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The application of small overloads for fractography of small fatigue cracks initiated under constant-amplitude loading

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ABSTRACT

Fatigue crack initiation and crack growth are relevant issues for various structures. Initially small fatigue cracks usually are a part-through crack. The growth rate is small and the initial crack growth life covers a significant part of the fatigue life. Prediction on crack growth of part-through cracks under constant-amplitude (CA) loading is still difficult. Experimental verification occurs by fractographic examination. It requires marker load cycles inserted between the CA cycles to delineate the shape of the crack front. In the present investigation it is proposed to adopt small overloads for this purpose. This can introduce crack growth delays. However, it may be insignificant for small OL's and large blocks of the CA baseline cycles. Furthermore, OL's should produce striations which are more easily detected in the electron microscope. These questions are the major topic of the present investigation. Crack growth tests are carried out on specimens of aerospace aluminium alloys with different marker load sequences. Crack fronts and crack growth rates of small part-through cracks at the edge of a tapered hole in a thick plate specimens are obtained. At the grain boundaries a chaotic crack surface is observed associated with different crystallographic orientations of the adjacent grains. The analysis of this issue has led to the conclusion that 2-dimensional models for crack extension in a load cycle along the entire crack front is unrealistic. It is a 3-dimensional phenomenon.

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1. Introduction

Fatigue of various structures still remains to be a practical problem, for instance for aircraft, cars, cranes, bridges, offshore structures, etc. It is associated with new types of structures, desirable weight reductions of the structure, new production techniques and new materials. Safety and economic arguments are important, especially in view of a more intensive and longer utilization of structures in service. As a consequence one thing does not change. There is still a risk of fatigue crack initiation and subsequent propagation to failure in service. If this can occur damage tolerance of the structure is a relevant issue. If a fatigue crack is initiated the question is how fast the crack propagation occurs. In general the initial growth is relatively slow. As a consequence a large part of the crack propagation life is spent when the crack is still rather small, see Fig. 1. Usually a small crack is still a part-through crack. Predictions on the propagation of such cracks are possible. However, it raises more questions than the simple propagation of a through the thickness crack with a straight crack front perpendicular to the material surface.

Prediction methods for part-through cracks should be validated by fractographic observations on the fatigue fracture surface. For fatigue under variable-amplitude loading crack front bands are usually observed on fracture surfaces in several metallic materials. Furthermore, special marker loads can be introduced in fatigue tests for quantitative fractography of the fatigue fractures surface. Extensive and systematic research was published by Barter, Molent and Wanhill [1]. However, the problem is different for fatigue cracks obtained under constant-amplitude (CA) loading. Visible crack front bands are not introduced CA loading. In the scanning electron microscope (SEM) striations can be observed which are corresponding with the individual load cycles. Crack growth rates can then be obtained in μm per cycle. However, the geometry of the crack front cannot be ascertained from the SEM observations. In several investigation the problem to visualize crack fronts obtained under CA loading was explored by introducing marker load cycles between the CA baseline cycles. Of course it is desirable that the marker load cycles should have a negligible effect on the fatigue crack propagation during the baseline cycles. Crack growth retardation or acceleration should be avoided. As a consequence of this restriction it was supposed in the literature that S_{max} and S_{min} of the marker load cycles should stay within the range of these values of the CA baseline cycles. Marker bands by introducing blocks

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Nomenclature

a	crack length	S_{max}	maximum stress of baseline cycles
CA	constant amplitude	S_{min}	minimum stress of baseline cycles
kc	kilocycles	S_{OL}	maximum stress of OL cycles
OL	overload	UL	underload
SEM	scanning electron microscope	VA	variable amplitude

of small load cycles have been used for this purpose. Perhaps it did not affect crack growth during the baseline cycles, but it contributes to crack extension which is also undesirable. A sophisticated marker load spectrum was introduced by Piascik and Willard [2], see Fig. 2. The Piascik marker loads were used in two PhD projects in Delft, by Fawaz [3] and by De Rijck [4]. De Rijck has made numerous SEM-pictures on 2024-T3 specimens with countersunk holes of riveted lap joints in order to study fatigue crack fronts of part-through cracks. An example is shown in Fig. 3a. More clearly visible marker load striations were obtained by Fawaz et al. [5] on a 7075-T6 specimen, see Fig. 3b.

De Rijck [4] has made SEM-pictures on a large number of specimens which allowed a reconstruction how the fatigue crack growth occurred. An example is shown in Fig. 4. It was a painstaking and a considerably time-consuming work. This practical problem has stimulated the idea that other types of marker load spectra should be adopted for creating marker-load striations which could be observed more easily in the SEM. In the present investigation marker loads which slightly exceed S_{max} of the baseline cycles are considered for this purpose. It is well known that overloads (OL) can lead to crack growth retardation during the following CA baseline cycles. However, this effect may be relatively small if the stress level of the OL does exceed the S_{max}-value of the baseline cycles with a small margin only. Moreover, a possible delaying effect can be made relatively small if large numbers of baseline cycles are applied between periodically applied OL cycles. The application of small OL's for obtaining useful marker-load striations was already proposed in a previous document [6].

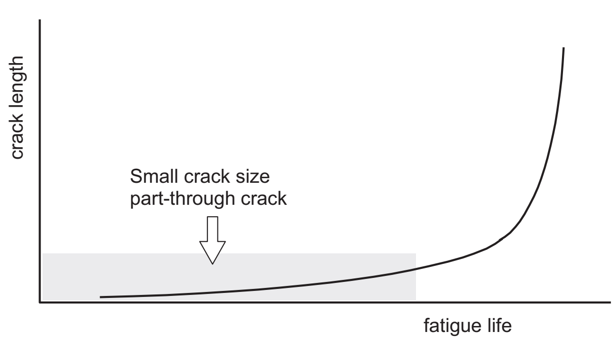

Fig. 1. A large part of the fatigue life is covered by fatigue crack growth of a small crack, usually a part-through crack.

The purpose of the present investigation is to explore the usefulness of load spectra consisting of large numbers of baseline cycles with various types of OL's programs. It has been tried to ascertain crack front shapes of small part-through cracks. The experiments are limited to specimens of aluminium alloys used in aircraft structures. Some previous work on marking fatigue fracture surface is discussed first in Section 2. It is followed by describing the marker load histories explored in the present investigation in Section 3. Crack growth experiments and fractographic observations are presented in Section 4. Crack front shapes of small part-through cracks near tapered holes are described in Section 5. The main observations and conclusions are summarized in the last section of the paper, Section 6.

It may be repeated here that results of the present investigation should be considered as a tool for fractographic SEM analysis of fatigue fracture surfaces obtained under CA-loading. But at the same time it has also revealed some understanding about the variation of the fatigue crack extension mechanism along the crack front of a fatigue crack.

2. Some previous work on marking the fracture surface of fatigue cracks

Two older investigations are briefly summarized. In both investigations a large number of small cycles was introduced between the CA baseline cycles. The purpose was to create visible bands on the fatigue fracture surface. The bands show the progression of the crack front. This is illustrated in Figs. 5 and 6. Fig. 5 shows

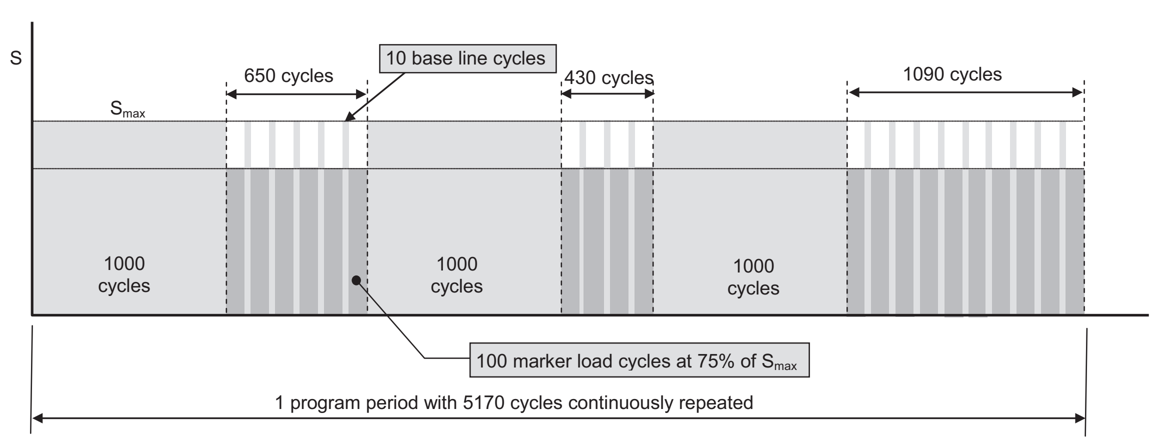

Fig. 2. The marker load spectrum proposed by Piascik and Willard [2].

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