THE ACCELERATED ΔK FATIGUE CRACK GROWTH TEST ON AA 5083-H321 AND SIMILITUDE VALIDATION.

Jan Zuidema[1], Saskia de Vries[2] and Adirakhmantyo Hascaryantono[1]

[1] Laboratory of Materials Science, Technical University of Delft, Rotterdamseweg 137,
2628 AL, Delft, The Netherlands
[2] Netherlands Institute for Metals Research, Rotterdamseweg 137,
2628 AL, Delft, The Netherlands, e-mail to: saskia.devries@tnw.tudelft.nl

ABSTRACT.

The Accelerated ΔK Fatigue Crack Growth Test is a newly developed testing method for fatigue crack growth experiments, which is introduced to avoid long testing times at low frequencies. During the test an increasing load is applied over a small range of crack growth. Therefore the response of the same ΔK range as in a constant amplitude test is enabled, but in a smaller amount of time. Another advantage of this new method is that more tests with a complete ΔK range can be performed on one specimen. The gain in time, as well as the limits to this, was shown by experiments on aluminium alloy AA 5083. Tests in both lab air and artificial seawater are performed at two stress ratios, of respectively R=0.1 and R=0.5. For the crack growth in air frequencies of 10 Hz and 0.1 Hz are used. There was seen little influence of the frequency on fatigue crack growth in this material in air. The accelerated ΔK crack growth test was validated with respect to the similitude between accelerated tests and normal constant amplitude tests, for which some criteria have been developed.

INTRODUCTION.

The research described in this paper is part of a larger research aimed at corrosion fatigue of welded AA5083 ship building plate material. In this research the mechanisms of enhanced fatigue crack growth rates in seawater compared with growth rates in air and vacuum will be investigated. The fatigue crack growth in the weld, the heat affected zone and in the plain plate material will be measured. Criteria are developed for characterising the micromechanisms that are responsible for the (enhanced) crack growth rates. The accelerated ΔK fatigue crack growth test will be applied in order to shorten the corrosion fatigue crack growth testing times at lower frequencies. In this paper the limits of the accelerated test will be investigated with respect to the similitude and to the accuracy imposed by the crack length measuring system. Experiments with different dK/da have been performed in order to find those limits. The time gain compared with a constant amplitude test is both measured and calculated. Further a few initial constant amplitude fatigue crack growth tests on AA5083 in air are shown, for which a da/dN-ΔK_{eff} relation was found.

Because corrosion fatigue crack growth results from a combination of the time-depending process of corrosion and the cycle-dependent process of fatigue, the cyclic frequency is an important and interesting parameter to investigate. When tests are performed at low frequencies, however, extended testing times result in an enhanced risk of premature failure by any disturbances during these long testing times in for example the test equipment. With the introduction of the accelerated ΔK crack growth test these risks are strongly reduced.

Usually, to avoid long testing times in corrosion fatigue crack growth, the widely used constant amplitude test is executed at higher frequencies, while only some parts of the crack growth are performed at lower frequencies. The disadvantage of this method is that not the response of a continuous ΔK range is measured. In a stress corrosion sensitive material like AA 5083 it is possible to miss the strong increase in crack growth rate due to stress corrosion. The accelerated ΔK crack growth test applies an increasing load over a small range of crack growth. Therefore the measurement of the same ΔK range as in a constant amplitude test is enabled, but in a smaller amount of time. Another advantage of this new method is that more tests with a complete ΔK range can be performed on one specimen.

PRINCIPLE OF THE ACCELERATED ΔK FATIGUE CRACK GROWTH TEST.

The principle of the test is shown in figure 1. In the figure the maximum load is shown as function of the crack length. Also the maximum stress intensity is given. Two tests are compared, the normally used constant load amplitude test and the newly developed accelerated test. The load for the accelerated test is chosen to increase linearly in such a way that both the initial ΔK and the ΔK at the end of crack growth for the accelerated test and for the constant amplitude type of test are the same. Thus the same ΔK range is covered in both tests, only the crack length range is different, resulting in a different dK/da. For example if a crack length range of 5 or 10 mm is used the time gain of the accelarated test over the normal constant amplitude test with crack growth from 5 to 40 mm is with a factor of 7.48 or 3.62 respectively. This result is calculated by integration of the crack growth formula, equation 2, for ΔP=30 kN and R=0.1. In practice a time gain of a factor 7.06 was found for a 5 mm crack length range.

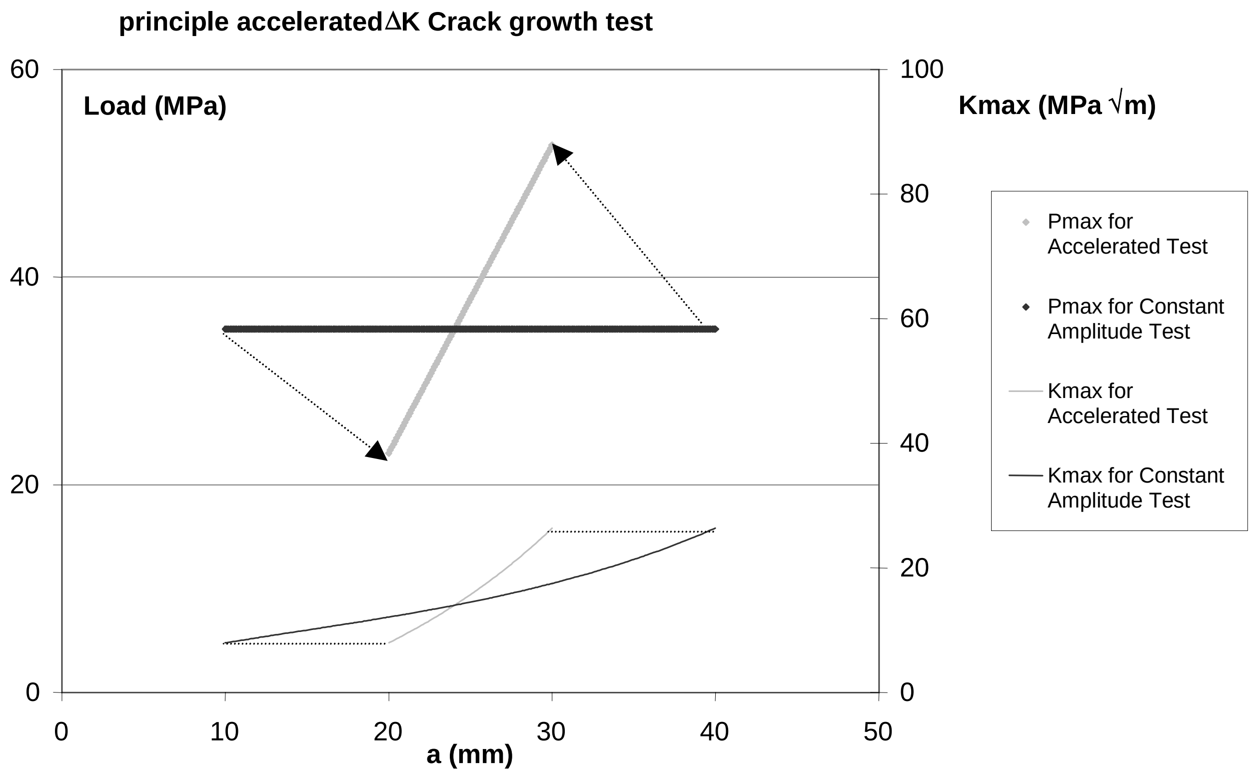

FIGURE 1. Maximum load and stress intensity against crack length for a constant amplitude test and an accelerated ΔK test.

In figure 2 two accelerated tests, with crack length ranges of 5 and 10 mm respectively, are shown to be performed on a CCT-specimen with a width of 100 mm. In order to avoid overload effects after the accelerated test the decrease in ΔK is performed according to the ASTM-standard for a ΔK threshold test [1]:

$$\Delta K = \Delta K_0 \cdot e^{c \cdot (a - a_0)} \quad (1)$$

with a c-value ≥ –0.08. The decreasing is performed until ΔK has reached the original start value of ΔK again. Then the second accelerated test is started.

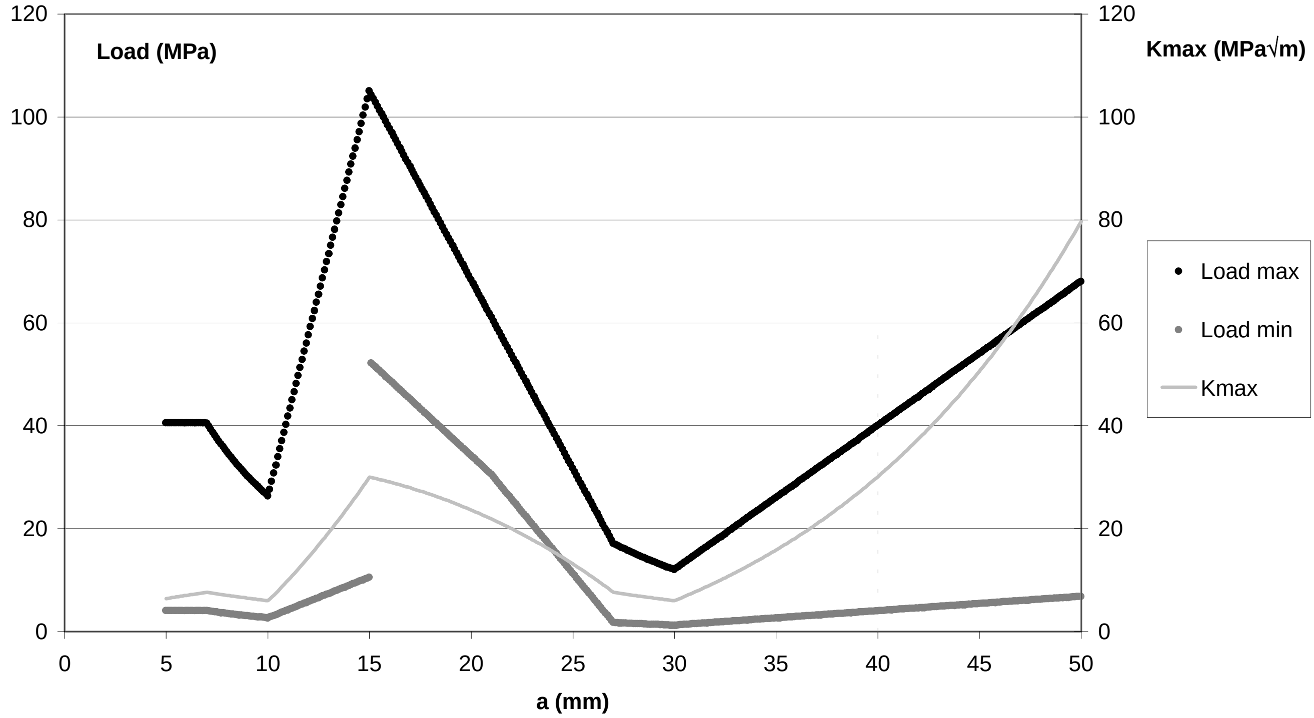

FIGURE 2. Maximum load and stress intensity against crack length for an accelerated ΔK test with two load sequences over a crack range of 5 mm and 10 mm respectivily.

SIMILITUDE.

Similitude between two events is reached when similar causes have the same consequences. Applied on fatigue crack growth similitude this means that the same ΔK will result in the same da/dN. When this latter statement is true, then the use of ΔK as a similitude parameter is validated, e.g. fatigue crack growth rates in real constructions are the same as in a standard specimen by the application of the same ΔK. In this research it was investigated whether the same ΔK, applied in the accelerated test and in the constant amplitude test results in the same response, i.e. the same da/dN. This was determined by comparing the complete da/dN-ΔK curves for both type of tests. The amount of correlation of the curves found in both tests is a measure for the similitude of the accelerated test. Another possible similitude parameter is the crack growth rate at which shear lips start [2]. This is at da/dN = 10^{-7} m/cycle in air, independent of the load ratio (and hence the K_{max}-value), see figure 3. The amount of deviation of this value in case of the accelerated test is a measure for the lack of similitude.

EXPERIMENTAL DETAILS.

The chemical composition of the material is as shown in table 1:

TABLE 1 CHEMICAL COMPOSITION OF AA 5083

Al	Mg	Mn	Si	Fe	Cr	Cu	Zn	Ti
94.8 %	4.5 %	0.65 %	0.26 %	0.22 %	0.09 %	0.09 %	0.06 %	0.03 %

The center-cracked specimens of AA-5083 have a length of 340 mm, a width of 100 mm and a thickness of 8 mm. The fatigue crack growth experiments are performed on a computer-controlled servohydraulic fatigue machine. The loading program is offered to the machine in the form of a load table where the maximum load, the minimum load, the crack length and the frequency are specified. The table is divided into steps of 0.1 mm crack length. Per crack length step the loads and frequency can be varied. The crack length is measured using a pulsed direct current potential drop measurement system.

THE ACCELERATED ΔK CRACK GROWTH RESULTS.

It is found that the similitude between constant amplitude tests and the accelerated tests is quite good. The da/dN–ΔK results for both types of test have the same slope on logarithmic scale, and the transition in the slope, which is caused by the start of the shear lips, occurs at the same crack growth rate (see figure 3). The accelerated tests were applied on crack length ranges of 5 mm, 8 mm and 10 mm respectively. Whether this loading sequence was executed at the beginning of crack growth or at the end, didn't seem to be of any significant influence. This indicates that, within the limits of $a/W < 0.8$, the exact position of the crack length range for the accellerated test can be chosen freely.

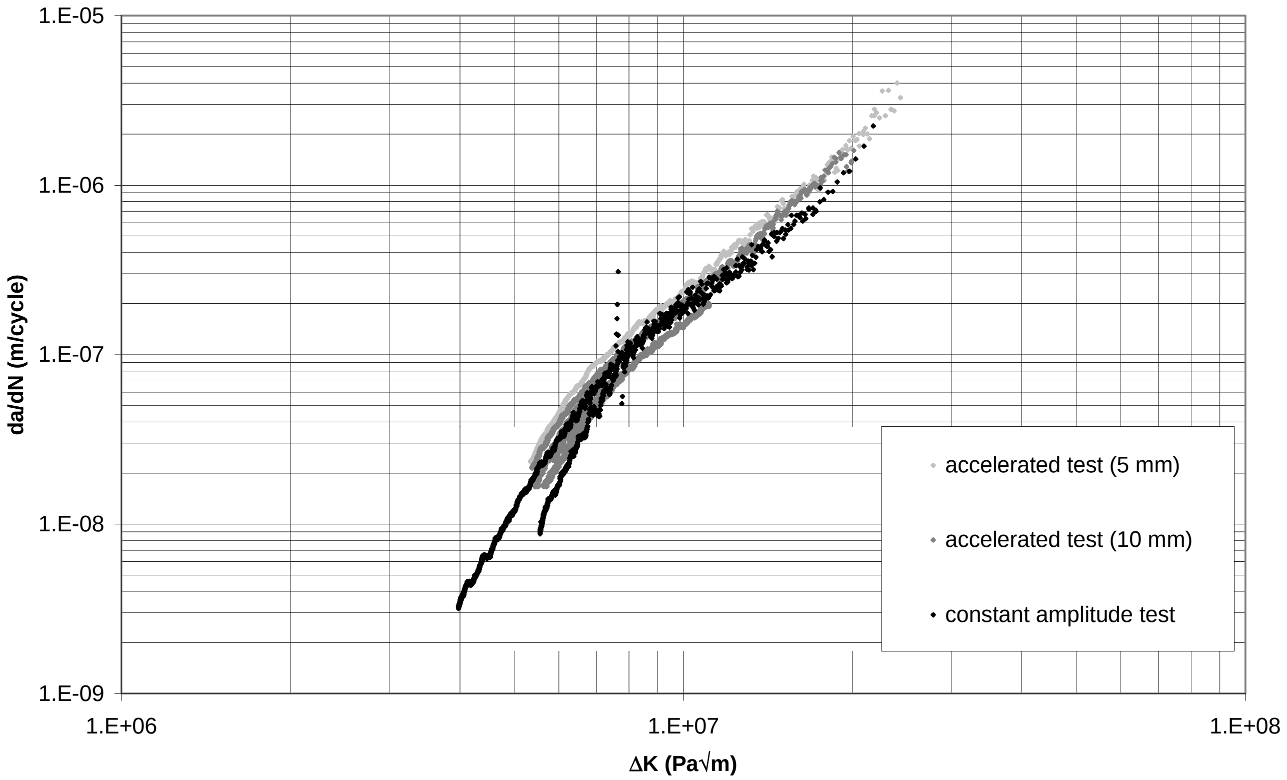

FIGURE 3. da/dN-ΔK curves of the same material obtained through the constant amplitude test and the accelerated ΔK fatigue crack growth test respectively.

RESULTS OF FATIGUE CRACK GROWTH TESTS IN AIR.

The results from constant load amplitude tests on the material AA 5083 in air are shown in figure 4. It can be noticed that at $da/dN = 10^{-7}$ m/cycle, the crack growth rates slightly change in slope. Observations of the different fracture surfaces revealed that at the corresponding ΔK-values the crack appearance changed from flat to slant. The change in slope is possibly caused by a different crack closure situation due to the growing shear lips. As the start of shear lips corresponds with different K_{max}-values (K_{max} = 8.8 and 13 respectivily for R = 0.1 and 0.5), it can be concluded from these observations that it depends mostly on the crack growth rate. This is in agreement with observations by Zuidema on AA 2024 [2]. Figure 4 also shows that there is a difference in initial crack growth rate for both stress ratios.

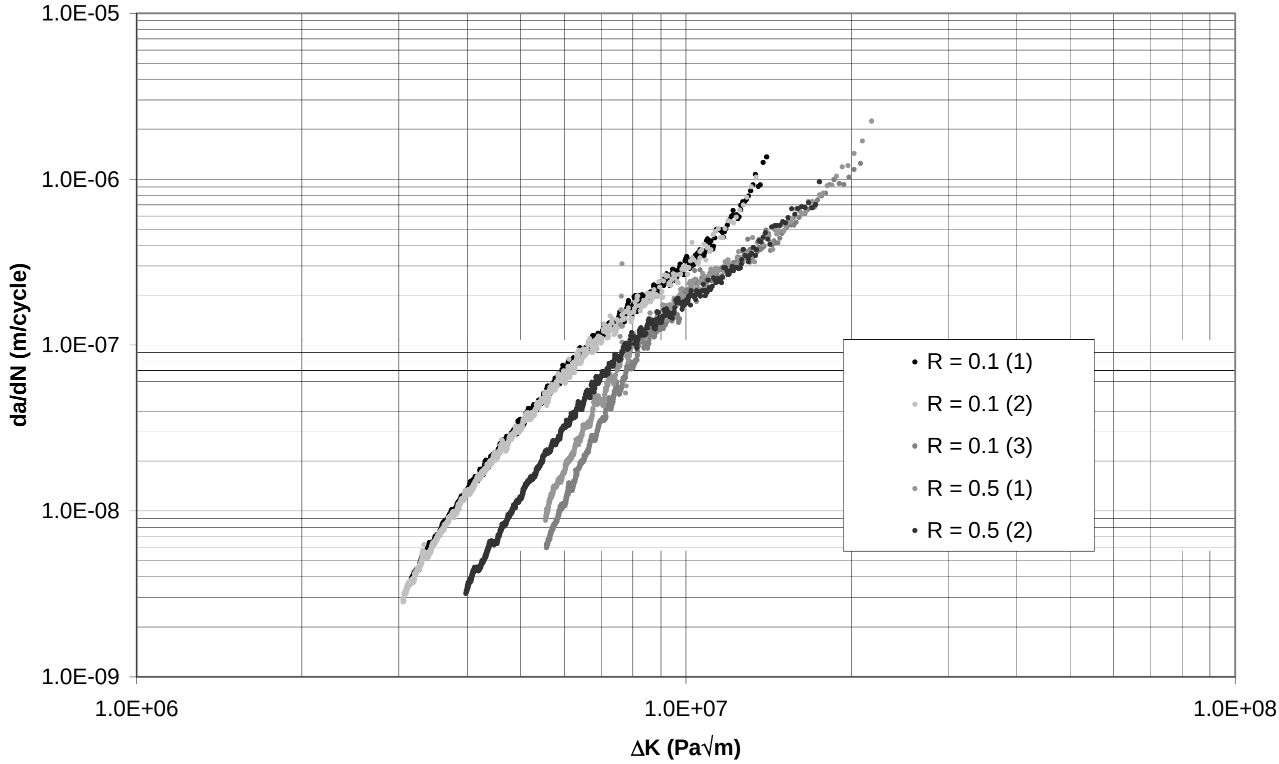

FIGURE 4. da/dN-ΔK curves of the AA 5083 obtained through the constant amplitude test at load ratios of 0.1 and 0.5.

One constant load amplitude test (*R = 0.1 (3)* in figure 4) was performed at two different frequencies. A frequency of 10 Hz was used for the main part of the test, but the frequency was changed to 0.1 Hz for short periods. Only little influence of the cyclic frequency on the crack growth rates was seen.

CRACK CLOSURE RELATION FOR AA 5083.

Crack closure is not directly measured, but is found by correlating the 4 constant amplitude da/dN versus ΔK results, two tests at R=0.1 and two at R=0.5, see figure 4. A linear crack closure function U=a+bR is found by taking all combinations of a and b and calculating $\Delta K_{eff}=U\Delta K$. A power formula of type $da/dN=c\ \Delta K_{eff}^{m}$ is linearised by taking the logarithms on both sides of the equality sign. The combination of a and b with a maximum value of the correlation coefficient is considered the best combination. The combination is normalized, i.e. the coefficients are divided by their sum, by demanding that a+b=1, meaning that U=1 if R=1. The best crack closure formula found in this way for this material is U=0.64+0.36R. For comparison also the best quadratic closure function $U=a+bR+cR^2$ was calculated in the same way. However the correlation was hardly any better so the linear U formula will be used. The formula for the best power fit is given in equation 2:

$$da/dN=1.2*10^{-3}\ \Delta K_{eff}^{2.6} \qquad (2)$$

DISCUSSION AND CONCLUSIONS

In the experiments it is proved that the accelerated ΔK crack growth test is a valid method for obtaining fatigue data. There are some issues however that need to be discussed here.
Firstly, the part of the test where the load is decreased needs special attention. Of course, to make sure that no effect is noticeable from the formerly performed part on the second loading sequence a long enough crack length range must be bridged by the decreasing part of the test. This implies that a large number of cycles is spend in this decreasing part of the load. However, this can be done at higher

frequencies, because the data will only be obtained from the part where the load was increased. Therefore the time gain taken over the whole test is still enormous.

Secondly, the application of high levels of ΔK already in the first part of the test, result in early formation of shear lips. When the load is decreased this can cause enhanced crack closure, due to the big hump and the steep slopes left by the shear lips. This has in some events even led to complete crack arrest (figure 5). Even when this only occurs on one side of the specimen, an asymmetrical crack will be the result, and the test will not be valid. This should be avoided, especially when more then one test is performed on one specimen by means of the accelerated crack growth test.

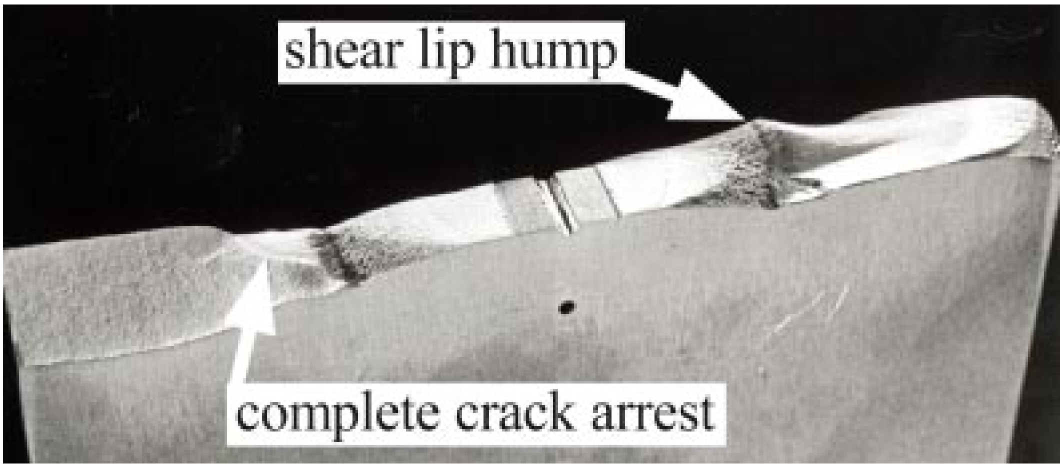

FIGURE 5. Fracture surface of a specimen just after the accelerated ΔK test and the crack closure marks on the hump caused by the shear lip.

Also a completely flat crack front needs to be acquired, before the second loading sequence can begin. This is necessary to ensure that the same fracture mechanism and the same loading mode is applicable for both sequences. To guarantee that the crack will continue to grow after the first loading sequence and that no asymmetry in crack length on both sides of the specimen will occur, the stress ratio can be raised to higher levels during the decreasing part of the test. This can be seen in figure 2, where both the maximum and minimum load is given as a function of the crack length. By raising the R, the crack will be open during a larger part of the cycle and the shear lip hump, which is formed at the end of the first loading sequence (figure 5), causes a lesser enhanced crack closure effect. Hence, continuous crack growth without asymmetry is ensured.

Finally, it needs to be said that the crack length measuring system influences the limits of the new test method. The accuracy of the measuring system, which in this case was a pulsed direct current potential drop system, is important when the load increase is controlled by the crack length. This implies that an accuracy of the measurement equipment is needed that is at least an order smaller than the step size that controls the load. Otherwise the load increase would be applied at an incorrect crack length value, hence invalidating the test.

REFERENCES

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