SERVICE LIFE PREDICTION OF POLYMER RUBBER COMPONENTS USING ACCELERATED AGING AND ARRHENIUS EQUATION

Kartik Srinivas
Principal Engineer
Advanced Scientific and Engineering Services (AdvanSES)
212, Shukan Mall, Sabarmati-Gandhinagar Highway,
Motera, Sabarmati, Ahmedabad 380005 India.
Phone: +91-9624447567, E-mail: kartik.srinivas@advanses.com
http://www.advanses.com

Introduction:

Polymeric rubber components are widely used in automotive, aerospace and biomedical systems in the form of seals, o-rings, gaskets, vibration isolators, suspension components etc. The service life of these systems is governed by the useful life of the polymeric materials used in these different applications. Aerospace and biomedical systems are expected to have service life in decades, while automotive components are expected to fully last the 5 years 100,000 warranted miles. Polymeric rubber components can get degraded when exposed to chemical and environmental degradants like ozone, UV rays, oxygen, thermal cycling, engine oils, water etc., and also due to mechanical service stress and strain conditions. It becomes very important to predict life of polymeric and rubber components under these degrading service environments. The most common approach is to accelerate the ageing of a material using elevated temperature tests combined with an extrapolation technique to predict the life time of the material/product at lower temperatures.

Theory and Technique:

One of the most widely used techniques to predict lifetimes of polymeric materials is the use of Arrhenius equation. The technique utilizes accelerated thermal aging of the materials under controlled conditions. Failure times and degradation rate studies are carried out at elevated temperatures and the data is used to extrapolate material performance to ambient conditions. Arrhenius extrapolations assume that a chemical degradation process is controlled by a reaction rate 'k',

$$k = A\,e^{-Ea/RT} \quad \textbf{OR} \quad \ln k = \ln A + \frac{-E_a}{RT} \qquad \text{---------------------------------(1)}$$

where E_a is the Arrhenius activation energy, R is the universal gas constant (8.314 J/mol °K), T the absolute temperature and A the pre-exponential factor. A log-plot of degradation times (1/k) versus inverse temperature (1/T in °K) is expected to result in a straight line. The linear interpolations along this line can be used to predict properties to lower temperatures.

To be able to successfully use the Arrhenius equation, accelerated testing must be carried out at a minimum of four temperatures above the product application temperature. To accurately estimate the degradation rate it is important to use a material property which exhibits sufficient range to assure a reliable and accurate determination of the property during the accelerated aging process. Properties like tensile modulus, tear strength, stress relaxation modulus can be used to study the accelerated aging process and degradation rates.

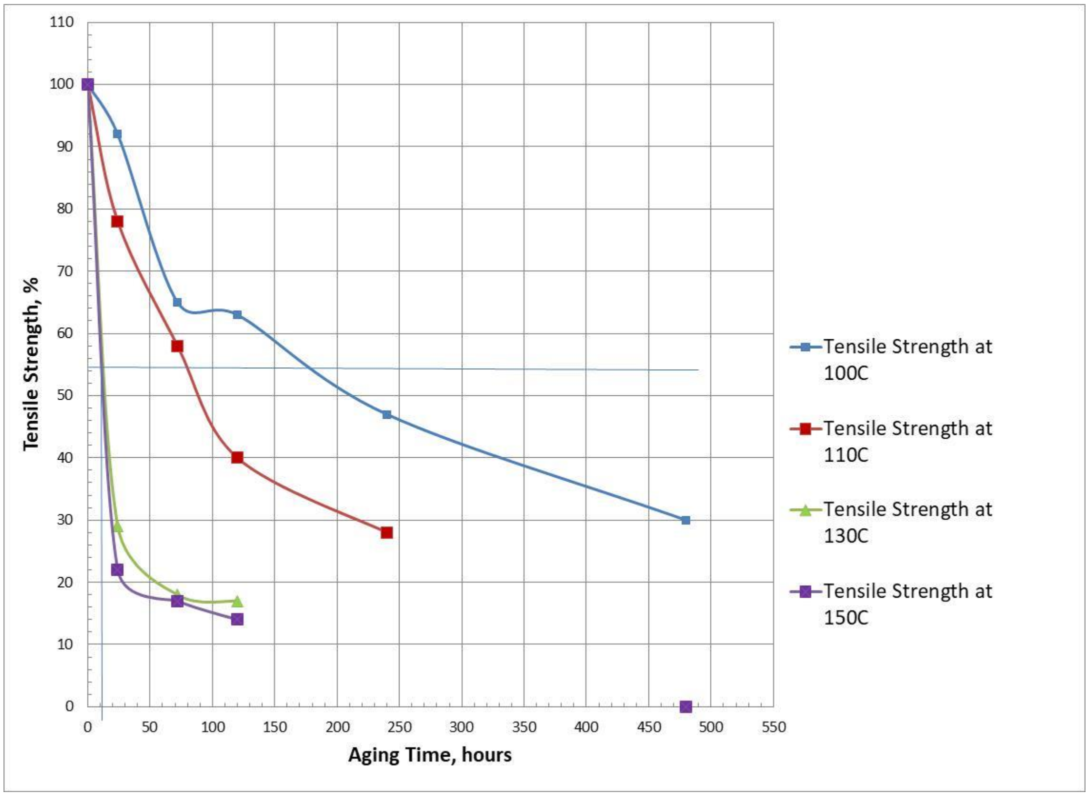

Figure 1: Tensile Strength of Material at Various Temperatures and Aging Times

The identification of ageing mechanisms and the evaluation of dependence of these mechanisms on the mechanical properties of components is important. To successfully apply life prediction technique using the Arrhenius equation, the predominant degradation process has to systematically identified and an appropriate accelerated aging test to replicate the degradation process has to be carried out. The degradation process and failures of aged laboratory samples needs to be correlated to the components in the field. The accelerated aging temperatures need to be suitably chosen to correlate field degradation rates. Generally, a test time of one decade is equivalent to a temperature rise of 10°C

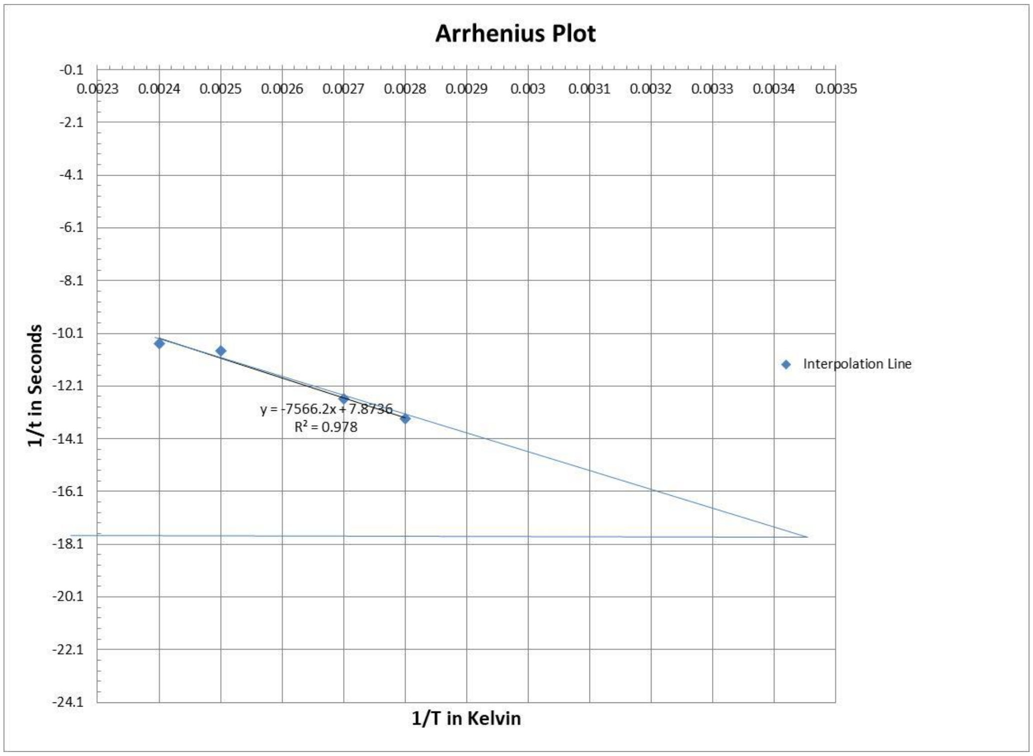

Figure 2: Arrhenius Plot Showing the Degradation Times and Inverse Temperature

Key Assumptions:

In most applications involving temperature acceleration replicating a failure mechanism, a degradation process might involve multiple steps with each of the steps having its own rate constants and activation energy. It is assumed that these phenomena can be approximated over the full temperature range by the Arrhenius equation. It is also assumed that the chemical degradation process plays major part in the failure mechanism, if the failure is a stress induced one then the Arrhenius equation method cannot be usefully employed. Method assumes that the chemical deterioration induced in the lab is directly correlated to the service life in the field.

Limitations and Benefits:

Arrhenius extrapolation to predict service life using accelerated aging and degradation exhibits some limitations and many reports showing that temperature effects on degradation kinetics cannot always be described using the Arrhenius equation have been published. However, Arrhenius extrapolation being easy to perform, reproducible, replicable and practically relevant in large amount of field service applications is widely used for lifetime prediction of polymers in different environments.

Conclusions:

Various approaches can be applied to determine life of elastomer components used in engineering applications. It is imperative to define their failure modes and failure mechanisms and establish verification and correlations between field service conditions and laboratory testing samples. The Arrhenius method provides a quantifiable determination of the service life of elastomer components in engineering applications.

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