CRACK TIP BEHAVIUOR UNDER DIFFERENT LOAD RATIO WITH CONSTANT K_{max}

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ABSTRACT

In this paper, fatigue crack growth rate (FCGR) analyses were conducted on compact specimens of an AISI 4340 alloy to study the behavior over a range in load ratios ($0.1 \leq R \leq 0.95$) and constant maximum stress intensity factor (K_{max}) condition. Previous study had indicated that high $R > 0.7$ and constant K_{max} test conditions near threshold conditions were suspected to be free crack-closure and that any differences were caused by K_{max} effects, from threshold to near fracture conditions. Cracks in high-cycle fatigue (HCF) components spend a large portion of their fatigue life near threshold conditions. In order to characterize the evolution of damage and crack propagation during these conditions, fatigue crack growth rate (FCGR) data at threshold and near-threshold conditions are essential in predicting service life and in determining the proper inspection intervals. Fatigue crack growth model, namely Forman were examined, this model implicit the effect of R ratio and ease of curve fitting to measured data. The Forman model may be suggested for use in critical applications in studying fatigue crack growth for different load ratios.

Keywords: Fatigue crack growth rate(FCGR), Crack closure, K_{max} effect, High-cycle fatigue (HCF)

INTRODUCTION

Cracks in high-cycle fatigue (HCF) components spend a large portion of their fatigue life near threshold conditions. In order to characterize the evolution of damage and crack propagation during these conditions, fatigue-crack-growth rate (FCGR) data at threshold and near-threshold conditions are essential in predicting service life and in determining the proper inspection intervals. Based on linear elastic fracture mechanics, FCG rate (da/dN) data are quantified in terms of the stress-intensity factor range ΔK, at a given load ratio (R = minimum to maximum load ratio). The relation between ΔK and da/dN was shown to be nearly linear on a log (ΔK) - log (da/dN) scale. The relationship becomes nonlinear when the crack approaches fracture [1] or when the FCG rate is very slow [2]. One of the significant mechanisms that influence crack-growth behavior is crack closure, which is partly caused by residual plastic deformations remaining in the wake of an advancing crack [3, 4], roughness of the crack surfaces [5], and debris created along the crack surfaces [6].

The discovery of the crack-closure mechanism and development of the crack-closure concept led to a better understanding of FCG behaviour, like the load-ratio (R) effect on crack growth. The crack-closure concept has been used to correlate crack-growth-rate data under constant-amplitude loading over a wide range in rates from threshold to fracture over a wide range in load ratios and load levels [7]. Difficulties have occurred in the threshold and near-threshold regimes using only plasticity-induced crack-closure modeling [8]. In the low rate system, at and near threshold conditions, roughness-induced crack closure (RICC) [9] and debris-induced crack closure (DICC) [10]. The crack-closure concept has not yet been able to correlate data in the threshold regime, either from load-reduction tests at constant R or constant K_{max} tests.

Variations in the threshold and near-threshold behavior with load ratio cannot be explained from PICC alone, but RICC and DICC mechanisms may be needed to correlate these data. The constant Kmax test procedure [11] also produces what has been referred to as the ‘‘Kmax effect”, in that, lower thresholds are obtained using higher K_{max} values [12]. Compared with the constant R test method, constant Kmax tests gradually decrease P_{max} and increase P_{min} to obtain a reduction in ΔK as the crack grows. One advantage of this programming test method is that it is commonly considered to produce crack-closure-free data ($R \geq 0.7$). But constant Kmax testing also produces data at variable load ratios (R) and fatigue crack growth thresholds at high load ratios (> 0.8). For steel alloys and larger Kmax values, more dimpling and tunneling on the fatigue surfaces were observed [13, 16], as the threshold was approached. This behavior indicated a change in the damage mechanism from classical fatigue-crack growth to more of a tensile fracture mode due to the K_{max} levels approaching the elastic fracture toughness. But extensive literature data reviewed by Vasudevan et al [14] and test data by Marci [15] on a wide variety of materials do not show the so-called K_{max} effect.

MATERIAL AND PROGRAMMING TEST PROCEDURE

Alloy steel are widely used in design of many engineering application, AISI 4340 has a favorable response to heat treatment (usually oil quenching followed by tempering). It also a good combination of ductility and strength when treated thusly and using many application such as; piston, pins, bearings, ordnance, gears, dies, pressure vessels. Chemical composition and mechanical properties are shown in Tables 1 and 2. The modeling and simulation are analyzed using GLYPH work software packages. Modeling of fatigue crack growth data has enhanced the ability to create damage tolerant design philosophies. Glyphwork , it is the special software for determine the crack initiation , propagation value with relationship number of cycle.

The Forman model was found to be the most appropriate model for the constant amplitude loading. Therefore, the Forman growth law implicitly models threshold and short cracks by applying a crack closure stress KCL expressed. The Forman equation is a modification of the Paris equation. Typical mean stress effects in the threshold region. The Forman growth law model is popular on account of its implicit modelling of R ratio effects and ease of curve fitting to measured data ,the onset of fast fracture and crack closure.

The number of cycles to failure is the fatigue life (N_f) and the form of cycles is illustrated in Figure 1. Most of time, the S-N fatigue determination is carried out through the use of fully reversed loading. This implies that loading is taking place about a zero mean stress.

In this analysis, the material of the shell ASTM A533 steel has been used , for which the chemical compositions at room temperatures are listed in Table 1.

The cyclic and cyclic properties are listed in Table2. In particular ,ASTM A533 is one such kind of steel which has applications in pressure vessels (ASTM standard V1.04). These steel types generally contain less than 0.25 Wt % C and are unresponsive to heat treatments intended to form martensite, as strengthening is accomplished by cold work. The typically have yield strength of 585 Mpa, tensile strength between 637 and 825 Mpa ,and ductility of 20-25 % Meanwhile , microstructure consists of ferrite and pearlite constituents. The data has been obtained from the tensile test machine in our lab.

Stress ratio has been Crack growth behaviour , especially at high and low da/ dN. At high ΔK, for example, increasing R leads to an increase in K_{max} with respect to ΔK , and thus enabling K_{max} to be near to k_{1c} . Cleavage and inter-granular cracking frequently observed at high ΔK are predominantly tensile stress controlled fracture modes which are introduced more frequently with the increase of K_{max} with R. that is , a variation in R can promote a change in the rate controlling fracture mode. There are a number of extra factors.

The majority of structures are subjected to VAL. During this type of loading ,various load interactions which may significantly alter the growth behaviour of a crack have been known to occur . The large effect of high loads on FCG has stimulated a lot of research , both experimental Investigation as well as analytical studies. The significance of crack tip plasticity was easily recognised and it obviously suggested that the plastic zone size must be important for crack growth retardation. The retardation of the growth of a through crack is dependent on the thickness and yield Stress of the material because the plastic zone size is determined by the state of stress (plane strain or plane stress or intermediate situations). This has been amply confirmed by the experimental results gathered. The promising application of the K- concept to predictions on fatigue crack growth under CAL was drastically upset by the first experiments with overloads (OLs) in the CAL test carried out.

RESULTS AND DISCUSSION

Fatigue crack growth (FCG) programming tests were conducted over a wide range in load-ratio conditions ($0.1 \leq R \leq 0.95$) and a constant K_{max} test. Fig 3. shows the test data, which generally ranged from threshold to near fracture. At high rates, the asymptote to fracture, as expected, was a function of the load ratio R. In this regime, the critical stress-intensity factor range at failure, ΔKc, is given by KIe (1 - R), where KIe is the elastic fracture toughness or maximum stress-intensity factor at failure. Thus, at higher R-values, a crack will grow to failure at lower values of ΔKc.

In the near-threshold regime, the R = 0.95 rates were slightly higher than the R = 0.9 rates at the same DK value. In the mid-rate regime, the R = 0.9 results gave slightly higher rates than the R = 0.7 results, but the R = 0.8 results agreed well with the R = 0.7 results.

The results from the low R (0.4 and 0.1) tests showed the usually parallel shift with load ratio. But at low rates, the R = 0.9 test data agreed well with the constant K_{max} test data at low rates, which had R-values ranging from 0.7 at the start of the test to 0.9 near threshold conditions.

The constant K_{max} test and most of the other tests had the same characteristic shape of the crack-growth-rate curve in the threshold regime, except the results from the R = 0.1 test.

Fig. 3 shows a comparison of test data generated at R = 0.1 and 0.7 using the load reduction method. This method is basically a K-reduction scheme to maintain a constant load ratio. However the load-reduction test method has been shown to produce higher thresholds and lower rates in the near-threshold regime than steady state constant-amplitude data on a wide variety of materials. In addition, the load-reduction test method produces fanning with the load ratio in the threshold regime for some materials. The results from the low R (0.7 and 0.1) tests show the usually parallel shift with load ratio. To generate constant load-ratio data in the threshold and near-threshold regimes. It has been shown that the test method induces a load-history effect, which may be caused by remote closure. Thus, the load-reduction test method does not, in general, produce constant-amplitude FCG data. Many well-known formulations for the effect of R-ratio have been proposed. Can these equations be used to calculate the crack growth life of components subjected to constant amplitude loading (CAL). Most mean stress effects on crack growth have been obtained for only positive stress ratios, i.e., $R \geq 0$. Fig. 4 shows the variation of the crack growth rate versus the corresponding crack length for different stress ratio for only positive values. The material displays significant R-ratio effect. With an identical stress intensity factor range, a higher R-ratio results in a higher crack growth rate. Although the threshold was not experimentally measured, the tendency indicates that the threshold value of the stress intensity factor range increases as the R-ratio decreases. It observed that the FCG affected by different stress ratios. The increasing of stress ratio which means increasing the mean stress has tendency to increase the crack growth rates.

CONCLUSION

Fatigue crack growth rate (FCGR) analysis were conducted on compact specimens of an AISI 4340 alloy to study the behavior over a wide range in load ratios ($0.1 \leq R \leq 0.95$) and constant maximum stress intensity factor (K_{max}) condition. During a test at a load ratio of 0.7, these results imply that the R = 0.7 programming test had a significant amount of rack closure as the threshold condition was approached. While the R = 0.9 and K_{max} test results may have had a small amount of crack closure, and may not be closure free, as originally suspected. Under the high load-ratio conditions ($R \geq 0.7$). The constant R tests at extremely high R (0.9 and 0.95) were also performed and compared with the constant K_{max} test results. The constant R test results at 0.95 agreed well with the ΔKeff-rate data, while the R = 0.9 data agreed well with constant K_{max} test data in the low-rate regime.

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Table 1: Chemical composition of AISI 4340

Ni	C	Mn	S	Si	Cr	P	Fe
Steel AISI 4340 (wt.%)							
1.83	0.370	0.70	<=0.040	0.230	0.90	<=0.025	96.0

Table 2: Mechanical properties of AISI 4340

Yield stress (MPa)	Ultimate stress (MPa)	Modulus of Elasticity (GPa)	Hardness [Brinell]	Poiss Ratio
731	855	205	255	0.290

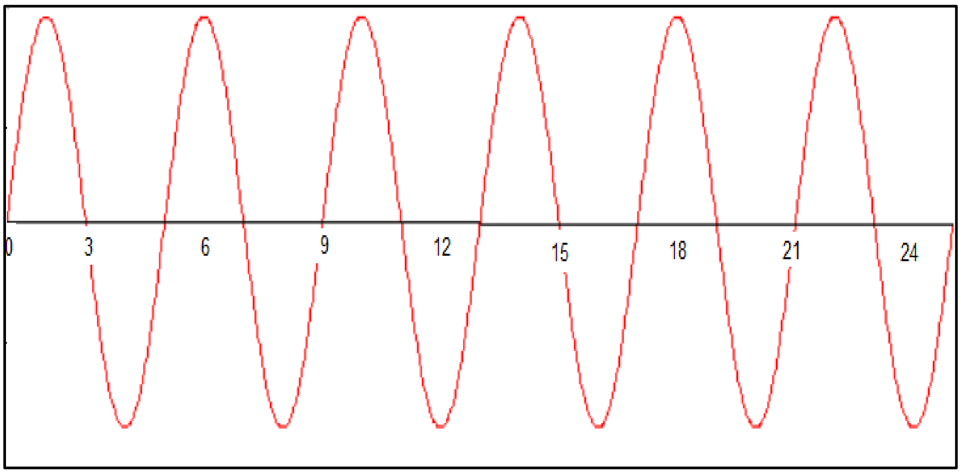

Figure 1: Symbols used with the cyclic stress and cycles

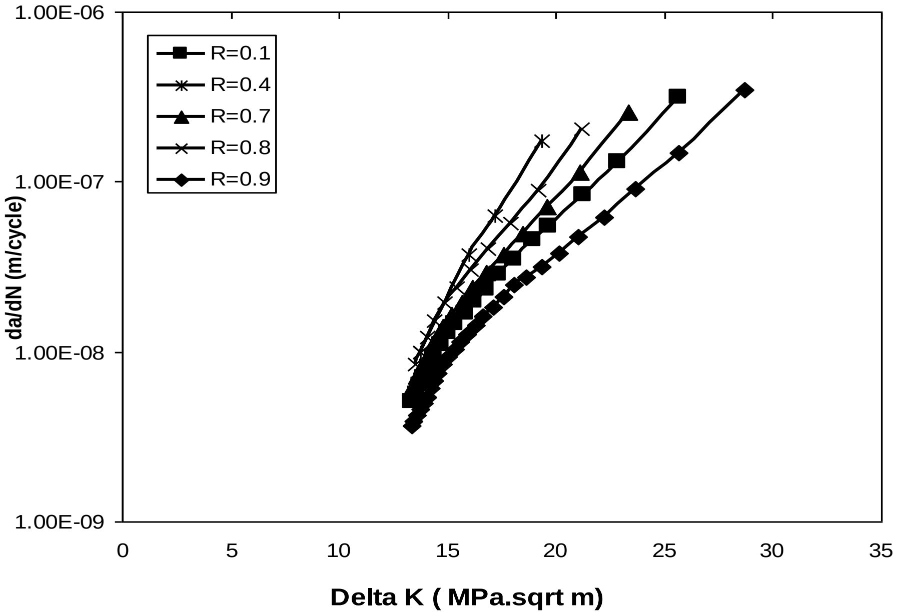

Figure 2: FCG rate data at low and high stress ratio for load-reduction

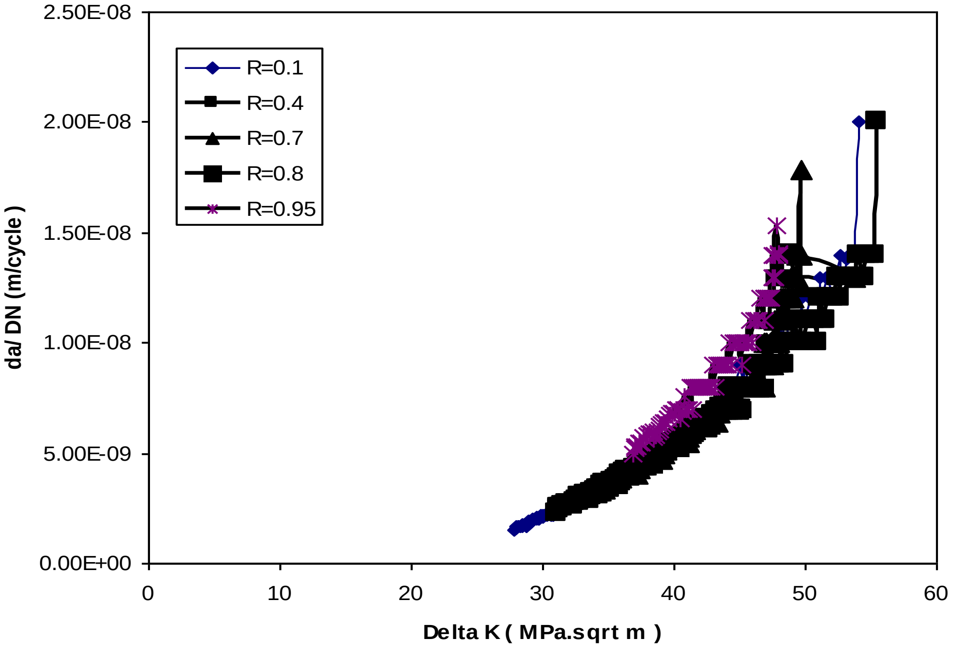

Figure 3: FCG rate data for a constant K_{max} and different stress ratio

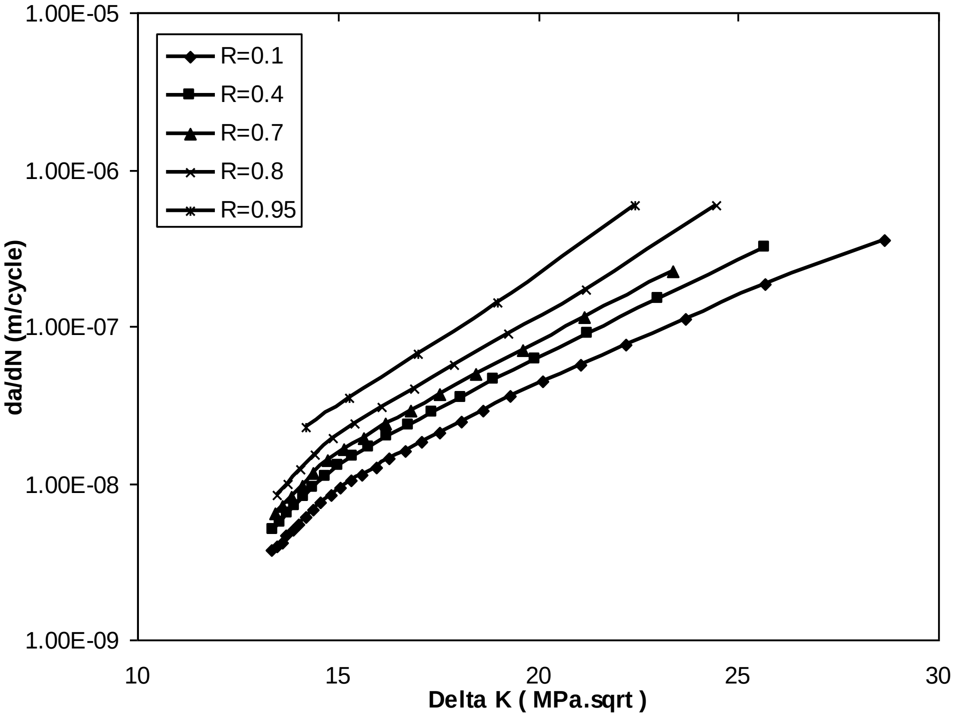

Figure 4: FCG with different stress ratio under CAL