OUTDOOR EXPOSURE OF EPDM ROOFING MEMBRANE

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The performance of membrane roofing systems is not dependent solely on climate and weathering. It is also influenced by stresses imposed by the building that it is protecting and by the roofing system of which it is a part. Rossiter and Mathey[1] have incorporated such stress features in a methodology on service factors, the comprehensiveness of which cannot be faulted. Their methodology also reveals a widespread lack of knowledge of the pertinent variables and their interactions.

The purpose of this paper is to review material and performance factors as they relate to one roofing membrane materiaz, EPDM, in light of information emerging from studies of longevity. The review does not, however, include factors directly relating to seam splicing. The industrial and roofing-site splicing techniques currently in use are numerous and various, and the suitability of each, for a given application, depends upon numerous variables. However, the RMA's Roofing Technical Committee and specific subcommittees of the ASTM and other testing and standards organizations are working on programs aimed at filling the need for universally acceptable splice test procedures and performance standards.

PHYSICAL DEMANDS ON MEMBRANES AND THE MARGIN OF SAFETY CONCEPT

The need for membranes to resist physical damage during installation and under all service temperature conditions, even when hardening or softening with age, is generally well appreciated. Less so is the need to accommodate factors relating to building movement, building design, and building components.

Consider, for example, how the way in which a membrane is attached to a roof can affect its performance. Commonly used attachments include strong or weak fully bonded systems; partially bonded systems; and ballast, which simply holds the membrane down. When adjoining members of a membrane-covered roof or building move, relative to each other, the weaker the bond between membrane and substrate, the smaller the stress imposed on the membrane at the substrate joint. When the bond is weak, the stress is not confined to the narrow strip of membrane spanning the joint. It is distributed across a much larger area. In the case of mechanical attachment, the stress on the membrane at the joint is negligible.

In fully bonded systems, localized stresses at a substrate joint which are not relieved by stretching or breaking of the adhesive, can cause the membrane to fail by splitting or tearing, or by accelerated oxidative degeneration of the membrane at this point. In the case of mechanical attachment, the stresses can be dissipated by the membrane stretching between fasteners. However, in the absence of an adhesive, lifting of the membrane by the wind can cause "flutter", which creates stress at the points of attachment.

The influence of other building components on membrane performance is illustrated by considering how differently an impact, such as caused by a dropped hammer, affects a membrane bonded to an expanded polystyrene insulation substrate and another bonded to concrete. At low temperatures, the impact would be more likely to damage the cold-stiffened membrane bonded to the deformable polystyrene. At higher temperatures it would be more likely to damage the heat-softened membrane bonded to the inflexible concrete.

Even without considering climatic factors, the physical demands on membranes are extremely varied. Durability in a membrane system relies on inherent property levels that provide a sufficient margin of safety to accommodate the combination of stresses imposed by design, material, temperature and other service conditions.

The study of the physical stresses involved is complex, and techniques for minimizing them by using different components, materials and designs, are evolving slowly.

Improving the quality of the unaged membrane, or at least reducing its loss of properties on aging, will increase the margin of safety and provide improved long-term performance.

ENVIRONMENTAL DEMANDS ON THE MEMBRANE

With the high grade membranes available today, any loss in properties and consequent reduction in the margin of safety is most likely to be attributable to high temperature and heat from solar radiation.

Effect of Temperature

The influence of solar radiation on ambient temperatures is well known. Figure 1 shows that the levels of solar radiation in parts of North America are among the highest in the world.[2] Radiation at these levels not only raises the ambient temperature but, on striking membrane materials, particularly those that are black, it increases their temperature 45 to 50C (80 to 90F) above ambient.

In laboratory studies simulating the highest level of solar radiation[3], that received by countries in the Middle East, measurements were made of the temperatures developed on membranes laid on concrete, in a concrete sandwich, and on constructions containing insulation. An eight-hour period was chosen to represent one day's exposure. Figure 2a and 2b, records the temperature changes at different interfaces of two systems in which a rubber membrane was first fully exposed, then placed under a concrete screed. The screed has an effect similar to a covering of ballast.

Note that the temperature rise is more rapid when the membrane is exposed. The presence of thermal insulation under the membrane accelerates the increase in temperature, and causes the membrane to reach a level almost 20C (33F) higher (*Figure 3a* and *3b*). The protective layer of concrete reduces both the rate of temperature increase and the maximum temperature attained, but the maximum is not much lower than that reached by the exposed membrane without insulation. Note also that the lower levels of heat are retained for longer periods. Such temperature effects are widely reported in the literature. It is evident that a roofing membrane can reach high temperatures and will develop a heat history whose effects depend on its composition, its location, and the building system.

Whereas heat history can affect the long-term durability of the membrane, a high temperature may cause it to soften, yield and creep. The stiffening effect of low temperatures is well recognized. Low temperature tests are included in most membrane specifications, but only a few specifications call for testing at elevated temperatures.

In an evaluation of stiffness, the shear modulus of samples of five different commercially produced membranes was measured over a temperature range of −50 to +100C (−58 to 212F). The results[4] are shown in Figure 4. In comparison with other membranes, the EPDM membrane not only shows less stiffening at low temperatures, but less softening at high temperatures. The narrow range of these changes indicates the ability of membranes to respond to building movements over a wide temperature range without splitting, thinning or yielding.

Effect of Solar Radiation

The heating effect just described originates from the absorption of solar radiation by the polymer and its ingredients. Radiation energy causes the polymer chains and some of the compounding ingredients to vibrate and generate heat. The energy released by solar radiation in, or near, the UV frequency range also can cause the polymer chains to break and undergo subsequent chemical oxidation, similar to aging.

Carbon black, which is normally present in rubber membrane compositions at levels up to 30 percent by weight, absorbs solar radiation extremely efficiently. Chain scission by solar radiation is largely a surface effect, but heat absorbed by the carbon black affects the membrane throughout its thickness. It is paradoxical that protection from UV induced chain scission is best achieved by including carbon black in the membrane compound, yet the radiant heat absorbed by the carbon black accelerates the aging process. However, the protection that carbon black provides by absorbing ultraviolet radiation more than offsets the potentially harmful effects of raising the membrane temperature.

LABORATORY SIMULATION OF SOLAR RADIATION

Weatherometer

Weatherometer aging to simulate long-term exposure to service conditions has been available for many years, but long test periods are required and confidence in correlating test performance with performance in service is generally lacking. This has been attributed,[5] with some justification, to the fact that test conditions have not been made severe enough for the more inert materials now being used.

Martin[6] found that 5,000 hours, or approximately seven months, of exposure to a xenon arc provided a loss in properties in a variety of rubbers and plastics, comparable to that of 30 months of weathering in Australia. Thus it appears that a test of some two-and-a-half years duration would be required to simulate only 10 years of weathering.

Heat Aging

Heat aging has been used for many years by the rubber industry as an indication of outdoor weather resistance. With natural rubber, 70 percent retention of properties after exposure of seven days at 70C (158F) was regarded as satisfactory.

With the introduction of new, age-resistant rubbers for membranes in the 1960s, the aging temperature was arbitrarily increased to 116C (240F), or to 125C (257F) to reflect the greater aging potential. However, the precise relevance to simulating the effects of solar radiation was not known. Comparable heat aging specifications have not been introduced for plastic membranes.

The difficulty of correlating a laboratory heat aging test, which provides a standard heat history, with the sum total of daily seasonal and annual temperature changes occurring on site at different locations can be appreciated. Accelerating the heat aging test by increasing the temperature above that encountered on site has a general validity, due to a time-temperature relationship developed by Arrhenius. A rule of thumb is that the reaction or exposure time is halved for each 10C (16F) increase in temperature.

In a comprehensive test program, Bergstrom[7],[8] exposed a wide range of rubbers for a 10-year period at locations in Alaska, Illinois and Panama. He found that with the exception of the polyurethanes and silicones, which were susceptible to moisture, there was a close relationship between the effects of outdoor exposure and laboratory heat aging tests. In general, for the wide range of rubbers tested, the effects of 10 years exposure on site in cold, temperate and hot locations was found to be equivalent to one, two, and more than four, weeks respectively, of laboratory aging at 100C (212F).

It also has been estimated[9] that 10 years' exposure in a hot climate in Africa was equivalent to seven weeks heat aging at 100C. Ten years' exposure to the temperate climate of Japan(3) was judged to be equivalent to 12 weeks of heat aging at 80C (176F), or to approximately two to three weeks at 100C (212F). In Europe, three independent investigators studying bitumen performance after 10 years of exposure[10] found that the deterioration corresponded to that caused by heat aging for between 1.5 and three weeks at 100C. Thus, recognizing the difficulties of defining regional climates, there is growing support for the contention that deterioration would occur twice as fast in temperature climates, as in arctic conditions, and three or four times as fast in hot climates as in temperate climates. Simulated tests therefore must be severe.

Rossiter and Mathey[11] reported that one week of heat aging at 100C followed by 1000 hours, or approximately six weeks, exposure to a xenon arc produced deterioration equivalent to that of two weeks aging at 100C (212F). It was found that for some compositions,[12] as will be discussed later, 250 hours of exposure to a xenon arc under conditions producing surface temperatures of 80C (176F) yielded a similar level of degradation to that of dark oven heat aging at 80C (176F) for the same period. On longer exposures the effect of the solar radiation component was more dominant.

Natural Weathering

Natural weathering tests are time consuming and the results still require correlation with the effects on membranes in less exposed sites. Accelerating the test with solar mirrors as demonstrated with the EMMAQUA test[13] offers more rapid results. The solar radiation components can be monitored, but the critical, actual heat history of the sample is more difficult to measure.

PERFORMANCE OF EPDM MEMBRANES AND CORRELATION WITH SIMULATED TESTS

Natural Exposure

Membrane performance is influenced by factors such as roof construction, installation technique and site location. The latter determines the solar radiation and wind levels. Performance also is influenced by the thickness and quality of the membrane, and by the extent by which its properties exceed the minimum required by industry specifications.

Accordingly, judgment of performance is inevitably retrospective, and only long-term experience with a variety of installations in different locations can provide an overall basis for comparisons. However, some long-term significance can be gleaned from the level of membrane properties retained.

Bergstrom's long-term aging studies[7,8] used black, stress-free laboratory samples 2.0mm (80-mils) thick. He found that EPDM and butyl samples were unaffected by humidity in tropical conditions. In 10 years, two EPDM compositions lost only 25 percent of their tensile strength, and only 25 percent of their elongation, under the severest exposure conditions.

Data on weathering in Florida[14] indicate that a laboratory prepared, black EPDM membrane 1mm (40-mils) thick had taken 15 years to lose 25 percent of its tensile strength, but had lost 50 percent of its elongation after 10 years. The comparative stress-strain properties are shown in Figure 5.

The performance of a black, commercially produced, 1.5mm (60-mils) EPDM membrane installed on a roof and exposed for 7 years in an east coast United States location was reported.[9] The stress-strain properties of the exposed membrane, and of a comparable, unexposed membrane made by the same manufacturer, measured at four different temperatures, are shown in Figure 6. The small loss in tensile strength and much greater loss in elongation again are apparent. The relatively modest changes over the temperature range −20C to +80C (−4F to +176F), compared to the membranes mentioned earlier, is clear. The pattern is not greatly changed on aging.

Simulated Weathering and Heat Aging

To reflect the environmental and test experience gained, a xenon weatherometer was modified to produce a sample temperature of 80C (176F), measured by a black body test panel. This was achieved by reducing the efficiency of the screens to filter out the infrared radiation. The wet cycle was eliminated so that this temperature could be maintained for long periods. The behavior of two commercially produced EPDM membranes after 250, 500 and 1000 hours of exposure is represented by the stress-strain properties shown in Figure 7. Although the compositions were different, the changes were similar and compare well with those that occurred during natural weathering in Florida and on the east coast of the United States (*Figures 5* and *6)*.

The results of heat aging membrane A at 116C (240F) and 125C (258F) are shown in Figure 8. Although the magnitude of the effects is different, the factors common to natural and modified weatherometer exposure are the initial loss of elongation, after which the rate of loss slows significantly, and the loss of tensile strength that occurs in the later stages.

It is noted, in general accordance with Bergstrom's correlation,[7,8] that severe heat aging is needed to produce properties comparable with those retained after twenty years of outdoor exposure. Notwithstanding the severity of the test, the properties still are very good. In Figures 9, 10 and 11, the changes in tensile strength, elongation and tear strength are shown over long-term heat aging at 125C. Tensile strength and elongation were measured at −20C and +80C. Note that the loss of properties for EPDM at higher aging temperatures is more critical than at lower temperatures, and that a satisfactory level of properties is retained even after such severe exposures.

The importance of longer periods of heat aging to reflect the heat history encountered in service recently has been recognized by the Rubber Manufacturers Association (RMA), which has amended the specification aging period at 116C (240F) from one week to four weeks. For EPDM, elongation is affected more than tensile strength. Accordingly Figure 12 depicts the changes in elongation on long-term heat aging of five commercial membranes available in the United States. Although the individual membranes show property variations, they meet the desired parameters.

Ancillary Effects of Membrane Heat History

Depending on the composition, some polymeric materials not only suffer from creep at elevated temperatures, but may also shrink. This results either from the release of stress created during the membrane manufacturing process, or from the loss of volatile components under service conditions.

For many membrane materials, shrinkage specifications only reflect the stress release factor, and very mild heat tests are specified. For EPDM, the RMA standard demands a maximum linear dimensional change of ±2 percent after one week aging at 116C (240F). Relating such dimensional changes to heat history more comparable with the worst site conditions, the data obtained after 25 weeks exposure at 116C (240F) indicate that the dimensional stability of the two EPDM test membranes was excellent and still below 2 percent.

	A		B	
Weeks at 116C (240F)	**Longitudinal (%)**	**Transverse (%)**	**Longitudinal (%)**	**Transverse (%)**
4	−0.80	−0.56	−0.80	−0.48
10	−1.20	−1.00	−1.01	−0.88
25	−1.56	−1.56	−1.65	−1.04

Table 1 Changes in the linear dimension of EPDM membranes A and B on long term aging

Although the effect of water on unaged membrane materials is small, an extensive heat history may change this situation. This was examined by aging the two EPDM membranes for long periods in air, and then subjecting them to water immersion for one and four weeks at 70C (158F). This combination of conditions is unlikely to occur, even on a roof with poor drainage.

The results in Table II show that the RMA specified limits of +8 and −2 percent weight change after one week of immersion in water at 70C on unaged samples, is not exceeded even after air aging for 10 weeks.

		A		B	
Immersion time	**(weeks)**	**1**	**4**	**1**	**4**
Aging at 116C	0	+3.32	+5.80	+2.50	+3.32
prior to	4	+3.49	+5.31	+2.06	+2.71
Immersion (weeks)	10	+3.68	+6.07	+2.76	+3.58

Table 2 Water immersion tests after extension heat aging at 110C (240F).

The change in the physical properties of the membrane after water immersion also is important. It was found that the effect of the additional four weeks of water immersion after air aging for 10 weeks at 116C (240F), is to lower the tensile strength by less than 5 percent and the elongation by less than 20 percent. This provides tensile strengths of 10.5 and 10.3 MPa (1520 and 1490 psi), and elongation values of 270 and 155 percent, respectively.

DISCUSSION AND CONCLUSIONS

Various factors relating to building design, materials, and installation influence the performance of waterproofing membranes, even in the same climatic environment. Consequently, membranes require properties that include a margin of safety sufficient to accommodate these factors in addition to climatic effects.

Economic factors dictate roofing quality in general terms. Membrane properties, which in practical terms are a function of the thickness of the membrane and its ability to resist degradation on aging, control the margin of safety. These factors are being resolved on the basis of economic and performance criteria derived from both experience and study. With regard to membrane developments, the advantages of optimizing both the level of properties and the retention of properties over a temperature range and after aging, have not been fully grasped because the requirements and the test criteria have been unclear. The change in emphasis from standard material testing towards performance testing represents a significant move in the right direction.

The data presented in this paper indicate that using tests of greater severity to simulate the effects of natural weathering represents a considerable improvement over conventional specification testing, and facilitates the evaluation of the critical performance parameters. Implicit in this approach is the idea that a valid performance test must be applicable to all membrane materials intended to perform the same function. The heat aging test correlates closely in the case of membranes based on EPDM and other rubbers. It has less validity, however, for membranes which soften or lose volatile components at test temperatures that exceed the optimum anticipated site temperature.

Weatherometer tests using an 80C black body temperature show more promise because they provide realistic test exposure conditions applicable to all roofing membranes. The extent to which surface degradation can influence the overall properties of different membrane materials and thicknesses will be invaluable information.

The margin-of-safety concept demands that physical tests be carried out on exposed materials over a range of temperatures, and should include shrinkage and water absorption tests.

The data produced indicate that EPDM offers chemical inertness and a wide margin of safety, a margin which no doubt can be further improved. Performance standards should correlate with longevity, and the tests and values should relate not to the potential of the material, but to functioning conditions and performance experienced with other membrane materials. The RMA test programs are making a major contribution.

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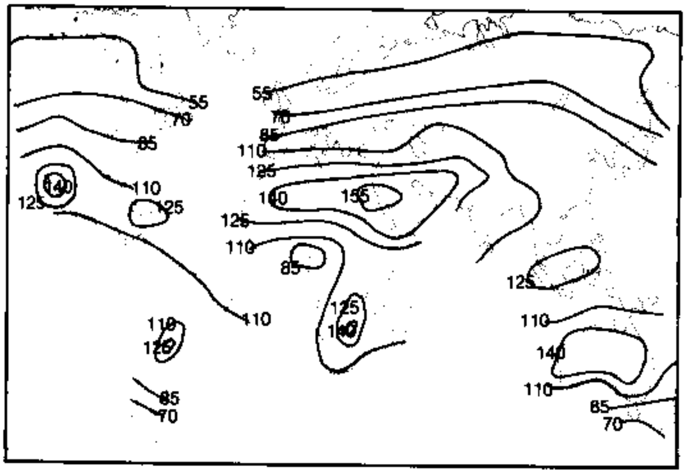

Figure 1 *Solar radiation (MW/m ± /annum)*

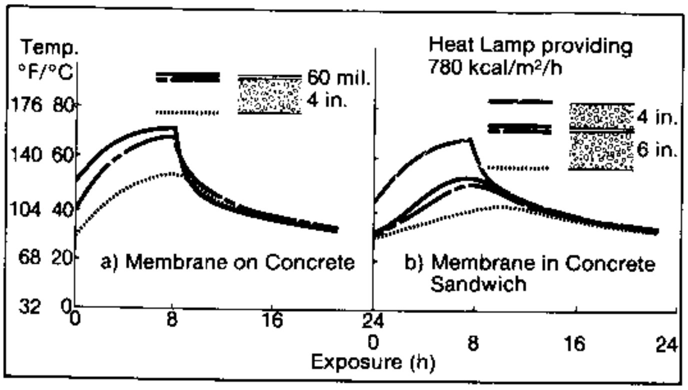

Figure 2 *Surface and boundary temperature of members in different roof constructions*

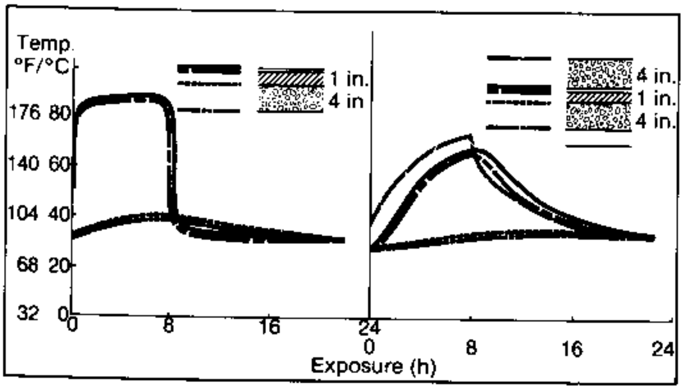

Figure 3 *Surface and boundary temperature of membranes in constructions with insulation*

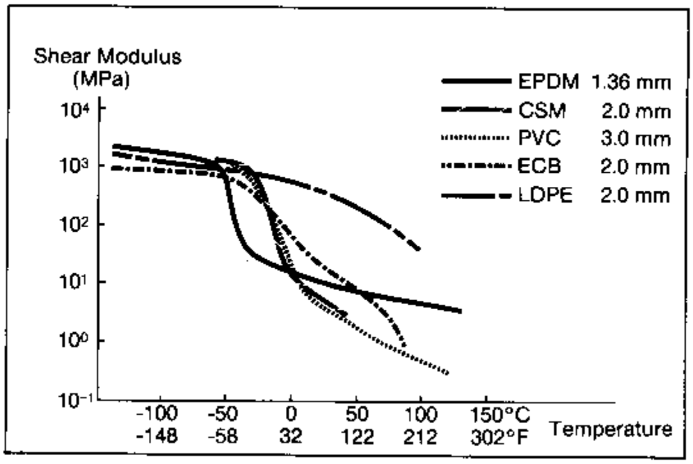

Figure 4 *Shear modulus properties of membranes measured over a temperature range*

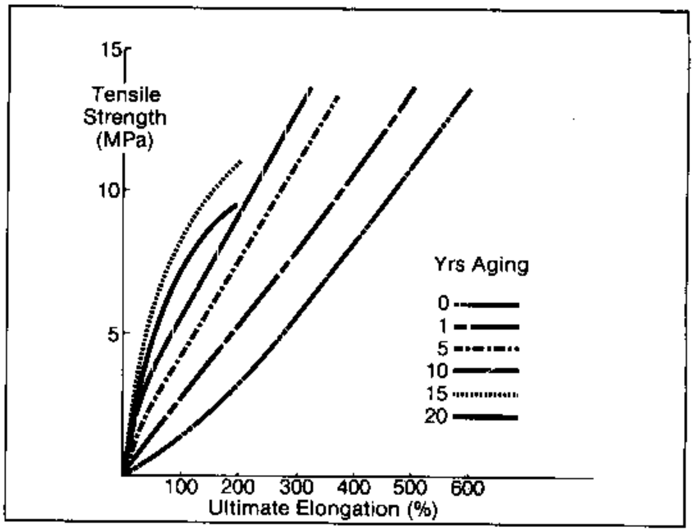

Figure 5 *Changes in properties on weathering black EPDM in Florida to 20 years*

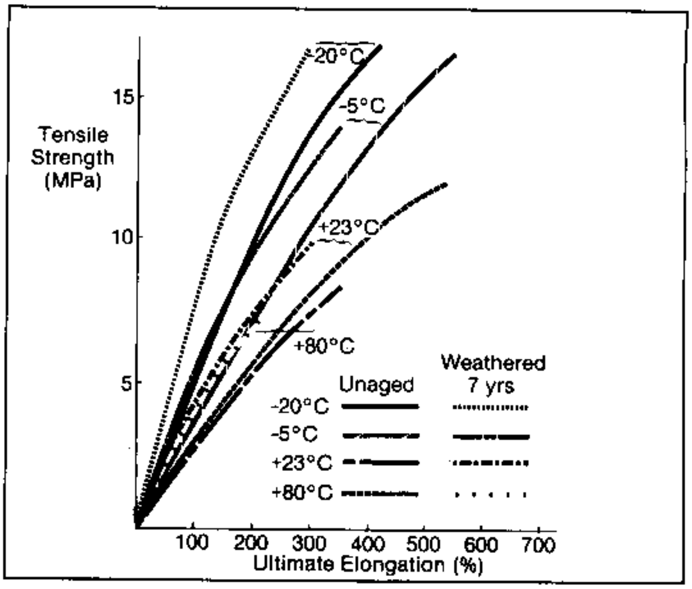

Figure 6 *Change in stress strain properties on weathering: tested over temperature range*

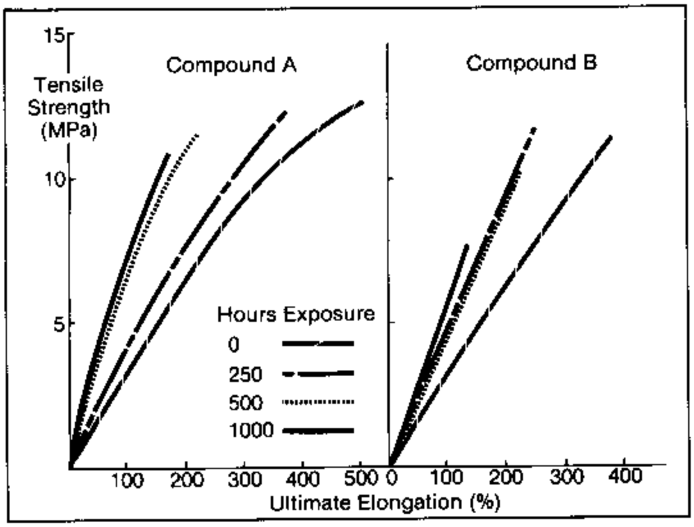

Figure 7 *Change in stress strain properties on exposure in a xenon cabinet at an 80C black body temperature*

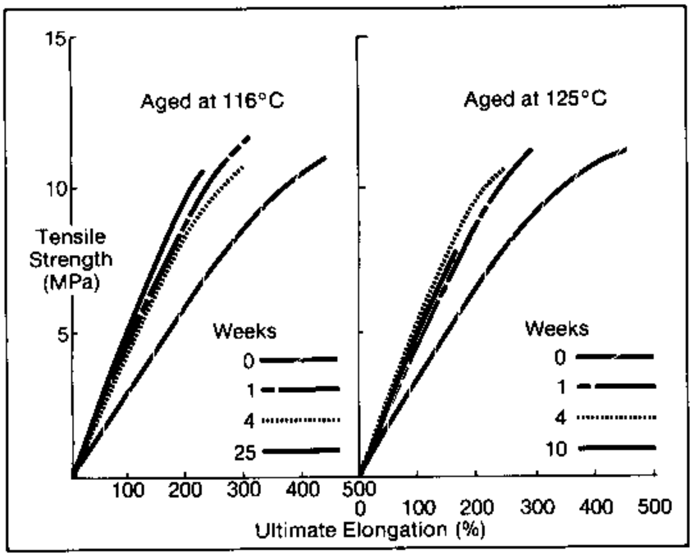

Figure 8 *Change in stress strain properties on heat aging compound 'A' at 116C (240F) and 125C(257F)*

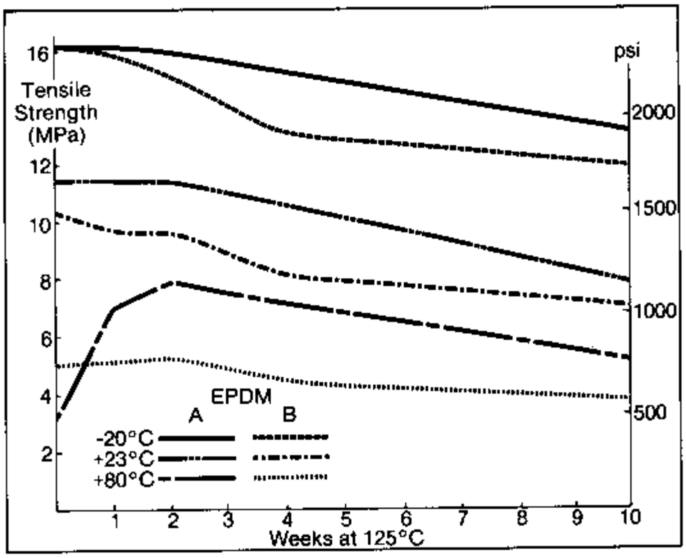

Figure 9 *Tensile strength of EPDM 'A' and 'B' after heat aging at 125C (257F) and property measurement at -20, '23 and '80C (-4, 73 and 176F)*

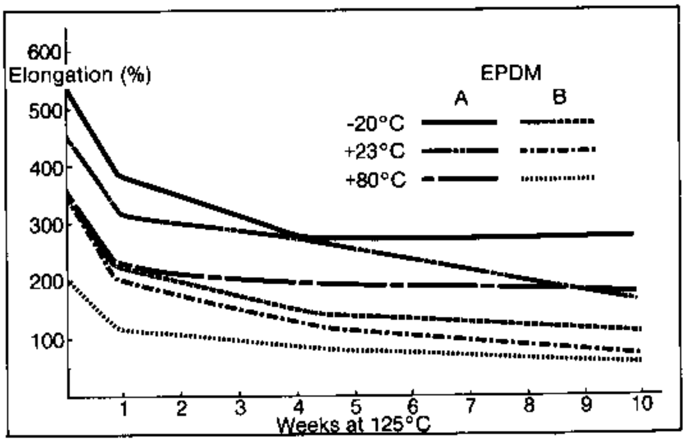

Figure 10 *Ultimate elongation of EPDM 'A' and 'B' after heat aging at 125C (257F) and property measurement at -20, '23 & 80C (-4, 73 and 176F)*

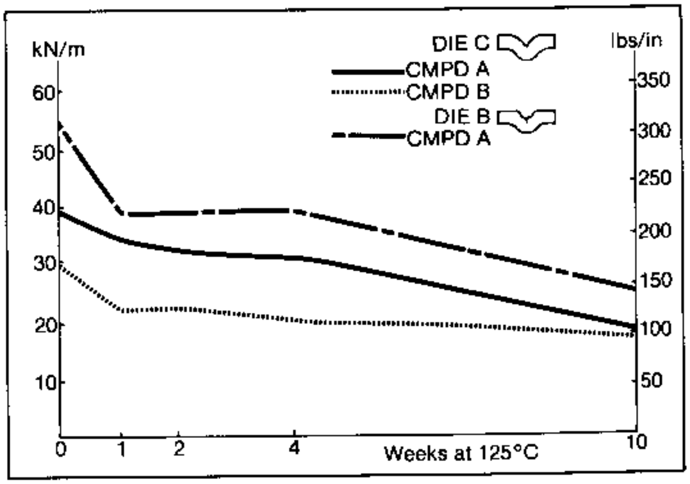

Figure 11 *Tear strength of EPDM 'A' and 'B' after heat aging at 125C (257F)*

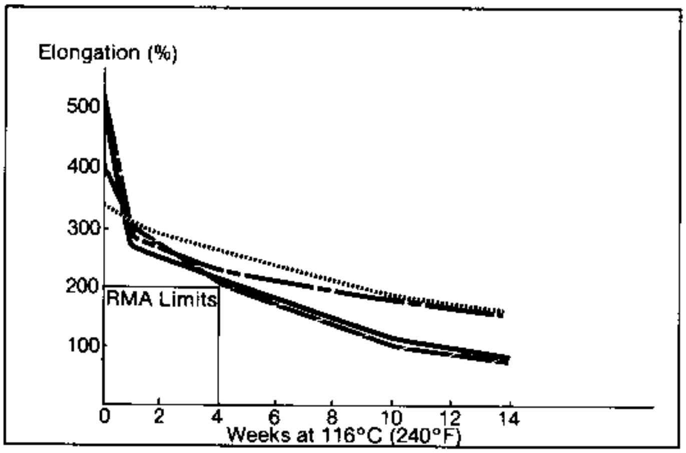

Figure 12 *Change in elongation on long term aging of four commercial EPDM membranes*