FATIGUE CRACK PROPAGATION IN RESONATING MACHINE MEMBERS AT ELEVATED ROOM TEMPERATURES

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Fatigue crack propagation in resonating machine members at elevated room temperatures is studied. The crack is simulated as local flexibility which influences the dynamic response of the member. The propagating crack introduces additional flexibility which results in gradual shift away from the resonance and to smaller loading of the cracked section. The effect of room temperature is taken under consideration in parallel through the variation of the C,n values of Paris Law. The above model can lead to dynamic crack arrest depending on the material internal damping and room temperature values.

INTRODUCTION

Crack nucleation and propagation is natural to be expected in vibrating machine members in particularly when resonance occurs. Chondros and Dimarogonas (1) and Dimarogonas and Masouros (2) have shown that the appearance of a crack influences considerably the vibration characteristics of such structures. Because of this variation, the stress field in the vicinity of the crack will change. Dentsoras and Dimarogonas (3), using Paris relation (4), have shown for simple or complex structures that, under such conditions, it is possible for the crack propagation rate to become lower than a threshold value characteristic of the material considered. It was shown that this process, known as dynamic crack arrest, is strongly affected by material internal damping, the dominating damping mechanism.

The mechanisms of temperature effect on crack

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growth rate during dynamic loading has been studied both analytically and experimentally. According to T.V. Duggan and J.Byrne (5), there is a problem of separating the effects of temperature from those of the environment for tests carried in air. Despite that, they have noticed that an increase of crack growth rate is expected with an increased temperature. Further, K.Ogura and I.Nishikawa (6) have shown recently that the fatigue crack growth threshold was found to increase in most of the tested alloys in air. Finally, P.J.Cotterill and J.F.Knott (7) have shown that for a certain steels and in the region of 125°-525°C there is an increase of crack growth rates within the Paris regime limits.

In the present paper, the crack model behavior proposed by Chondros and Dimarogonas and the work done by Dentsoras and Dimarogonas are used together with experimental results obtained by P.J.Cotterill and J.F.Knott in order to investigate the crack growth rates at resonance and in various ambient temperatures in air.

ANALYSIS

In order to study the crack growth rate under the conditions stated above, a simple member model is considered. A cantilever beam with orthogonal section is cracked at its fixed end as is shown in Figure 1. The stress intensity factor for first mode opening is equal to $\sigma\sqrt{\pi a}F(a/W)$ and $F(a/W)$ is given in reference (8) as:

$$F(a/W)=1.22-1.4(a/W)+7.33(a/W)^2-13.08(a/W)^3+14(a/W) \quad (1)$$

If ω is the exciting frequency, ω_n is the beam frequency without the crack and ω_α the cracked beam frequency, then according to reference (3):

$$\left(\frac{\omega_\alpha}{\omega_n}\right)^2 = \frac{1}{18(1-v^2)I(a/W)(W/L)+1} \quad (2)$$

where v is the Poisson's ratio and:

$$I(a/W)=1.8624(a/W)^2-3.95(a/W)^3+16.375(a/W)^4-37.266(a/W)^5+76.81(a/W)^6-126.9(a/W)^7+172.5(a/W)^8-143.97(a/W)^9+66.56(a/W)^{10} \quad (3)$$

The frequency ratio variation expressed by relation (2) is shown in Figure 2.

For completely reversed stress the mean stress and the stress ratio R are equal to zero. Then the Paris relation for crack propagation rate becomes:

$$\frac{da}{dN} = C(K_{Imax})^n \qquad (4)$$

or:

$$\frac{da}{dN} = C\frac{(\sigma\sqrt{\pi a}\ F(a/W)W^{1/2})^n}{\left\{\left[1-((\omega/\omega_\alpha)[18(1-v^2)I(a/W)(W/L)+1])^2\right]^2 + Y^2\right\}^{n/2}} \qquad (5)$$

where Y is the material damping coefficient. It is evident from the above relation that the crack growth rate is strongly dependent on the frequency ratio and the material damping coefficient especially at or near resonance.

Next, the experimental data presented in (7) for a 9%Cr1%Mo steel are used to establish the relation between temperature and C,n constants of Paris equation in air. Elaboration of these data leads to the following values:

TABLE 1 Values of C,n for certain temperature values

Temperature (^{0}C)	C(m/cycleN^{n}m$^{-3n/2}$)	n
125	4.18037×10^{-28}	2.6960
225	1.18891×10^{-27}	2.6459
325	6.80573×10^{-26}	2.4198
425	5.22983×10^{-22}	1.9229
525	1.74669×10^{-21}	1.8890

Since C,n are now temperature-dependent, the above values from TABLE 1 can be used in relation (5) to show the variation of crack growth rate with temperature when resonance occurs. For this reason an initial normalized crack length of 0.25 is assumed and the corresponding natural frequency ratio is calculated using relation (2). Then the exciting frequency ratio is taken equal to 0.9275 of the natural frequency ratio and correspondingly both the stress intensity factor range and the crack growth rate of the normalized length are calculated using relations (4-5). The results are presented in Figure 3 for the stress intensity factor and in Figures 4,5 for the crack growth rate.

CONCLUSIONS

According to the above analysis, the following main conclusions can be made:

1. Due to the material damping and the variation of the crack depth, the crack growth rate decreases -after resonance- significantly for all temperature values. The crack growth values are then analogous to the corresponding temperature values.

2. For low material damping values, the crack growth rate reaches higher values for low temperature level at resonance. Additionally, the maximum crack growth rate at the same point seems to be almost constant irrespectively of the temperature level. This phenomenon vanish as the material damping values increase.

3. The value of the stress intensity factor depends mainly on material damping except of the value around 0.264 of normalized crack length where seems to be constant.

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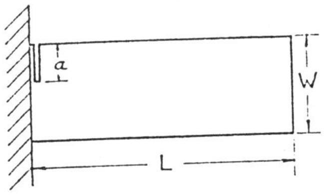


Fig.1 A .Cantilever Beam with a Crack.

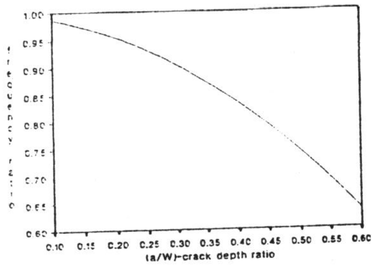
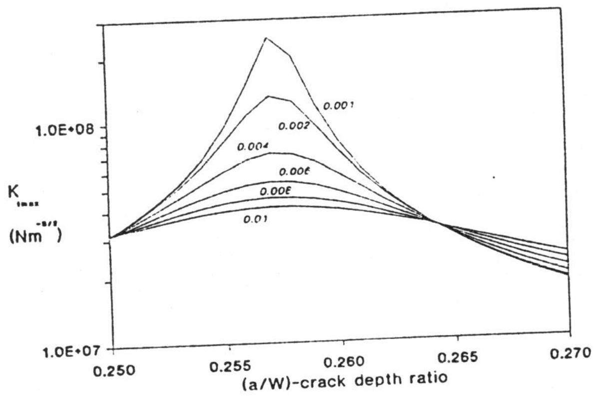


Fig.2. Frequency Drop vs. Crack Depth.



Temperature = 125 deg. C

Fig.3. Variation of Stress Int.Factor with damping.

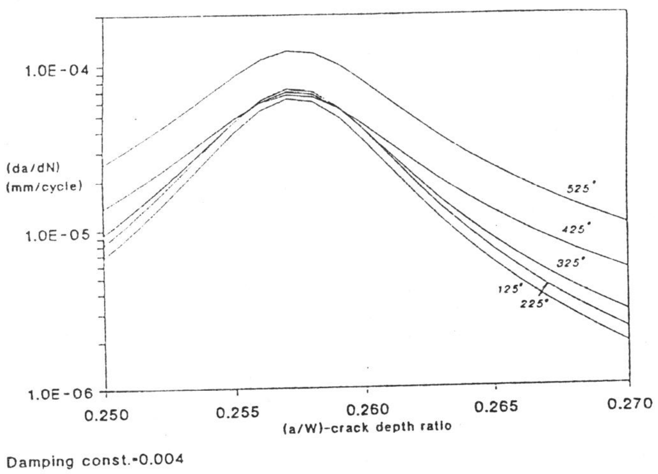


Fig.4. Variation of Crack Growth Rate with Temperature at Resonance.

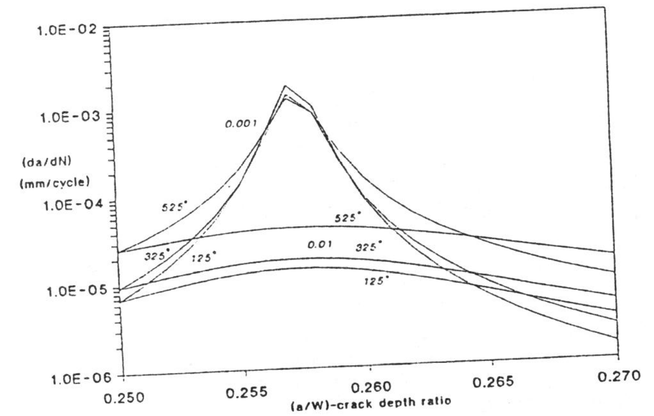


Fig.5. Crack Growth Rate vs. Temperature and Damping at Resonance.