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(R) Designing for Long Life With Elastomers

RATIONALE

This document has been revised to include current reference publications and a more thorough discussion of creep, stress relaxation and permanent set as these phenomena relate to sealing 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 function properly . 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 specification requirements. Moreover, the designer cannot assume that published specifications or proprietary callouts will automatically provide elastomeric performance to meet his specific needs.

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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. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

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

ASTM D 3045 Heat Aging of Plastics Without Load

ASTM D 6147 Vulcanized Rubber and Thermoplastic Elastomer – Determination of Force Decay (Stress Relaxation) in Compression

2.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 3384 Rubber, vulcanized – Determination of stress-relaztion in compression at ambient and at elevated temperatures

ISO 6056 Rubber, vulcanized or thermoplastic – Determination of compression stress relaxation (rings)

2.3 UL Publications

Available from Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 746B, Polymeric Materials: Long Term Property Evaluations

2.4 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

F. R. Eirich, ed., "Science and Technology of Rubber", Academic Press, New York, 1978.

A. V. Tobolsky and H. F. Mark, ed., "Polymer Science and Materials", John Wiley and Sons, New York, 1980.

H. Liebowitz, ed., "Fracture - An Advanced Treatise", Vol. VII, Academic Press, New York, 1972.

H. F. Mark and N. G. Garylor, N. J. Bikales, ed., "Encyclopedia of Polymer Science and Technology", Vol. 8, p. 419 & p. XXX, Interscience Publishers, New York, 1968.

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

L. P. Smith, "The Language of Rubber", Butterworth-Heinemann Ltd., Oxford, UK, 1993.

A.N. Gent, ed., "Engineering with Rubber – How to Design Rubber Components", 2nd Edition, HanserGardner Publications Inc., Cincinnati, Ohio, 2001.

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, creep, 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 may 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 designer must insure that a suitable test of this type is included in the specification invoked. 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 be used safely in a design at a rated service temperature. Antioxidant technology has been developing for almost 75 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 heataccelerated volume change tests may not always predict what will happen at room 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 Creep, Stress Relaxation, and Permanent Set

When elastomers are used as sealing devices, they are compressed or strained to some degree. When that strain is removed after a period of time, the material will not fully recover its original shape. Creep, stress relaxation and compression set are undesirable related phenomena, which occur in all elastomeric articles and reflect the inherent viscoelastic nature of the elastomer and the limited stability of crosslinks of its vulcanizate.

Creep is a time dependent increase in deformation under conditions of constant stress. Continuous stress relaxation is decay in stress, as a function of time, under conditions of constant strain. It is of great importance to sealing devices such as O-rings and gaskets. Both creep and stress relaxation are significant because they often play a role in the failure of rubber components. Set, often referred to as "permanent set", or irrecoverable creep, is the permanent deformation which remains when a material is released from the strain imposed and is measured in tension, or more commonly in compression.

Both stress relaxation and creep are the result of physical and chemical relaxation processes. The physical process is due to the viscoelastic nature of rubber and usually decreases linearly with the logarithm of time. It is associated with reorientation of the elastomer molecular network under strain, with disengagement and rearrangement of chain entanglements. The chemical process is caused by chain scission or isomerization of crosslinks and usually occurs linearly as a function of linear time. Both processes occur simultaneously. Physical relaxation predominates at short times, while chemical effects are more significant at longer duration. Chemical effects are more obvious under conditions that favor oxidation, such as high temperatures and absence of chemical antioxidants in rubber compounds.

4.4.1 Creep

When an elastomeric component is subjected to a static load, the load will cause a progressive increase in deformation as a function of time. Bi-axial stress relaxation on compression in rubber consists of both physical creep and chemical creep (due to molecular chain breaking).

4.4.2 Stress Relaxation

When a constant strain is imposed on an elastomer, the force necessary to maintain that strain is not constant but decays exponentially with time from the initial maximum to an eventual equilibrium state. This phenomenon of force decay is called stress relaxation and is of great importance in rubber sealing devices such as O-rings, packings and gaskets. Stress relaxation can be the dominant factor that limits the effective life of the sealing device. ASTM D 6147 and ISO 3384 reference a test method for determining stress relaxation in rubber.

4.4.3 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 minutes 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 may be sufficient to maintain a seal. Therefore, whenever possible, sealing force measurements should be used in design of critical long life sealing components.