A COMPARISON OF MEASURED AND COMPUTED CYCLODYNAMIC FATIGUE FAILURE TIMES OF SiC AT ROOM AND ELEVATED TEMPERATURES

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Dynamic and cyclodynamic fatigue tests are made at room temperature and 1200 °C in air. A reaction bonded SiC material with 13 Vol.% free silicon was used. The subcritical crack extension parameters evaluated from a dynamic test were used to compute cyclodynamic times to failure. The computed data are compared with data from cyclodynamic measurements. Measured and computed values are in good agreement.

INTRODUCTION

The dynamic and cyclodynamic fatigue tests gives some advantages to static and cyclostatic measurements on ceramic materials.

1.In the dynamic and cyclodynamic tests all specimens are used for the evaluation of the subcritical crack extension parameters, whereas in a static or cyclostatic test only a small percentage of specimens may be utilized (Bornhauser et al.,1).

2.At high temperatures in air where oxidation processes take place a short dynamic test procedure is necessary if the time dependence of critical and subcritical parameters is not known.

3.The determination of the time dependence is only possible in a short test. During the test time no change of the microstructure should occur.

For studying cyclic fatigue effects, e.g. dependences on frequency and amplitude, the cyclic procedure should be combined with a short dynamic test forming a short cyclodynamic fatigue test (Fig.5).

However for measurements under cyclic loading conditions with ceramic materials, a cyclic fatigue apparatus is needed which may not be available. Also, cyclic fatigue experiments are more difficult to control due to the brittleness of the material. It would

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be therefore very advantageous to replace cyclic measurements by a more reliable dynamic fatigue test which is much easier to conduct.

In this paper cyclodynamic test datas are compared with computed ones. The subcritical crack extension parameters necessary for the computation were evaluated from a reliable dynamic test. The computation was performed with the understanding that the mechanisms of dynamic and cyclodynamic fatigue are the same. The disagreement of measured and computed values points to the presence of special cyclic mechanisms.

THEORY

The Cyclodynamic g-Function

Assuming that the same fatigue mechanisms in dynamic and cyclodynamic tests exist the crack velocity v is computed as :

$$v = AK_I^n \qquad (1)$$

K_I=stress intensity, n,A subcritical crack extension parameters where K_I is defined as :

$$K_I = \sigma\sqrt{a}Y \qquad (2)$$

σ=applied stress, a=crack length, Y=correction function. The critical value of K_I is defined in an inert enviroment as :

$$K_{Ic} = \sigma_{Ic}\sqrt{a_i}Y \qquad (3)$$

σ_{Ic}=inert fracture stress, a_i=initial crack length. Relations (1), (2),(3) give then (Pabst,2),

$$\frac{2\sigma_{Ic}^{n-2}}{(n-2)AY^2K_{Ic}^{n-2}} = \int_0^{t_f}\sigma^n(t)dt \qquad (4)$$

or

$$B\sigma_{Ic}^{n-2} = \int_0^{t_f}\sigma^n(t)dt$$

t_f=failure time, $\sigma(t)$=time dependent stress function. The dynamic loading is given by :

$$\sigma(t) = \sigma_d(t) = \dot{\sigma}t \qquad (5)$$

The cyclodynamic loading is given by :

$$\sigma(t) = \sigma_{cd}(t) = \dot{\sigma}t + \sigma_o\sin\omega t \qquad (6)$$

where σ_o denotes the amplitude and $\omega=2\pi/\lambda$.

From relation (4) follows for a dynamic test :

$$\sigma_{Ic}^{n-2} = \frac{1}{B}\int_{0}^{t_f} (\dot{\sigma} t)^n dt = \frac{\dot{\sigma}^n t_d^{n+1}}{B(n+1)} \quad \ldots\ldots\ldots (7)$$

Cyclodynamic test yields :

$$\sigma_{Ic}^{n-2} = \frac{1}{B}\int_{0}^{t_{cd}} (\dot{\sigma} t + \sigma_o \sin\omega t)^n dt = \frac{1}{B}\int_{0}^{t_{cd}} \sigma_{cd}^n(t)\,dt \quad \ldots\ldots\ldots (8)$$

From equation (7) and (8) follows :

$$\frac{\dot{\sigma}^n t_d^{n+1}}{n+1} = \int_{0}^{t_{cd}} \sigma_{cd}^n(t)\,dt \quad \ldots\ldots\ldots (9)$$

The equation (9) gives the relation between t_d the dynamic time to failure and t_{cd} the cyclodynamic time to failure. Dividing (9) by the identity

$$\frac{\dot{\sigma}^n}{n+1} t_{cd}^{n+1} = \int_{0}^{t_{cd}} \sigma_d^n(t)\,dt \quad \ldots\ldots\ldots (10)$$

the following yields :

$$\frac{t_d}{t_{cd}} = \left(\frac{\int_{0}^{t_{cd}} \sigma_{cd}^n(t)\,dt}{\int_{0}^{t_{cd}} \sigma_d^n(t)\,dt} \right)^{\frac{1}{n+1}} \quad \ldots\ldots\ldots (11)$$

The right side of equation (11) formally depends on t_{cd}. Using high frequencies and long times t_{cd} the term (11) does not differ from

$$g_{cd}(n,\sigma_o/\dot{\sigma}) = \left(\lim_{t_{cd}\to\infty} \frac{\int_{0}^{t_{cd}} \sigma_{cd}^n(t)\,dt}{\int_{0}^{t_{cd}} \sigma_d^n(t)\,dt} \right)^{\frac{1}{n+1}} \quad \ldots\ldots\ldots (12)$$

and is independent of t_{cd}. Using the relation (12) the cyclodynamic failure time t_{cd} may be computed from the dynamic time to failure t_d if g_{cd} is known.

$$t_{cd} = g_{cd}^{-1}(n,\sigma_o/\dot{\sigma})\, t_d \quad \ldots\ldots\ldots (13)$$

g_{cd} is called the cyclodynamic g-function (1) which only depends on n and $\sigma_o/\dot{\sigma}$.

MATERIAL

A non-oxide ceramic material SiC was used. Table 1 gives some data. The subcritical parameter n was measured in a dynamic fatigue test at room temperature and 1200 °C. SiC is reaction bonded with a 13 Vol% free silicon content.

TABLE 1 - Material data

Material	Vol% Si	$\bar{d}_{SiC}$ (µm)	$\bar{d}_{Si}$ (µm)	$\bar{K}_{Ic}$(23 °C) ($MN/m^{3/2}$)	n-value at RT/1200 °C
SiC(IF) Refel	13.1	3.1	7.3	4.2	1000/56

The n-values were taken from measurements performed by Popp and Pabst (3).

EXPERIMENTAL

Experiments were performed in a three-point bending device. Span width : 24 mm. Specimen dimensions 35 x 7 x 3.5 mm^3. High temperatures were achieved by induction heating. Table 2 summarizes the test parameters : Loading rate $\dot{\sigma}$, Frequency $\omega/2\pi$, and Amplitude σ_o.

TABLE 2 - Test parameters at room temperature and 1200 °C.

Loading	Loading rate $\dot{\sigma}$ (MPa/sec)	Frequency $\omega/2\pi$ (Hz)	Amplitude σ_o (MPa)
Dynamic	0.22	0	0
Cyclodynamic	0.22	2/20/180	21

The experimental procedure was as follows :

a.) 15 bend specimens were fractured in a dynamic test at a loading rate of 0.22 MPa/sec. The times to failure were plotted against relative frequency. The frequency distribution was fitted by a Weibull distribution.

b.) The data of dynamic times to failure were used to compute the cyclodynamic times to failure utilizing the relation (13). The results were plotted in a frequency distribution curve.

c.) 20 bend specimens were fractured in a cyclodynamic test as a function of frequency. The measured values are compared with the computed ones.

RESULTS AND DISCUSSION

The measured and calculated times to failure fitted by a Weibull distribution are given in Fig.1-4.

Room-Temperature Measurements (Fig.1-2)

The comparison of measured and predicted (calculated) times to failure exhibits a fairly good agreement within certain intervalls of time distribution. Also a separation between dynamic and cyclodynamic time to failure distributions is evident as is expected. The dynamic time distribution is shifted to higher times as the load in the cyclodynamic case is always higher (due to the finite amplitude).

At 20 Hz (Fig.2a) the shape of the distribution curves is nearly identical. The measured and predicted data almost coincide. At 2 Hz (Fig.1) and especially at 180 Hz (Fig.2b) a large discrepancy in the case of the measured cyclodynamic distribution is induced at lower failure times. From this it may be assumed that a special cyclic effect exists at high frequencies which is not considered in the cyclodynamic g-function. The low number of tested specimens, however, and the unsymmetric distribution does not permit an unequivocally evaluation.

High Temperature Measurements (Fig.3-4)

In the high temperature test (Fig.3-4) the time distributions are shifted to lower values compared to room-temperature measurements. This is due to a reduction in bend strength caused by a more distinct subcritical crack extension at elevated temperatures (low n-value, n=56). The subcritical crack extension starts earlier and at lower loads as it is in the case at room-temperature where the n-value approaches infinity. The measured dynamic time distribution curve is shifted to higher times as was the case at room-temperature. The measured and predicted cyclodynamic times coincide fairly well at least for 2 Hz and 20 Hz (Fig.3,4a).

At a frequency of 180 Hz, however, the different distribution curves are indistinguishable.There is more agreement between the dynamic and cyclodynamic experiment as between the measured and computed cyclodynamic data. Obviously a cyclic effect exist at high temperatures and high frequencies which enlarges the time to failure. It may be assumed that high frequencies cause an embrittlement which increases the n-value and lowers the capability for subcritical crack extension. Consequently strength and failure time increase. As the frequency effect is not considered in the cyclodynamic g-function formalism no coincidence between measured and computed data exists.

CONCLUSION

A short dynamic or cyclodynamic test is necessary for high temperature fatigue experiments performed in an oxidizing environment.

To avoid difficulties with the cyclodynamic test procedure, computed cyclodynamic time distributions using an appropriate g-function are of great advantage. At high frequencies the g-function has to be completed by a term which accounts for nonlinear 'plasticity' effects. Increasing the number of specimens will result in exact time distribution curves which provide for an unequivocal interpretation of the results.

SYMBOLS USED

A, n = subcritical crack extension parameters

a = crack length (mm)

g_{cd} = cyclodynamic g-function

K_I = stress intensity ($Pam^{1/2}$)

K_{Ic} = fracture toughness ($Pam^{1/2}$)

λ = cyclic period (s)

σ = stress (Pa)

σ_{Ic} = inert strength (Pa)

v = crack velocity (mm/s)

Y = correction function

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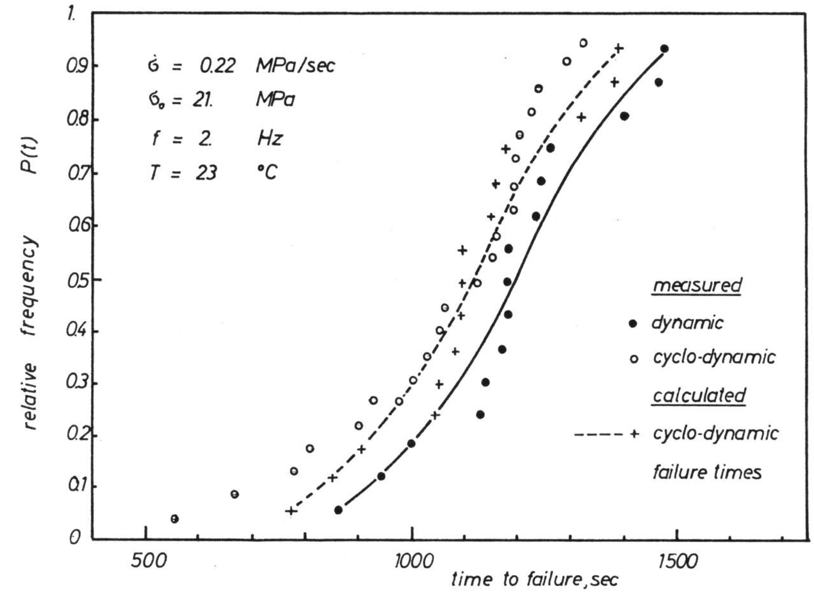


Figure 1 Calculated and measured cyclodynamic failure times

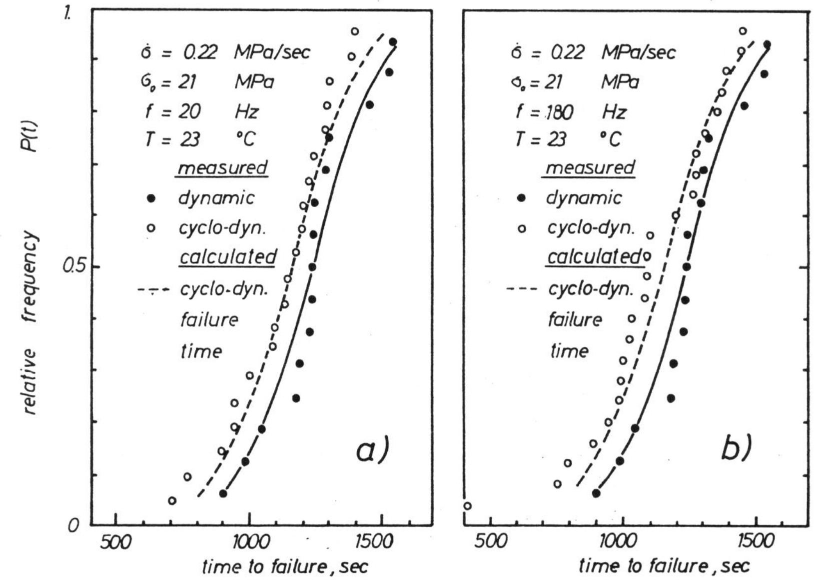


Figure 2 Calculated and measured cyclodynamic failure times

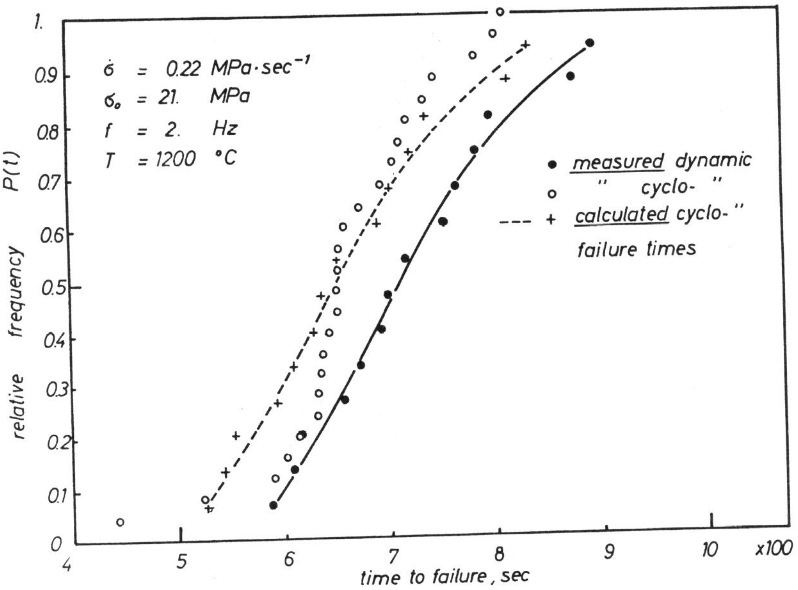


Figure 3 Calculated and measured cyclodynamic failure times

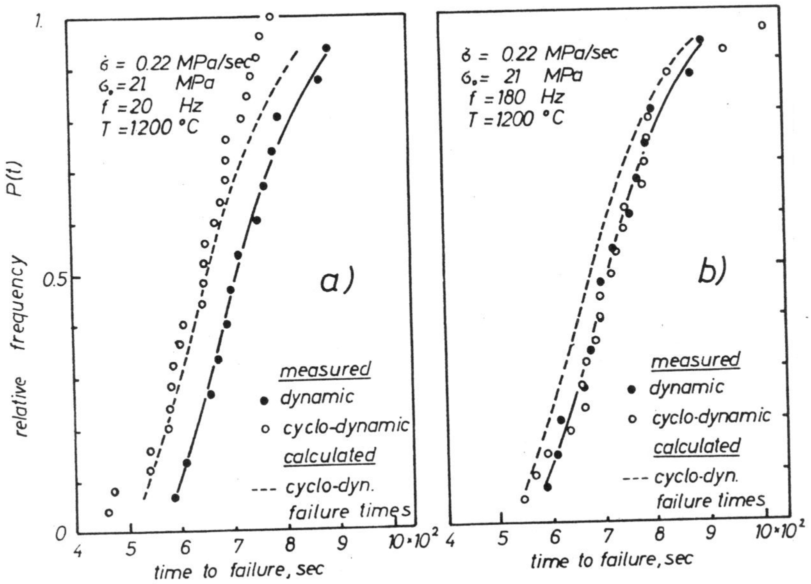
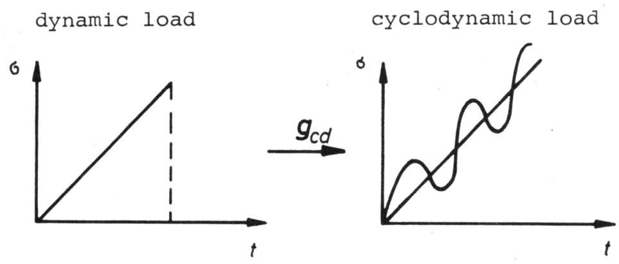


Figure 4 Calculated and measured cyclodynamic failure times



$$g_{cd} = \sqrt[n+1]{\lim_{t_x \to 0} \frac{\int_0^{t_x} \sigma_{cd}(t)^n \, dt}{\int_0^{t_x} \sigma_d(t)^n \, dt}}$$

Figure 5 Dynamic and cyclodynamic load