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DESIGNING FOR LONG LIFE WITH ELASTOMERS

FOREWORD

The properties of elastomers change with time and temperature; in some cases these changes are substantial. As a result of long-term storage stability problems with some early elastomeric materials, the aerospace industry to a large extent has become accustomed to the application of age controls on O-rings, hoses, and certain other rubber products. This has proven to be very costly, time-consuming, and unwieldy. Additionally, elastomeric materials qualified for service based on the results of short-term simulation tests conducted only at service temperature extremes have not always performed adequately in the field. Accelerated tests, when required, should be performed significantly above the continuous service temperature to provide a meaningful estimate of life at reduced temperatures.

Replacement and reassembly of parts have been found to lower reliability. Maintenance on very complex aerospace products is difficult to carry out because of compactness of these products and disassembly required to gain access to seals or other rubber goods. The reliability and cost requirements of aerospace components are very high, hence short life, unreliable elastomeric parts cannot be tolerated. Long life elastomers are available for use in aerospace designs. It therefore, follows that designing for long life is a much more viable approach.

Experience has shown that even though properties of properly compounded elastomers change with time at ambient conditions, they do not change to the extent that they will not properly function. For this and other reasons, age controls on elastomers such as buna-N have been removed to a large degree. An overwhelming amount of data revealing acceptable aging characteristics have been collected on shelf-aged materials and on assembled parts over long periods of time.

The designer must convey a specific requirement to all concerned that he is building critical aerospace equipment intended for long life and high reliability. This can be as straightforward as a detailed drawing note citing the life requirement in years and the expected environments. This overall requirement has to be backed up by specific elastomer material performance and mechanical property

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specification requirements. Moreover, the designer cannot assume that published specifications or proprietary callouts will automatically provide elastomeric performance to meet his specific needs.

1. SCOPE:

This document lists those guidelines recognized as being essential for consideration by the designer who is preparing to select an elastomer as part of an aerospace design.

1.1 Purpose:

To provide guidelines to the aerospace designer in the testing and selection of elastomers so that long life service will be realized in critical components.

2. REFERENCES:

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U. Meier, J. Kuster, and J. F. Mandel, "Rubber Chemistry and Technology", Vol. 54, 254 (1984)

UL 746B, Polymeric Materials: Long Term Property Evaluations

ASTM 2990, Tensile Compressive and Flexural Creep and Creep Rupture of Plastics

ASTM D 3045, Heat Aging of Plastics Without Load

ISO 3384 Rubber, Vulcanized - Determination of Stress-Relaxation in Compression at Ambient and at Elevated Temperatures

3. GUIDELINES:

The following minimal guidelines are presented to aid the designer in the selection of long life elastomeric parts:

a. The elastomer compound should be resistant to oxidative attack.

b. The elastomer compound should be resistant to ozone cracking.

c. The elastomer compound should be resistant to the service fluid media involved.

d. The elastomer compound should suitably resist permanent set and/or stress relaxation.

e. The elastomer compound should possess a sufficient safety factor in mechanical properties to allow for known degradation.

f. The elastomer compound should possess sufficient resistance to cut, tear, and abrasion to give the required life.

g. The elastomer compound should resist special environments such as temperature, water, humidity, radiation, fungus, hard vacuum, corrosion, cleaning and processing media, and the like when required.

h. Functional hardware should be artificially aged as part of normal qualification testing.

i. The quality and product control systems should be explicit and be enforced to make certain the specified elastomer is received and is properly packaged and stored.

It must be recognized that it is not necessary that an elastomer meet all of the above guidelines in all cases. If for example, ozone resistance is not a major item of consideration, some polymers such as buna-N with poor ozone resistance could perform satisfactorily.

4. DISCUSSION:

Discussions covering each of the guidelines are as follows:

4.1 Oxidative Attack:

Most elastomers are subject to oxidative attack, but antioxidants have been developed to offset this mode of degradation. Certain elastomers, such as fluorocarbons, silicones or ethylene propylenes, are inherently resistant to oxidation, and do not require the addition of antioxidants. The control of oxidation is a complex empirical problem. Hence, specifications do not specify the chemical type(s) of antioxidants or the amount to be used. Rather, they define the effect using accelerated heat oven tests to set limits to the extent of degradation. The

4.1 (Continued):

designer must insure that a suitable test of this type is included in the specification they invoke. The time and temperature of an accelerated test such as defined in ASTM D 3045 can provide an indication as to how long this material may safely be used in a design at a rated service temperature. Antioxidant technology has been developing for almost 50 years and extensive tests have shown that most quality antioxidant protected elastomer compounds will resist gross degradation due to oxidation for periods much greater than ten years at ambient temperature.

4.2 Ozone Cracking:

Chemically unsaturated elastomers are subject to ozone cracking. This is familiar to most persons who have seen ozone cracking on the sidewalls of their automotive tires. In former times, this was incorrectly attributed to sunlight. Ozone is an extremely active form of oxygen. Its attack is not to be confused with oxidative attack as discussed above. Chemically saturated elastomers can be used with little or no concern for ozone cracking. These include among others: polyacrylates, ethylene propylene, fluorocarbons, silicones, butyl rubber, and polysulfides.

4.2.1 The more common chemically unsaturated elastomers which may be attacked by ozone are: neoprene, nitrile-butadiene rubber (NBR), polybutadiene, natural, isoprene and styrene-butadiene rubber (SBR). These should be used only where protected from atmospheric or other source of ozone, or provided by addition of antiozonants or by physical separation from exposure to ozone. As with antioxidants, the requirement is implemented by tests for resistance to ozone cracking, rather than by tests for antiozonant content.

4.3 Fluid Media:

Elastomers can be dissolved, swollen, or degraded by fluids that have chemical structures or solubilities similar to their own. There is no such thing as an elastomer that resists all fluid media. The rubber must be compatible with any operational fluid media (or nonoperational fluid such as lubricants or cleaning fluids with which it comes in contact at any time). True compatibility will depend on the concentration of the fluid, temperature, duration of exposure, and the state of cure of the elastomer.

4.3.1 Elastomer specifications often have fluid immersion tests in various standard fluids under heat accelerated conditions. Volume change is one measurement. Negative volume change (shrinkage) is almost always considered unacceptable, but positive changes up to 25% or even higher with some designs are often acceptable. Unless carefully structured it has been found that heat accelerated volume change tests may not always predict what will happen at room

4.3.1 (Continued):

temperature, i.e., positive volume changes were found in the heat accelerated tests, but shrinkage was experienced in long-term usage at room temperature.

Pneumatic sealing conditions may vary from those typically experienced with fluids contained in hydraulic systems and engine components. In some applications, more squeeze may be required, perhaps double the squeeze required in hydraulic systems. The use of nonstandard O-rings and/or modification of groove dimensions may be advisable. In others, less squeeze may be required, for example, in dynamic pneumatic cylinders where high sealing forces tend to produce binding.

4.3.2 Changes in physical properties are also tested under heat accelerated conditions. A truly meaningful immersion test uses the actual exposure fluid in the actual environments (except for temperature) and for extended periods. Parts or material so exposed must be tested for change of volume, ultimate tensile strength, tensile stress at a specified elongation (called "modulus"), elongation, and hardness as a minimum.

4.4 Permanent Set:

Permanent set, or irrecoverable creep, is the failure of an elastomeric part to completely recover from prolonged deformation in a finite time, usually 30 min for test purposes. Permanent set may occur in tension, shear, torsion, or compression. Compression set resistance is the property most often specified in seal specifications. Sealing force, an elastomer seal's resistance to a given deflection, is a better indicator of sealing ability but one more difficult to measure than compression set. Compression set and sealing force are related in the sense that a material with high compression set will generally exhibit poor sealing force retention. However, in some instances, an elastomeric material with reasonable compression set may provide poor sealing force retention with subsequent leakage. Conversely, a material with high compression set and poor sealing force retention may not always leak since the retained absolute sealing force is sufficient to maintain a seal. Therefore, whenever possible, sealing force measurements should be used in design of critical long life sealing components.

The compression set resistance and sealing force retention of a compound depend on its state of cure; complete tight cures give the best set resistance. However, for economic reasons, production cure cycles are kept as short as possible. The designer must insist on a thoroughly cured seal, controlled by invoking a specific accelerated compression set test and by running lot acceptance tests on actual production parts. Utilizing test parameters appropriate to the generic polymer base for the compound, the compression set for critical parts as a general guide should preferably be less than 25% but most generally be less than 35%. With a few specific types of elastomers, such as the fluorocarbons, room

4.4 (Continued):

temperature compression set tests must be run in addition to accelerated temperature tests. Accelerated tests using Arrhenius aging, may be run using ASTM D 3045 or ASTM 2990, or alternately, UL 746B as guidelines. In addition, ISO 3384 references stress relaxation in compression.

4.5 High Initial Tensile and Elongation Properties:

The higher the dilution of the elastomer with fillers and the poorer the strengthening action of the specific class of reinforcing fillers, the lower the strength and elongation of the resulting compound. Similarly, high dilution with plasticizers will reduce mechanical properties. Hence, tensile strength and elongation are primarily an index of quality rather than properties for use in stress analysis. Low strength (low quality) elastomer compounds generally age poorly. Further, high quality (high strength) compounds have better abrasion and tear resistance and can degrade to a greater extent and for much longer periods of time and still remain functional. Extensive studies have shown that with many elastomers the tensile stress at 100% elongation will approximately double in about three years of aging at room temperature and will remain fairly constant from three years to ten years and beyond. Hardness does not measure this effect. Elongation drops continuously with aging time. Many concepts consider 100% elongation as the end point because the material becomes too rigid and inelastic to be useful in most elastomeric applications.

4.6 Cut, Tear, and Abrasion Resistance:

A surprising number of elastomer items fail through cutting, tearing, or abrasive action. This is particularly true of room temperature vulcanization (RTV) silicone materials, which are also deficient in high initial properties and compression set resistance. Certain non-RTV, high temperature press cured silicones also tend to be deficient in cut, tear, and abrasion resistance. The newest products based on advanced heat cured silicone rubber technology overcome the cut and tear problem, provided specifications requiring them are invoked by design. They are still inferior in abrasion resistance. Hence, silicone and fluorosilicone elastomers should not be used in dynamic seals. Low quality seals based on other polymers may also be deficient in cut, tear, or abrasion.

4.7 Special Environments:

The elastomer compound must be compatible with the appropriate special environments in additicn to those noted. The resistance of elastomers to fungus growth depends upon additives, such as extender oils and plasticizers, in addition to the base polymer. Therefore, only tests on specific compounds have any meaning. The resistance of elastomers to water, humidity, and nuclear radiation varies with the base polymer and the specific formulation. Antirads, similar to the antiozonants, are available for specific types of elastomers as a means of improving