LIFETIME PREDICTION OF ELASTOMERS - A UNIFICATION OF THE FRACTURE MECHANICS AND THE (WÖHLER) S-N-CONCEPT

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1. Introduction

In the last ten years elastomers were more frequently used in complex technical fields which require high performance. Therefore it is very important to have an instrument to estimate the service life of these technical parts. At the moment there are two classical methods for service life prediction. Both are more or less adapted from metal parts engineering [1, 2].

Fracture mechanics uses the characteristic values of dynamic crack propagation experiments to calculate the load cycles to failure for different load amplitudes. The other method, based on the concept of Wöhler [2], measures the lifetime of a sample for different load amplitudes (fatigue to failure tests, s-n curves). Both are useful for specific applications. But for rubber materials they can lead to different results for the same material. In this work an approach is shown to combine the two classical methods and an attempt is made to explain the different results. A new concept for lifetime prediction will be presented.

2. Materials and Methods

The idea, which will be explained, is a combination of the fracture mechanics concept with the Wöhler concept to reduce the experimental investigation of time and costs. Therefore the fundamental equations of Paris, Erdogan (a) are used and developed to an integral form (b) [3].

(a) $$\frac{dc}{dn} = B \cdot T^{\beta}$$

(b) $$n = \frac{1}{(\beta - 1) \cdot B \cdot (2kW)^{\beta}} \cdot \left(\frac{1}{c_0^{(\beta-1)}} - \frac{1}{c_n^{(\beta-1)}} \right)$$

Where T is the tear energy which can be calculated for different specimen geometries according to Thomas and Rivlin [4]. And ‘B’ and ‘β’ are characteristic material constants independent of geometry. ‘c_0’ and ‘c_n’ are the initial crack length and the crack length after n cycles.

Examples of Wöhler or s-n measurements on rubber materials is shown in Figure 2. The materials are based on a typical EPDM polymer filled with carbon black and sulphur cured. Two variations of the material are shown, one with pure carbon black dispersion due to a short mixing time (EPDM 1) and a typical dispersion due to a longer mixing time (EPDM 2).

The crack propagation behaviour of both materials was investigated on single edge notched (SEN) specimens with a Coesfeld[5] Tear Fatigue Analyzer. In order to determine the characteristic material constants ‘B’ and ‘β’ a minimum of three different strain amplitudes were used. The apparatus records the number of cycles and the crack length as well as the strain, the stress and the elastic strain energy density ‘W’. The crack propagation rate and the tear energy ‘T’ were evaluated in the initial stable crack propagation region.

‘Fatigue to failure’ experiments were carried out on dumbbell specimens in a MTS servo hydraulic tester under load control until complete rupture of the dumbbells (diameter 15 mm) [6].

An important prerequisite for fracture mechanics calculations is the knowledge of the initial crack or flaw sizes within the elastomer material. High-resolution x-ray computer tomography (CT) was used as a new and powerful method to characterize these structures. The analysis of the microstructures of compounds in a non-destructive way (dispersion analysis) is demonstrated.

3. Results

The CT analyses clearly reveal that the different mixing procedures lead to different stages of carbon black dispersion. Figure 1 shows the particle size distribution (specific number of particles per volume) evaluated by CT. Reference materials showed that most particles are carbon black agglomerates. The EPDM material 1 (short mixing time) contains more particles than EPDM 2 over the whole range of particle sizes investigated.

Note that EPDM 1 shows significantly higher numbers of particles especially for greater particle diameters in the range from 250 µm to 550 µm. This latter difference is argued to be the main reason for the different lifetime or fatigue to failure properties of EPDM 1 and EPDM 2 (factor: approx. 2.5) of Figure 2.

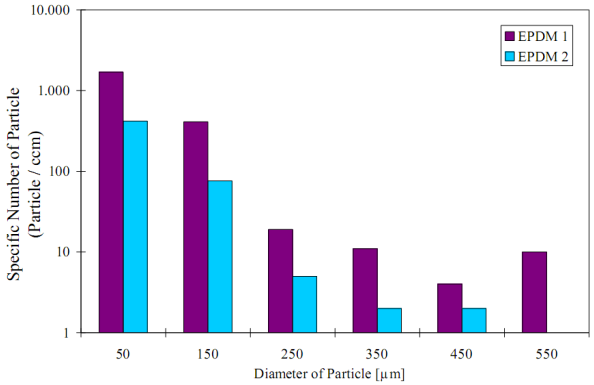

Fig. 1: Specific Number of Particle for EPDM 1 and 2

Fracture mechanics calculations or lifetime simulations of dumbbell specimens were carried out using equation (b). Note that 'B' and 'β' were taken from crack propagation experiments on SEN specimens and k and W from fatigue to failure tests on dumbbell specimens. 'c_n' was set to 15 mm which is the diameter of the dumbbells tested until complete rupture. The initial crack or particle size 'c_0' was tentatively set to 250 up to 550 µm.

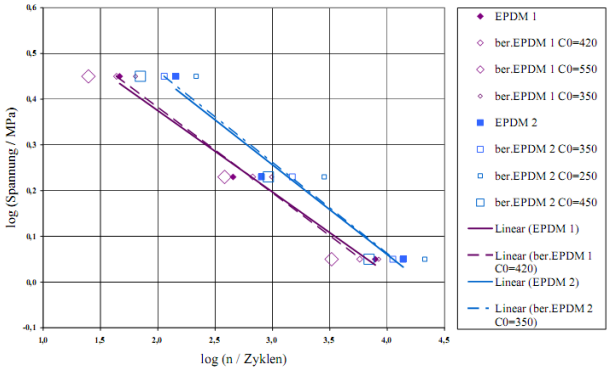

Fig. 2: Lifetime - Simulation vs. Measurement

This leads to different predictions of lifetimes which are well within the typical range of scatter of s-n- or Wöhler-curves (**Fig. 2**). The simulations show at the same time how critical only a few large particles can be. The best agreement between the simulation and the mean values of the fatigue to failure measurements is found for an initial crack size of 420 µm for EPDM 1 and 350 µm for EPDM 2. This shows that an average diameter of the greatest particles found in the materials are a good approach for the initial crack length in the lifetime simulation.

References

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