THE INFLUENCE OF MINIMUM STRESS ON THE FATIGUE LIFE OF NON STRAIN-CRYSTALLISING ELASTOMERS

by

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Summary

This PhD-Thesis describes the fatigue life and dynamic crack propagation behaviour of elastomers, especially their dependency on test parameters. It, furthermore, presents concepts of data evaluation in order to develop criteria for more precise predictions of service life of elastomeric parts. Fatigue life was investigated using EPDM and SBR dumbbell specimens tested under load control at 1Hz until failure. Tests were made in order to create a common Wöhler-(S-N)-curve while increasing stress amplitude. Additionally, the influence on fatigue properties of increasing minimum stress at constant stress amplitude was investigated. All testing were carried out in the Deutsches Institut für Kautschuktechnologie e.V. (DIK). The results of these tests confirmed the well-known amplitude dependence of fatigue life in filled rubbers. An additional significant influence on fatigue life was found to be the level of minimum stress and consequently mean stress applied to these materials, which in turn to most other materials increase the fatigue life of rubbers. This additional influence on fatigue life is not dependent on strain crystallisation in Ethylene-Propylene-Diene Polymer (EPDM) or Styrene-Butadiene Polymer (SBR) as it is for Natural Rubber (NR).. It could be proved that this effect rather specific to filled systems. The investigation shows that the fatigue behaviour of carbon black filled non strain crystallising rubbers can not be described with a maximum stress or a maximum strain criterion. It shows that an energy criterion should be considered.

Another important effect is highlighted in this research. Following the dependence on load cycles it can be seen that most mechanical properties, but particularly the stiffness of specimens change throughout the whole test, and never reach equilibrium. This behaviour is particularly observed in elastomers containing reinforcing fillers. It was found that all carbon black filled EPDM test specimen failed when they reached approximately 76% of their initial stiffness or complex modulus, despite the high variation of test conditions. The carbon black filled SBR test specimen failed when they reached 71% of their initial stiffness. These results indicate that there is a characteristic material parameter of loss in complex modulus that is reached at failure.

The results of the dynamic crack propagation tests on these unfilled and carbon black filled non strain crystallising elastomers show a similar behaviour like the fatigue to failure tests with respect to their minimum load dependence. Increasing minimum loads at a constant strain (displacement) amplitude under pulsed as well as sinusoidal excitation decrease the crack growth rate of the carbon black filled rubber material and, thus can lead to a higher service life of parts produced from these materials. The unfilled materials showed the expected opposite effect on an increase of the minimum load at constant strain amplitude which confirms the findings of the fatigue to failure experiments. It should be noted that maximum stress and maximum strain criteria are no tools to uniquely describe the crack propagation properties of filled rubbers.

As the normal failure observed during the fatigue to failure experiments was a sudden catastrophic crack after reaching a certain level of remaining stiffness or modulus it is assumed that these tests characterise the initiation process. It is, thus, an important finding of this research that crack initiation and crack growth of rubber material show a similar dependence on test parameters. Furthermore, initiation and growth seem to be energy controlled processes in rubber materials.

Contents

1 Introduction/Literature Search

1.1 Aims

The fatigue behaviour of linear materials such as the majority of metals and ceramics is well researched and described in the literature. In particular emphasis has been placed on testing of fatigue properties with varying stress amplitudes at particular values of minimum stress or mean stress and these data have largely been represented as Wöhler curves and Haigh diagrams. Few fatigue analyses of non-linear elastomeric materials have been carried out and these used Natural Rubber (NR). The influence of minimum stress and stress amplitude on the fatigue resistance of NR has been studied by André *et al* [**1**] and the data was displayed on Haigh diagrams. Fatigue life was shown to increase as minimum stresses, both compressive and tensile, increased from zero for a single stress amplitude. The improved fatigue and crack growth resistance with increased minimum (and hence maximum) stresses was previously explained by Cadwell et al [**2**] and Lake & Thomas [**3**] and attributed to the strain crystallisation of NR inhibiting crack growth. A subsequent analysis carried out by the DIK also showed a reduction of crack propagation with increases in minimum stress for non strain crystallising rubber.

Consequently, the principal objective of this work is the characterisation of the dependence of fatigue on stress amplitude and minimum stress in non strain crystallising elastomers. Additionally, materials with and without filler are considered in the investigation. This permits simultaneous studies of the effects of reinforcement, stress softening and Payne-effects [**4**, **5**, **6**, **7**] in filled systems.

A second objective is to clarify the question of which criteria (stress, strain, energy etc.) characterises the fatigue properties of elastomeric materials. Reliable predictions of the service life of dynamically loaded components, using fracture mechanics concepts as well as FEA, depend entirely on the use of the correct criteria and their characterisation.

The third objective is to develop a fatigue criterion which can be used in FEA-software and the characterisation of a material parameter to describe the fatigue properties under different test conditions of pre-stressing and pre-straining.

A fourth possible objective could be to find an in-service criterion which will allow for the replacement of a rubber component just before failure. This criterion should be capable of integration into an online measurement system.

An understanding of elastomeric fatigue behaviour is very important for the development of new elastomeric materials. Additionally it gives the industry the opportunity to develop/design components made from elastomers with increased fatigue lives and to design smaller, lighter and cheaper parts with less material consumption whilst retaining service life levels.

If for example the automotive industry could use the results of this research in the development of elastomeric parts, it will reduce costs, sizes and weights during production and consequently will be able to save energy during manufacture and service and thereafter only small amounts of elastomeric material will have to be recycled, burned or dumped.

The development of an online measurement system to evaluate the fatigue status of an in service elastomeric part will increase the safety of vehicles and machines and also it will reduce the number of parts to be replaced and dumped.

One other aim is the comparison of results of different testing procedures. A comparison of fatigue and cut growth of rubbers under nonrelaxing conditions was previously made by Gent et al [**8**] and Lake & Lindley [**9**]. The fatigue to failure properties of the elastomeric materials should be compared with the crack propagation properties of the same material. Both should be tested under a variation of minimum loads. The conclusions of this research will increase the knowledge of materials and their dependency on different testing procedures. This is very important for the research and development of new components and the predictive testing of their in service performance.

The output of this research has the potential to have a large positive influence on the environment and will simultaneously reduce costs. The results will help designers and compounders to improve the service lives and/or reduce the mass of individual products.

1.2 Introduction

Elastomers have the ability to withstand very large strains without permanent deformation or fracture which makes them an ideal material for many engineering applications. For elastomers it is possible to work at high static strains and even dynamic strains for long time periods. Elastomeric materials are used dynamically in many different engineering components. The first reason for this is certainly their unrivalled flexibility, combined with the potential to dissipate energy. But elastomers also offer high friction coefficients even under wet conditions and additionally there are tailor-made elastomers which function over a broad range of temperatures. Additionally various types of elastomers are resistant to fluids including very aggressive fluids, which combined with high flexibility makes them ideal as sealing materials. Modern fast transportation and advanced machine development have become possible because of the use of rubber products like tyres, belts, seals, springs and mounts.

Under most service conditions dynamic loads are applied to elastomeric parts and only a few are used under displacement control. Typical examples for dynamically loaded components are timing belts, V-belts, conveyor belts, rubber springs, engine mounts and tyres. Dependent on the applied load, elastomeric components are deformed according to their stiffness.

A very important property in nearly all applications is fatigue. The designer is often required to create an elastomeric component for imprecisely described service conditions. A component should attain a certain service life but should be correctly sized and certainly not too heavy and expensive for its functions.

At the moment, no acceptable method exists to calculate the fatigue lives of elastomeric components. The designer produces prototypes and tests them under service conditions and this is very expensive and time consuming. There is a high probability that the part has to be optimised by an interactive design process. Alternatively the component is over designed so that the expected service life is easily obtained, but this results in the problem of producing parts that are too heavy, large or expensive for mass production.

Hence, there is a great need for calculation/simulation of the fatigue behaviour of technical rubber components. At the moment it is not clear how service life can be determined. One possibility is the maximum strain criterion [**10**], another the maximum stress criterion [**11**, **12**] and also different energy criteria [**13**, **14**] have been suggested for use.