factor and high breakdown strength (see Table I). The most important compound ingredient is the EPR because it defines the minimum level of filler for acceptable extrusion and mechanical properties. The challenge for the compounder is to achieve the best compromise among the various requirements.

EPR has been used for insulation since its commercial introduction 30 years ago. EPR insulation has several attractive features:

- Corona resistance
- Wet electrical stability
- Water tree resistance
- High temperature performance
- Flexibility

EPR shows superior resistance to the degradation caused by partial discharge from electrical stress across voids within insulation or at the interface with semiconductive shields in medium voltage cable. Stability in water is excellent, as shown by the long-term ageing in 90°C water in Table II. EPR insulation in service and in accelerated tests has shown excellent resistance to degradation by water treeing. EPR retains its integrity as an insulation at the emergency overload temperature of 130°C by maintaining acceptable physical strength [10]. Thermal expansion increase at overload temperature is gradual and modest, so that any tendency for the insulation and insulation shield to separate is minimized. Attractive flexibility features of EPR insulation help to achieve reliable splices and terminations, especially in cold weather.

Table II
Low Filler Semicrystalline EPDM Insulation
Water Immersion Testing

Wire— 45 mil (1.1 mm) Coating on 12 AWG Solid Al
Conditions— Immersion 90°C. Water, 600V/60 Hz
Continuously Applied, Testing at 80 V/mil
(3200 V/mm)

Aged	Dielectric Constant	Power Factor, %
1 Day	2.60	0.76
1 Week	2.60	.70
1 Month	2.63	.62
1 Year	2.84	.50
3 Years	3.16	.46
7 Years	3.87	.68
10 Years	4.17	.99

Short-term laboratory tests that predict in-service cable performance is very desirable. The accelerated cable life test (ACLT) introduced in 1981 compares insulation materials in commercial cable systems under accelerated but simulated service conditions. M. Brown compared the performance of low filler semicrystalline EPDM insulation to XLPE and tree-retardant XLPE in the ACLT [11]. Recently, this same EPDM insulation was reported to last more than three years in the ACLT without any cable failures [12a,b]. Another commercial EPR insulation has been reported to last in excess of three years in the ACLT without cable failure [13]. EPRI has commissioned a program to determine ACLT conditions that correlate with in-service cable performance. A recent preliminary report has brought into question the appropriate ACLT conditions for EPR insulation [14]. Further test results no doubt will be forthcoming from EPRI and other concerned parties.

Summary

This paper reviews the basic chemistry of EPR insulation. EPR polymer structure, diene cure site, crystallinity, molecular weight and distribution, branching, and polymer properties are discussed. In addition, manufacture, applications, compounding, curing, processing, and performance are treated. The important effect that compounding has on EPR insulation properties and performance is emphasized.

Richard J. Arhart received the B.S. degree in chemistry from the University of North Carolina at Chapel Hill in 1966, the Ph.D degree in organic chemistry from

the University of Illinois at Urbana-Champaign in 1971 and did postdoctoral work at the University of Alberta in Edmonton, Alberta, Canada. In 1972, he joined DuPont in Wilmington, Delaware, where he currently is a technical consultant in polymers, responsible for polymeric materials development for solid dielectric, semi-conductive, and jacket materials for cable.

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