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# CRACK GROWTH PROPAGATION STUDY ON ELASTOMETRIC MATERIALS: AN EXPERIMENTAL AND FEA MODELING APPROACH

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## 1. INTRODUCTION

Elastomeric components are used extensively in a wide range of engineering applications. A proper estimation of long-term durability or the time to failure is critical for the practical use of elastomer materials. The current research aim is to make life-time prediction based on fracture mechanics approach. This uses the tear energy and crack growth rate data derived from ARDL crack growth experiments, combining with the finite element analysis method.

## 2. THEORY

Tear Energy

The fundamental measure of fatigue parameters for elastomer components is based on Griffith's energy approach. This leads to the assumption that the elastic energy (*T*) available to drive a crack determines the rate of crack growth

$$T = -\left[\frac{\partial U}{\partial A}\right]_v \qquad (1)$$

where *T* is the "strain energy release rate" or "tear energy'. *U* is the strain energy stored in a specimen containing a crack, and *A* is the area of the crack fracture surface. The applicability of this approach has been verified by a number of researchers using various test pieces [*1,2,3,4*]. This approach shows that a tearing (*T*) versus crack growth rate relationship exists.

Consider a thin uniform rubber sheet with a small crack length *c*

$$U = U_o - U_c = kc^2 tW \qquad (2)$$

where *k* is a strain-dependent term, *t* is the specimen thickness, and *W* is the strain energy density in the rubber far removed from the crack. By using Eq. 1 it is possible to differentiate Eq. 2 with respect to the area of a single surface of the crack *A* ( =ct ) giving

$$T = \frac{\partial U}{\partial A} = \frac{\partial U}{\partial c} \cdot \frac{\partial c}{\partial A} = 2kcW \qquad (3)$$

Crack Growth Characteristics

The crack-growth characteristics of rubber under cyclic loading condition have been extensively studied for the case of a crack in a thin, uniform sheet of material. It has been established that the crack-growth characteristics is a unique function of *T*, the maximum tearing energy achieved in the loading cycle

$$\frac{\partial c}{\partial n} = f(T) \qquad (4)$$

where *n* is the number of loading cycles. The exact form of *f*(*T*) is a material characteristic that has to be determined experimentally. As the energy is above a threshold value $T_o$, the crack growth rate can be described by the relations

$$\frac{\partial c}{\partial n} = A(T - T_o) \qquad \text{for } T_o < T < T_t \qquad (5)$$

$$\frac{\partial c}{\partial n} = BT^{\beta} \qquad \text{for } T_t < T < T_c \qquad (6)$$

where *A, B,* $T_o$ and β are material constants. Substituting Eq.3 into Eqns. 5 and 6, and integrating

$$N = \frac{1}{2AkW} \ln\left(\frac{2kWc_1 - T_o}{2kWc_o - T_o}\right) \qquad (7)$$

$$N = \frac{1}{(\beta - 1)B(2kW)^{\beta}} \left(\frac{1}{c_o^{\beta-1}} - \frac{1}{c_1^{\beta-1}}\right) \qquad (8)$$

where N is the fatigue life in cycles or kilocycles.

## 3. EXPERIMENTAL PROCEDURE

Fatigue tests of rubber were conducted on a MTS servohydraulic machine using a pure-shear specimen (Figure 1). Nominal dimensions of the test pieces were 6 x 1.25 x 0.06 in. The test pieces were first pre-stretched using fatigue cycles beyond the expected deflection to eliminate the Mullins effect. The strain energy density was estimated by integrating the force-displacement curve during the loading part of the cycle and divided by the volumer of rubber. A crack extending about 40 mm and running parallel to the clamps was then inserted from one side. Cycling of the test specimen continued while the growth of the crack was followed with travelling microscope. The tear energy was calculated from the well-established relationship for this type of specimen

$$T = Wh_o \qquad (10)$$

where $h_o$ is the unstrained height of the test specimen.

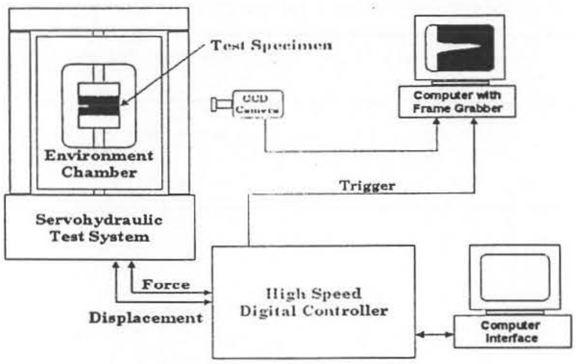


Figure 1: Schematic drawing showing the apparatus for rubber fatigue testing.

## 4. FINITE ELEMENT ANAYSIS

The finite element program employed was ABAQUS. Due to the symmetry, only a quarter of the thin sheet was modeled. The mesh used is shown in Figure 2. The 8-node, hybrid element (CPE8H) was used for modeling the hyperelastic material. The material properties were defined by Ogden strain energy coefficients, determined from experimental data.

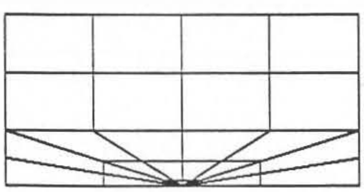

Figure 2: FEA mesh showing a quarter of a planar shear specimen with center surface crack.

## 5. RESULTS AND DISCUSSION

Estimating Tear Energy

The estimation of tear energy ($T$) requires knowledge of strain energy density ($W$), which is normally made by integrating the force/displacement curve during the loading part and divided by the effective volume of the specimen. This work is somehow complicate since the non-linear force-displacement variation of rubber materials. A more accurate estimation of $W$ was made using finite element method. Figure 3 illustrates the crack profile at a range of tensions, and Figure 4 shows the strain energy density calculated using FEA.

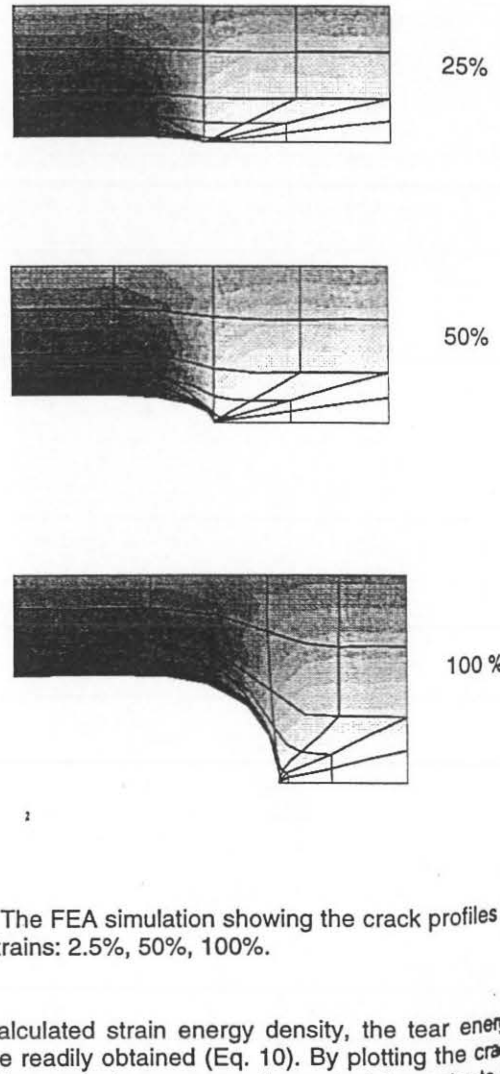


Figure 3: The FEA simulation showing the crack profiles at varying strains: 2.5%, 50%, 100%.

Having calculated strain energy density, the tear energy ($T$) can be readily obtained (Eq. 10). By plotting the crack growth rate versus tear energy, the material constants A, $T_o$, B, β are thus estimated. Figure 5 illustrates an example, from which the constants $A$ and $T_o$ are derived.

Substituting those constants into Eqns.8 and 9, the fatigue life, N, can be estimated, corresponding to the intermediate and high strain fatigue stage, respectively.

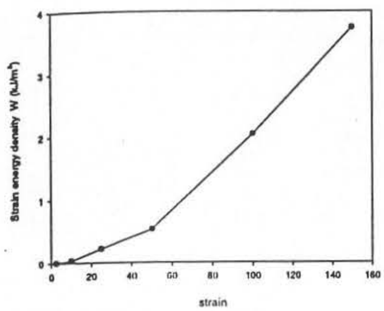


Figure 4: Strain energy density (W) versus strain calculated using FEA

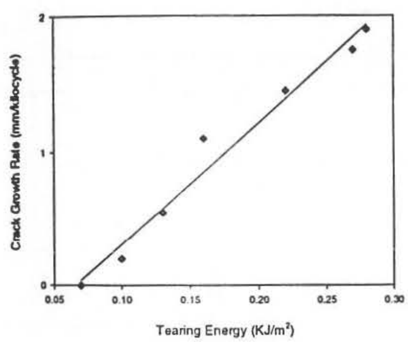


Figure 5: The typical curve of crack growth characteristics of filled natural rubber used for estimating materials constants A and $T_0$.

## 6. CONCLUSIONS

The work described has shown that a fracture mechanics approach based on the strain energy release rate can be used successfully to predict the fatigue life of rubber components. By the use of finite element analysis, the strain energy density, crack growth length, tear energy, etc. can be accurately estimated. The current approach has been found to be useful in tackling real service problems for rubber materials.

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