A Review of Raychem Polyolefin Co-Polymer Outdoor Insulating Polymer Material
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Summary and overview
This paper describes the history of Raychem's polyolefin co-polymer outdoor insulating materials, which have been in use at medium and high voltages for 40 years. The performance criteria by which the materials have been qualified along with a review of the applications and benefits of these materials are discussed, as well as relevant data concerning the materials.

Why polyolefin co-polymer? Field experience has proven that it works well.

Raychem initially developed polymer outdoor insulating materials for field delivery of the insulation of cable accessories. Heat-shrink was used as the delivery system because it has numerous technical advantages over alternate application systems.

To have heat-shrink capability, a material must be semi-crystalline like polyethylene, whereas rubbers like silicone rubber and EPDM are elastomers. Pure elastomers cannot be applied in a heat-shrink form. Thus, EPDM and silicone rubber are not suitable material candidates where heat-shrink delivery is desired. Polyethylene and some of the related co-polymers are, however, suitable material candidates for heat-shrink delivery.

Polyolefin co-polymers with a proper additive package have been well proven in service. Raychem's material performance is well known in applications on a diverse range of products over a broad range of voltages throughout the world in the form of heat-shrink tubing, as individual weathersheds, or as molded housings with weathersheds. This same material is also utilised in direct mold-in-place applications, such as insulators, where proven product performance is required or as formed parts from sheet for insulating covers.

Raychem has also developed silicone elastomer based materials for use in non heat-shrink applications. They are tested using the same methods and criteria. Each material has relative advantages, and the choice of material for a particular application depends on these.

Polyolefin co-polymer history
1960's First Generation Material. Raychem started work on electrically insulating materials with optimised surface properties for outdoor use in the 1960's. The objective was to develop a material which could be used for outdoor heat-shrink cable terminations throughout the world on all types of cables. This target was achieved and cable termination products were first commercially introduced in the UK in 1969 and then rapidly throughout the world. The total R&D investment at the time was approximately 50 man years. This gives some idea of the level of human capital investment needed to initially develop a material and then do sufficient accelerated and long term tests to verify that the material will have a minimum 25 year service life. The modes of deterioration in the field and the criteria by which materials were assessed and the reasons why they are appropriate are described in early Raychem papers. [1,2,3]

The first generation material introduced to the market can be described as a polyolefin/silicone blend with additional fillers, screens and stabilisers. The polyolefin component of the blend provided: a) the crystallinity needed for heat shrinkability, b) good electrical and mechanical properties, and c) low moisture vapor permeability. The silicone elastomer provided: a) filler acceptance, and b) improved flexibility without compromising the tracking and weather resistance. The filler and stabiliser package provided the vital performance enhancements of weathering resistance while maintaining a non-tracking surface. Characteristics that none of the other materials on the market could offer at the time.

1970's Second generation. Work on understanding the improvements on the original materials and endeavoring to make materials continued throughout the 1970's. [3] Several alternative formulations were evaluated, one of which had EPDM substituted for the silicone elastomer used in the original formulation together with some other detail changes. It had improved physical properties and moisture vapor permeability, but the weathering resistance was clearly worse. One of the other development formulations on which data was tabulated (formulation 5 of Ref. 3) was not based on an alloy of different polymers and elastomers, but on a co-polymer of ethylene and ethylene vinyl acetate commonly abbreviated as EVA. When this was combined with the filler and stabiliser package developed for the EPDM based formulation, it was found to give outstanding properties, with far superior weathering and erosion resistance compared to the EPDM formulations.
EVA is a polymer commonly used in a wide range of demanding applications. For example:

- a) greenhouse coverings where UV/sunlight stability and resistance to mechanical damage are important,
- b) footwear applications where impact resistance, wear resistance and resistance to fungal/bacterial attack are essential, and
- c) packaging films where toughness and low moisture vapor transmission are required.

In the electrical industry, this polymer is widely used for both cable jacket and cable insulation applications. Its excellent electrical properties combine with good mechanical properties to make it a cost effective, reliable product. Because of its attractive properties, it is an excellent candidate for inclusion into an outdoor insulating material. However, the wide variety of grades available and the importance of matching all the different components of the stabiliser/filler package to both the base polymer and each other makes a difficult formulation problem to realise all desired properties. The expertise to achieve this is a core competence of Raychem, which may not be the case with other suppliers.

This formulation candidate became the subject of a long-term comprehensive test program in order to verify performance. Commercial sales started in the mid-1980’s after many years of field data had been accumulated as well as real-time and accelerated test data. The advantages of the second generation formulation are:

1) increased expansion ratio for greater range taking for heat-shrink applications,
2) improved mechanical properties
3) a lower moisture vapor transmission rate.

**Material advantages**

Raychem’s polyolefin co-polymer materials are best known in their heat-shrinkable cable accessory form, a requirement established in the 1960’s for initial use. Heat-shrink material offers numerous advantages for field application of insulating material. These include:

1) simple installation of pre-engineered components eliminates user measurements of applied material,
2) no shelf life, unlike tapes and resins,
3) conformity to irregular shapes such as bus bar connections or sectored shaped cables, or dimensional transitions such as the diameter over the cable core to that of the lug,
4) wide dimensional range taking for installation versatility,
5) when combined with appropriate sealants, the material can be used to enhance other technologies such as porcelain.

From a performance point of view, the advantages include:

1) establishment and maintenance of strong electrical and environmentally sealed interfaces which retain integrity with aging even with significant temperature gradients (changes in temperature in bus bar or cable conductor from load changes, temperature rise in surge arresters from energy absorption produce axial interfacial shear forces),
2) proven performance over a diverse range of voltage classes, product functions, applications and service environments in both Raychem products and as components in products manufactured by others,
3) availability of this proven material in tubing, tape, sheet, individual weathershed and multi-sheded housing form which may be utilised with sealants for use in almost any application.

In addition to heat-shrink delivery, this material may also be applied by the mold-in-place technique. Common uses for mold-in-place in the industry are insulators and surge arresters where the material can be factory applied to the core materials. With direct conversion of the raw material into finished product, the proven Raychem polyolefin co-polymer material can be utilised in a cost effective manner for applications where heat-shrink delivery of the material is not required. In such cases, the interfacial strength will likely need reinforcement by the use of coupling agents to insure bonding of the polymer material to the internal components. Sheet material may be formed into insulating covers to improve system security while guarding against wildlife induced flashover. This permits the user to install numerous products on their networks with consistent and proven capabilities.

**Test criteria**

Performance evaluation and product qualification usually involve a 2-step process of materials development and product qualification testing.
Early polymer insulating materials had poor UV performance, and it is of user concern to demonstrate adequate capability. Typical industry tests require only 1,000 hours UV exposure in synthetic test cells. UV damage will cause surface cracking or crazing, which has a negative effect on physical properties, especially tensile strength (Fig.4) and elongation to break (Fig.3). Raychem exposes test samples to UV aging well in excess of the 1,000 hours required by the industry to insure good long-term performance as well as verify that the physical properties do not change significantly for exposure times shortly after 1,000 hours. Property changes occur when additives are consumed and can no longer enhance performance. Despite industry norms for 1,000 hour exposure, Raychem believes 5,000 hour exposure is a more realistic requirement, but has also conducted 20,000 hour testing as reported in Fig.1-4 as proof of long term performance capability. Refer to the section on accelerated aging.

**Tracking and Erosion Resistance**

The most important test method and Raychem requirement set out in Ref. 1 is the resistance of a wet polluted surface to dry band electrical arcing, evaluated using the inclined plane test method, ASTM D2303 [4] (commonly called the TERT test) under the step increasing voltage mode. This checks whether the surface will track under a carefully graduated set of stress conditions likely to occur in different service environments. Note that many materials only track in a very narrow window of conditions. Testing only one condition is likely to provide misleading results, and a range of conditions must be utilised. The TERT step test is the only test in common use that tries to cover a large range of conditions.

The surface electrical property required is that the material be non-tracking with eventual failure to be by erosion only. Flame failure is not allowed. This surface property has to be present on new material and retained by material aged by any likely degradation mode. Note that this test procedure does not define a pass or fail criteria. It only specifies how to run the test. 200 minutes is generally considered as a very reasonable duration to demonstrate performance.
Physical Properties
Properties such as tensile strength, elongation, etc. are determined by standardized techniques and used to determine initial properties for benchmark performance data. Figs. 1-5 provide detailed data on various physical properties as a function of test time, indicating the long-term retention necessary for long-term service reliability. These properties give a measure of how tough the material is. This is important during installation and also during service where bird damage by pecking is a likelihood. Ref.5 lists silicones and EPDMs as susceptible to bird damage but materials similar to EVA like crosslinked polyethylene are not.

Heat aging studies are used to predict life time for a specific product in its expected service conditions. Fig. 5 shows the results of a high temperature thermal endurance test. This data together with longer time tests at lower temperatures establish an IEC 216 thermal rating for the material. This is important for cable terminations which are heated by conductor loss or surge arresters which experience temperature rise from energy absorption. Insulators should not experience temperature rises over ambient conditions.

Accelerated Aging
Ref. 1 discusses, in length, concerns over the long term weathering properties of a polymer material, the reasons for degradation, and the likely effects. Experience has shown how justified such concerns are. When material is analyzed after many years service, it is apparent that the long term weathering is the major cause of degradation. [6] The preferred way of accelerating weathering is to use a Weatherometer (accelerated laboratory sunlight exposure aging) with additional gaseous pollutants like ozone. Sunlight on its own is not as damaging as sunlight plus aggressive chemicals on the surface which combine to degrade the material. An alternative is to use pure UV light plus humidity as in the ASTM G 53 test. [7] a standardised test used by Raychem and others. The data shown in Figs. 1 through 4 were obtained from ASTM G53 testing, known as QUV, using conditions of UV A light 8 hours on 4 hours condensation, with 60°C black panel temperature.
Photos 2 and 3 depict Weatherometer equipment and the QUV tester for ASTM G53 testing. Note that the Raychem test data extends to 20,000 hours of UV exposure with clear evidence of specimen degradation. Some standards only require a minimum of 1,000 hours testing, which is what is commonly reported in the industry. In our opinion, this is quite inadequate and longer exposure times (5000 hours minimum) are necessary to assure users of adequate UV performance.

**Post-Aging Properties**

After aging, the materials are tested on the inclined plane testing (TERT) machine, illustrated in Photo 1. Photo 4 shows a tracking failure, an erosion failure and a flame failure. Tensile strength, elongation and electric strength measurements are also taken to verify that the material has not exceeded the design end of life criteria, as set by the material developer.

**Additional Testing of Long-Term Aging**

Other long-term materials testing done in our laboratories include rooftop real-time exposure of material samples. Photo 5 shows samples which have been exposed up to 20 years. Photos 6 and 8 indicate what happens to the material’s physical properties when inadequately formulated to withstand environmental conditions without voltage stress. Long-term real-time testing is necessary to validate accelerated testing to ensure user confidence in the supplier and their products.

Product Qualification Testing

After extensive materials development and qualification testing, product testing is still necessary in order to ensure product performance. Much of the material development work is done on plaques, which are laboratory moulded samples. While these generally utilize the same general process conditions, testing is not run on stock, standard production.

Therefore, product from standard production process conditions must also be tested as verification. This generally involves type testing in accordance with relevant industry standards. However, materials testing in product form is not well standardized. This creates problems for users trying to compare testing conducted by suppliers with different test methods or modified test methods.
Salt Fog Chamber
In this accelerated pollution test, samples are continuously energized and maintained in a salt fog environment with a controlled conductivity. This test is essentially an erosion resistance test since the contaminated conditions cause loss of hydrophobicity with the onset of electrical surface activity. Products whose material may not be properly formulated tend to exhibit excessive erosion with possible onset of tracking. Raychem conducts extensive testing of its own products in salt fog chambers to verify performance and to compare candidate materials against known references. Raychem polyolefin co-polymer material has been shown to perform extremely well in salt fog chamber testing, with performance superior to some silicone terminations. [8] One test protocol which is standardised is a 1,000 hour test designed for insulators. [9] Raychem has conducted this test on its material, along with independent testing on surge arresters. [10]

Tracking wheel testing
This test was devised by Ontario Hydro and is a salt water wetting test. The wetting occurs once per rotation of the continuously moving wheel and draining and associated dry band arcing occurring during the rest of the cycle. Instead of testing under steady state conditions like the salt fog test, the repetition of wetting/draining is more representative of service conditions. Variations on this test are used by different utilities. The results of one specific test program on a Raychem polymer surge arrester are shown in Fig. 6. This test was conducted for 1041 hours with a salt water conductivity of 350 Qs/cm. The current peak data shows the desirable characteristic of being stable with age as the test progresses and the surface of the molded part is progressively attacked by the arcing. No localised erosion took place during this test on Raychem products.

Multiple Stress Testing
In Ref. 9, there is a 5,000 hour multiple stress test which seeks to apply a variety of typical service stresses on a regularly scheduled basis. This test is the most credible long-term exposure test which is currently in the standards. While both long and expensive, it subjects samples to numerous stresses to determine if damage induced by one stress accelerates damage by other stresses. Raychem has the necessary test equipment to do this test. Various housing profiles and end fitting configurations have been successfully tested through this 5,000 hour test. Photos 9 and 10 show insulators after this long and difficult test. In addition, Raychem has also conducted independent testing to the ENEL (Italian) specification DY 1009, which differs from the IEC 1109 Annex C procedure. [11]

Field experience
Raychem polyolefin co-polymer outdoor insulating materials have been used in products which have been providing reliable service at voltages up to 72 kV in excess of 25 years. Material is supplied as heat-shrinkable tubing, tape and sheet, individual weathersheds and multiple shedded housings for installation on cable, bus bar, existing insulation system enhancement, surge arresters, insulators, bushings and for other applications where robust, high-performance insulating material is needed. Covers formed from sheet or direct mold in place of the compound onto appropriate substrates extend applications on a cost effective basis.

Raychem materials have shown their considerable breadth of properties by long-term performance in locations with high UV exposure, very hot or very cold ambient temperatures, severe industrial pollution and coastal contamination.
Conclusions

The question "Why polyolefin co-polymer material works" can be answered as follows: In the 1960’s, the pioneering development work for outdoor polymer cable terminations centered around providing improved performance with simplified installation compared to existing technologies. Heat-shrink was chosen as the field delivery mechanism which met these objectives. Pure elastomers such as silicone rubber and EPDM cannot be supplied or installed in heat-shrink form.

Polymer material performance requires a complex formulation optimization process which includes a great deal of materials science expertise. It is the additive package which dominates the product performance as no specific base polymer material alone has the necessary properties and characteristics for an outdoor weathering material. Considerable skill, expertise and long-term testing is necessary to verify the material properties which must be supported by product testing. One cannot simply rely on others for formulation or purchase commercially available polymer compound and expect the necessary level of performance without attention to the appropriate material science considerations. We invite users to poll other suppliers and request similar data and evidence of materials science expertise.

Raychem polyolefin co-polymer material has been proven over time to be a very reliable material able to be used in a variety of applications and service environments.

References


