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PROPAGATION OF MULTIPLE ENDED FATIGUE CRACKS IN HYBRID BODIES

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INTRODUCTION

The reliability of structures subjected to cyclic loading may be strongly influenced by propagation of multiple ended fatigue cracks starting from initial defects smaller than those detected by inspection methods. An understanding of crack growth interaction can lead to a prediction of the useful life of the structure during which one of the subcritical cracks propagates to the critical size. The cracks interaction problem was investigated by the author during recent years using the coupled specimens model, see Figure 1 and references [1, 2, 3]. The correspondence of several test results and theoretical predictions in case of homogeneous coupled specimens allowed to propose a formulation of cracks interaction principle, see reference [4], based on the maximum elastic energy release rate.

The unsatisfactory application of the above mentioned principle to coupled specimens from different steel grades turned the attention to the investigation of coupled *hybrid* specimens. The purpose of this paper is to provide information about the results of recent theoretical as well as experimental investigation of fatigue cracks interaction in hybrid bodies [5].

PROBLEMS INVOLVED

Fatigue cracks are often multiple ended or the shape of the crack front is very intricate. Each crack tip (or each element of the crack front) may propagate in a region of different material and different applied and residual stresses, etc. This problem has not yet been extensively treated by the fracture mechanics analysis.

The difficulties related to the definition of the stress intensity factor and plastic zone along the crack front as well as the problems involved in the experimental part of the investigation required to introduce the coupled specimens model in order to study the interaction of fatigue cracks with respect to different plastification of individual specimens near the crack tips.

HYBRID COUPLED SPECIMENS

The prediction of the interaction curve for two coupled hybrid specimens (e.g., steel grades A 514 and A 36) was based on the following formulation.

The interaction of multiple ended fatigue cracks corresponds to the path of the maximum release rate of the total energy (elastic strain energy

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related to the extension of the crack, and plastic energy related to the extension of the plastic zone) and depends on the loading history, elastic-plastic distribution of the stresses in the body, and the mechanism of the propagation of fatigue cracks.

For two compact tension specimens coupled together using common pins, see Figure 1, the total applied force P is distributed to individual specimens.

$$P = P_1 + P_2$$

The compatibility conditions may be expressed using a simplified relationship for the displacement,

$$P_1 \cdot C_2 + v_{pl,1} = P_2 \cdot C_2 + v_{pl,2}$$

where C_1, C_2 are compliances, and $v_{pl,1}$ and $v_{pl,2}$ are the plastic components of the displacements as shown in Figure 2 (depending on K_{max}, crack lengths, yield strengths of materials, history of loading, etc.)

Due to extension of the crack by da, the energy released per unit of new crack surface is defined by the equation:

$$G = G_{el} + G_{pl} = 0.5.P^2 \cdot \frac{\partial c}{\partial a} + P \cdot \frac{\partial v_{pl}}{\partial a} .$$

The energy released per unit of the new crack surface per cycle for two coupled specimens is

$$GN = \sum_{i=1}^{2} \left[\left(0.5.P_i^2 \cdot \frac{\partial c_i}{\partial a_i} + P_i \cdot \frac{\partial v_{pl,i}}{\partial a_i}\right)\frac{da_i}{dn}\right]$$

where n is number of cycles. A schematic demonstration of the released energy is shown on Figure 3. In order to predict the interaction curve $f(a_1, a_2)$ an incremental method and computer have been used.

The Figures 4, 5 and 6 demonstrate the result of the experimental investigation of two coupled specimens, (three different alternatives). The theoretical aspects of the work are the subject of further investigations.

CONCLUSIONS

The paper describes briefly the results of an investigation of the effect of released plastic energy on the interaction of fatigue cracks. An interaction law has been proposed based on the maximum energy release rate principle. Coupled compact tension specimens are well suited to study the fatigue crack interaction in hybrid bodies with a wide variety of test variables.

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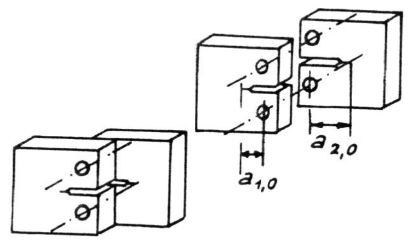

Figure 1 Set-Up of the Coupled Specimens Test. $a_{1,o}$ and $a_{2,o}$ are the lengths of the initial fatigue cracks.

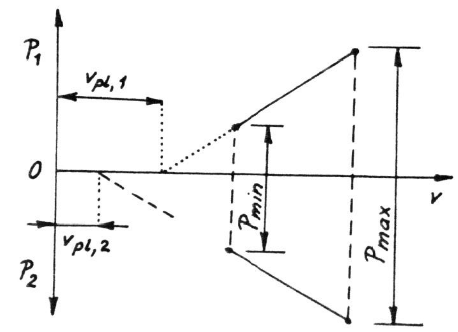

Figure 2 Distribution of the Force P_{max} and P_{min}. P_1 and P_2 are the components of the total force P. $v_{pl,1}$ and $v_{pl,2}$ are the permanent plastic deformations.

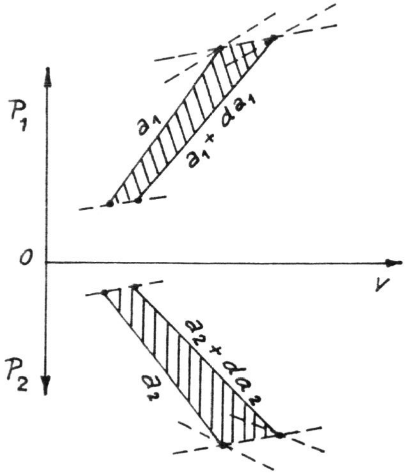

Figure 3 Energy Released in Two Coupled Specimens after Extension of Cracks a_1, a_2 by da_1 and da_2.

The marked areas correspond to the sum of the released elastic and plastic energies.

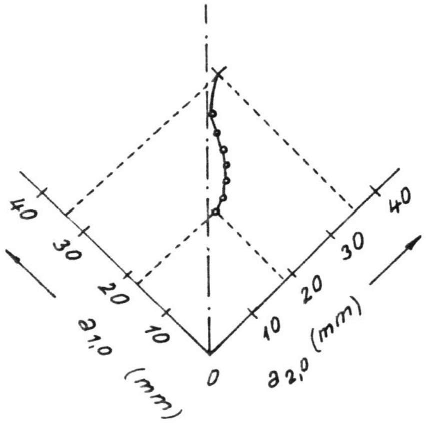

Figure 4 Experimental Result of Interaction Test.

Specimen 1 - Steel Grade A 514
Specimen 2 - Steel Grade A 36
(Hybrid Specimens)

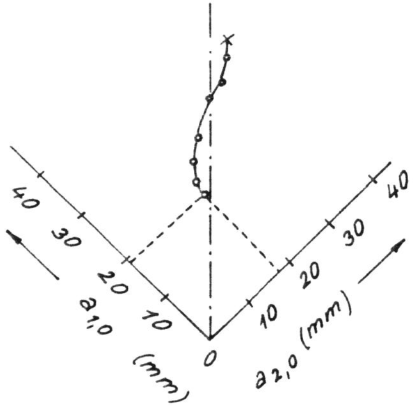

Figure 5 Experimental Results of Interaction Test.

Specimen 1 - Steel Grade A 36
Specimen 2 - Steel Grade A 514
(Hybrid Specimens)

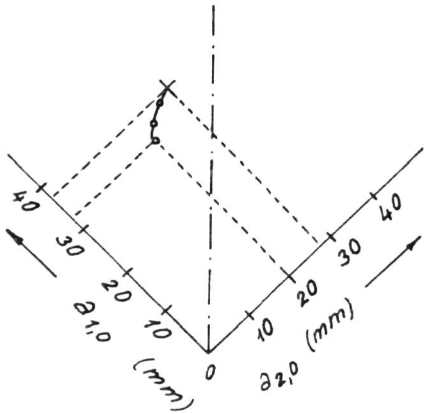

Figure 6 Experimental Results of Interaction Test.

Specimens 1 and 2 - Steel Grade A 36
(Homogeneous Specimens)