AN AUTOMATED METHOD OF COMPUTER-CONTROLLED HIGH-CYCLE FATIGUE CRACK GROWTH TESTING

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The experience of the author with the automation of the fatigue crack growth experiment is described. The automated method of computer-controlled fatigue crack growth testing was applied to determine crack growth rate in near - threshold region. In order to get a conservative value of the threshold, Kmax constant ΔK-decreasing test was utilized.

INTRODUCTION

The methods for the prediction of the fatigue life of the structures subjected to a cyclic load require the konwledge of fatigue crack growth from the threshold stress intensity range to the instability point of fast fracture. For generating fatigue crack growth data in the fatigue threshold region, ΔK-decreasing R constant procedure was recommended by Saxena et al (1). According to this method, fractional change in the plastic zone size remains constant with increase in a. However, it was observed that this test procedure may well introduce abnormally high closure levels (overload effect) and nonconservative values of ΔK_{th} (Hertzberg et al (2), Suresh and Ritchie (3)). High rate of load shedding will result in premature crack arrest and an apparently higher thershold value from enhanced plasticity-induced closure. Too slow rate of load shedding causes an apparently higher ΔK_{th} from enhanced oxide-induced closure. For this reason, some authors ((2), Castro et al (4))have suggested K_{max} constant ΔK-decreasing test method for the determination of a fatigue threshold. Herman et al (5) have shown that K_{max} constant ΔK-decreasing test results can account for short-long crack data discrepancies. K_{max} constant ΔK-decreasing method was utilized in the experiment described in this paper.

HARDWARE SYSTEM DESCRIPTION

The test was performed using MTS servohydraulic test machine. The computer interfaced function generator allows computer control of

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the test conditions applied by the test machine. Also added to the system are two precision voltmeters connected to the load and clip gage tranducer conditioner outputs. These units act as A/D inputs to the computer allowing high precision measurement of the specimen compliance and crack length. The minicomputer PDP 11 was used for the test control.

SOFTWARE SYSTEM DESCRIPTION AND TEST PROCEDURE

To generate fatigue crack growth data for steel A588, CT specimen was used in this work. The crack plane orientation is L-T. The machine is in load control. At the beginning of the test significant data should be typed into the program. At first, calibration factors for load and COD which show the relationship between voltage and physical units are typed. Then, material properties and specimen dimensions are typed: σ_{ys}, E, W, B, a_o. The following options are available for fatigue testing using software and test system: ΔK constant, ΔP constant, ΔK-decreasing R constant, ΔK-decreasing K_{max} constant. After reaching the reccomended size of the fatigue precrack, the test for generating fatigue crack growth data begins in K_{max} constant ΔK-decreasing mode (Fig. 1). The load levels are calculated using the following equations acco- rding to ASTM Standard Test Method for Measurement of Fatigue Crack Growth Rates (E647-86a):

(1)

$$\Delta K = \Delta K_o \exp\left[C(a - a_o)\right] \quad (2)$$

$$\Delta P = BW^{0.5}\Delta K / f_1(a/W) \quad (3)$$

$$P_{max} = \Delta P/(1-R)\ ;\ P_{min} = P_{max}R$$

$$f_1(a/W) = (2+a/W)\left[0.886 + 4.64(a/W) - 13.32(a/W)^2 + 14.72(a/W)^3 - 5.6(a/W)^4\right] / \left[1-(a/W)\right]^{1.5} \quad (4)$$

These calculations are performed after each, in advance chosen crack increment. The value of normalized gradient of stress intensity factor - C has not the same significance here as in ΔK - decreasing R constant mode, since overload effect is avoided. Based on these calculations the load signal is generated: wave form, frequency, maximum and minimum load. This value is compared with the measured value from the load cell. If a difference exists a load signal will be modified. A crack length is determined by using the compliance method. In order to perform this procedure, the program collects P and COD data from the load cell and clip gage. At first, the program determines the linear region of the load - versus - COD curve and then by the regression analysis the slope of this part of the curve. The following equations are then used to calculate the crack length (6):

$$a/W = C_o + C_1U_x + C_2U_x^2 + C_3U_x^3 + C_4U_x^4 + C_5U_x^5 \quad (5)$$

where U_x is a transfer function: (6)

$$U_x = \left[(EBV_x/P)^{0.5} + 1\right]^{-1}$$

C_i - polynomial coefficient used to calculate crack length

After each, in advance chosen measuring interval, the computer stores all the significant data in special files, in the first place: crack length, cycle number and stress intensity factor range . Some of the recorded P - COD data are shown in Fig. 2 . The number of the elapsed fatigue cycles was obtained from the time elapsed at the actual testing frequency. Crack length - versus - number of cycles data are shown in Fig. 3 . The seven - point incremental polynomial method was utilized to determine the fatigue crack growth rate from crack length versus number of cycles data . The result is shown in Fig. 4 . This program is capable to recognize one or more interruptions during the test (as shown in Fig.3) and process all data . The fatigue crack growth threshold was determined by using a linear regression of log da/dN versus log ΔK data between the growth rates of 10^{-9} and 10^{-10} m/cycle according to ASTM Standard Test Method for Measurement of Fatigue Crack Growth Rates E647-86a. The threshold value $\Delta K_{th}=3.83$ (MPa $\sqrt{m}$) is a calculated value of ΔK which corresponds to a growth rate of 10^{-10} m/cycle . Since closure effect was not noticed (see Fig . 2) during this test, it means that $\Delta K_{eff}=\Delta K$ and conservative equation for crack growth rate for region II was obtained by the regression analysis:

$$da/dN = 3.4 \times 10^{-12} (\Delta K)^{2.3} \quad (7)$$

The absence of closure effect in this test presumably could be attributed to the fact that appearance of crack closure is more pronounced at low R ratios and long crack lengths . In this test at long crack length, high R ratios are applied and in threshold region R=0.9 . An artificial level of crack closure caused by overload effect is avoided as well.

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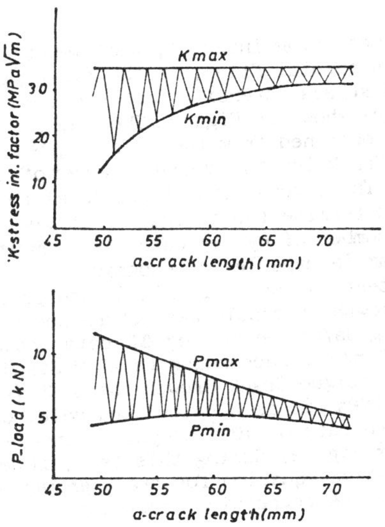

Figure 1 Constant K_{max} procedure

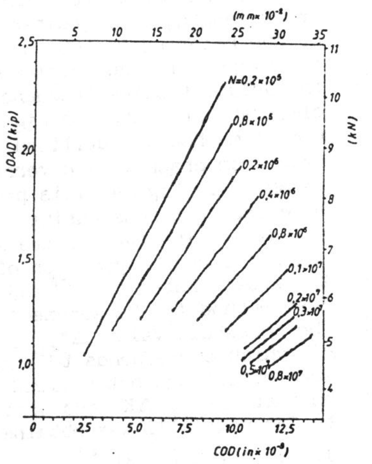

Figure 2 Load versus COD data

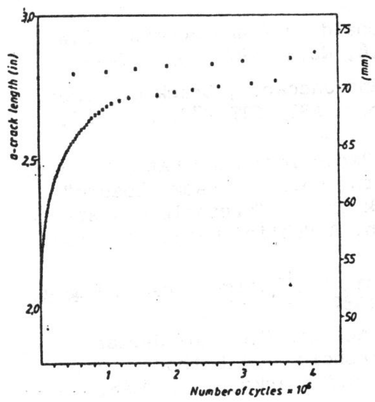

Figure 3 Crack length versus number of cycles data

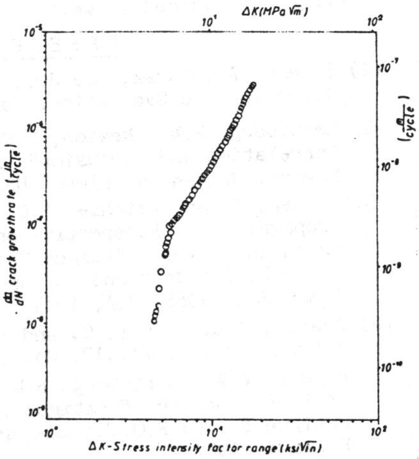

Figure 4 Fatigue crack growth rate data