# FATIGUE CRACK INITIATION FROM A NOTCH TIP UNDER A CYCLIC COMPRESSIVE LOAD

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## INTRODUCTION

Under a cyclic applied load, the initiation of a fatigue crack is related to plastic deformation by slip, i.e., it results from a cumulative damage caused by an alternative slip. Because the alternative slip can also take place at a notch tip under cyclic compressive applied load, a fatigue crack can nucleate under a compressive stress. Reid et al. investigated the initiation of a fatigue crack from a compressive overload notch tip under cyclic compressive load [1], and considered that the crack initiation was due to the net tensile residual stress, i.e., the compressive stress could not induce fatigue crack initiation. The purpose of this paper is to investigate the possibility and the behavior of the initiation and growth of the fatigue crack under a cyclic compressive load.

## EXPERIMENTAL PROCEDUCES AND RESULTS

The notch radius and the depth of the specimens were 0.075 and 7.8 mm respecitively but the specimens under cyclic tensile load were four times as long as that under cyclic compressive load (Fig. 1). The crack length was measured with a microscope (30x). The number of cycles required to initiate a 0.05 mm crack was designated as $N_i$ and $10^6$ cycles were selected as a closure number of cycles.

1. Threshold Value of Fatigue Crack Initiation under Cyclic Compressive Load.



For ultra-high strength steel (30Cr2WV, Y.S.=1380MPa), the variation of the number of crack initiation cycles $N_i$ under cyclic compressive stress with the stress range $-\Delta\sigma$ is shown in Fig. 2. The threshold value for fatigue crack initiation under a cyclic compressive load with $-\sigma_{min}$=310MPa could be obtained as $\Delta\sigma_{th}$=350MPa (curve 1 of Fig. 2). Because there is a stress concentration at the notch tip under the compressive stress and $\sigma_{max}$ at the notch tip is proportional to $\Delta K_I/(\pi\rho)^{\frac{1}{2}}$, the threshold value can be represented by $\Delta K_{th}(\rho)$, i.e. $\Delta K_{th} = \sigma_{th}(\pi a)^{\frac{1}{2}}\rho$=70MPam$^{\frac{1}{2}}$. If the minimum cyclic stress $-\sigma_{min}$ was near zero, the $\Delta\sigma_{th}$ value would decrease greatly as indicated in curve 2, i.e., $\Delta\sigma_{th}$ = 100MPa or $\Delta K_{th}(\rho)$ = 20MPam$^{\frac{1}{2}}$. The threshold value of the crack initiation under cyclic tensile stress with the same minimum stress $\sigma_{min}$ = 150MPa was $\Delta\sigma_{th}$ = 80MPa or $\Delta K_{th}(\rho)$=16MPam$^{\frac{1}{2}}$ (curve 4 in Fig. 2.), but the threshold value did not decrease when the minimum tensile stress was near zero (curve 3 in Fig. 2).

For an ultra-high strength aluminum alloy (7075-T65, Y.S = 510MPa), the results are shown in Fig. 3. The $\Delta\sigma_{th}$ value under a cyclic compressive load with a minimum cyclic stress $-\sigma_{min}$ = 150MPa was $\Delta\sigma_{th}$ = 135MPa or $\Delta K_{th}$ = 27MPam$^{\frac{1}{2}}$ but the corresponding value under a cyclic tensile load with the same minimum cyclic stress $\sigma_{min}$ =15MPa was $\Delta\sigma_{th}$ = 35MPa or $\Delta K_{th}(\rho)$ = 7MPam$^{\frac{1}{2}}$.

2. The growth of the fatigue crack under cyclic compressive stress.

The length of the fatigue crack under a cyclic compressive load with $-\sigma_{min}$ = 310MPa is plotted in Fig. 4 as a function of the number of compressive load cycles. It is clear that the crack grew at a decreasing rate until eventually it stopped growing and the maximal length of the propagating crack was only 0.2 to 0.5mm. A similar result was obtained for aluminium alloy. In this case the crack length on the surface of the specimen was the same as that in the interior as indicated in Fig. 5(a). Only the crack on the surface layer could continue to propagate 0.2-1.0mm if the $-\sigma_{min}$ was decreased after the growth of the crack had stopped (Fig. 5b). Not only on the surface but also in the interior the fatigue crack could continue to propagate 2-4mm if the $-\sigma_{min}$ was decreased to near zero, as indicated in Fig. 5 (c). The fatigue crack under cyclic compressive load was perpendicular to the direction of the loading (Fig. 5d), similar to that under tensile stress. The variation of da/dt with $\Delta K_I(\rho)$ is shown in Fig. 6. For either the steel or aluminum alloy, the da/dt under a cyclic compressive load with $-\sigma_{min} = 0$ was ten to hundred times larger than that under a cyclic tensile load. Scanning electron photo micrographs showed that the fatigue fractures under a cyclic compressive load were the same as that under a cyclic tensile load.

## DISCUSSION

There is a stress concentration at the notch tip under compressive stress, the local alternative slip and cumulative damage process can occur and then the fatigue crack can nucleate under cyclic compressive load.

For a deep and sharp notch specimen (Fig. 1), the maximum stress at the notch tip is $\sigma_{max} = 2K_I(\pi\rho)^{\frac{1}{2}} = 26.3\,\sigma$. If yield strength under a compressive load is the same as that under a tensile load, i.e., $\sigma_s = 1380$MPa for the ultra-high strength steel or 510 MPa for the aluminum alloy, there is a compressive plastic zone ahead of the notch tip when the applied compressive stress $\sigma \geq \sigma_c = \sigma_s/26.3 = 53$MPa (for steel) or 20MPa (for aluminum alloy). Experimental results showed that the threshold value under a cyclic compressive stress with the minimum cyclic stress $-\sigma_{min} = (6\text{-}7)\,\sigma_c$ was four times as high as that under cyclic tensile stress (Fig. 2 and Fig. 3). However, when the minimum cyclic stress $-\sigma_{min}$ was near zero, the notch could open under the tensile residual stress. As a result, the threshold value decreased significantly and was near to that under cyclic tensile stress. If we consider that the macro-crack initiation results from the nucleation and the linking of the microcracks or voids caused by alternating slip, the existence of tensile stress would facilitate the linking process and then the threshold value would decrease greatly.

Because there is no stress concentration at the fatigue crack tip under compressive stress after the crack has propagated to a certain size, i.e., 0.2 to 0.5mm, the fatigue crack will not grow under cyclic compressive stress. If the minimum cyclic stress was near zero, the crack could propagate under a cyclic compressive load due to the tensile residual stress. It is clear that the opening of the crack plays an important role in the propagation of the fatigue crack.

## CONCLUSIONS

1. A fatigue crack could initiate from a notch under a cyclic compressive load but the threshold value was four times as large as that under a cyclic tensile load.

2. The fatigue crack would not propagate under a cyclic compressive load after it grew to a certain size. If the minimum cyclic load was near zero, the threshold value of crack initiation under cyclic compressive stress decreased greatly and the fatigue crack continued to propagate.



## REFERENCE

[1] C.N. Reid et al, Fatigue of Engineering Meterials and Structure, 1 (1979), p. 267.

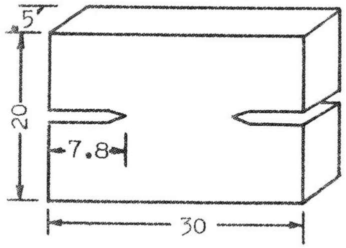


Fig. 1 Notch compressive fatigue specimen

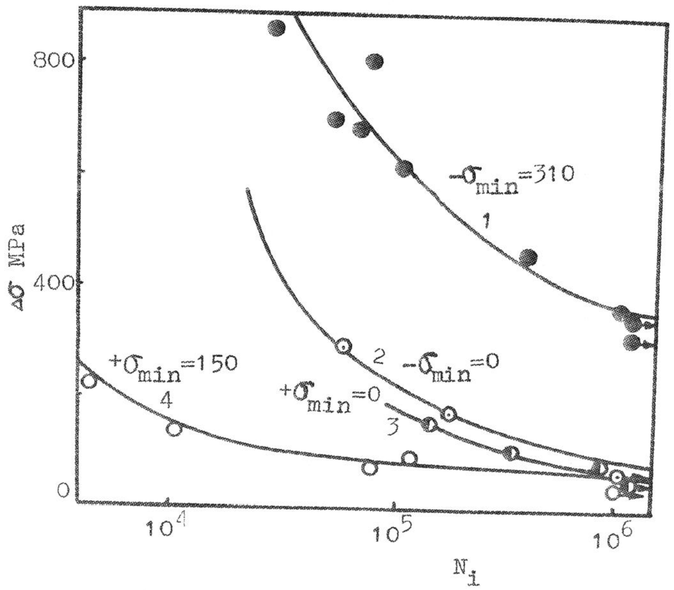


Fig. 2 Variation of the number of crack initiation cycles with the stress range $\Delta\sigma$, 30Cr2WV, Y.S = 1480MPa.

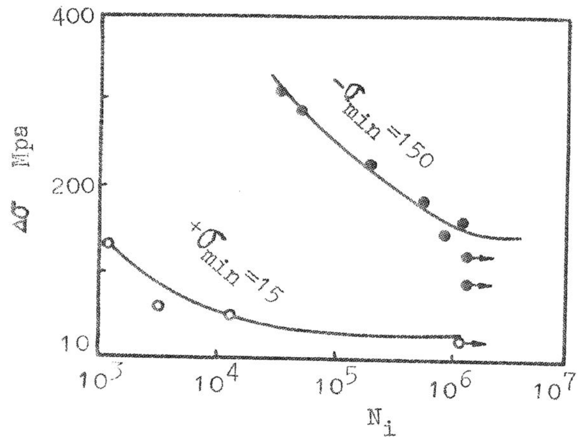


Fig. 3 Variation of the number of crack initiation cycles of aluminum alloy (Y.S=510MPa) with the stress range

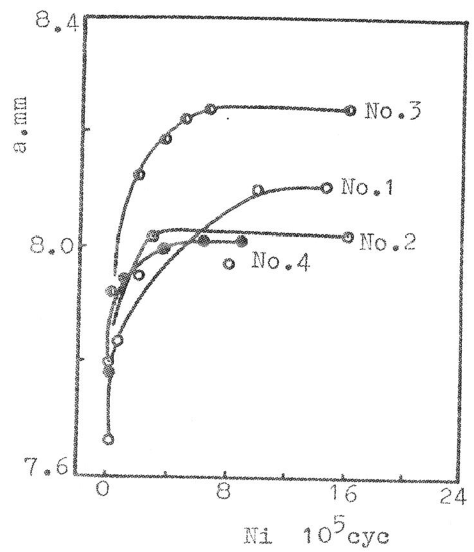


Fig. 4 Variation of the crack length under cycle compressive load with the number of fatigue cycles



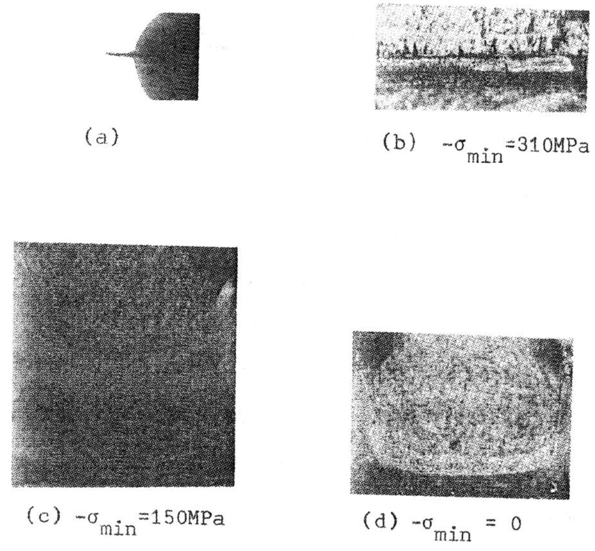


Fig. 5 Fatigue crack (a) and macro-fractographs (b-d) under cyclic compressive stress

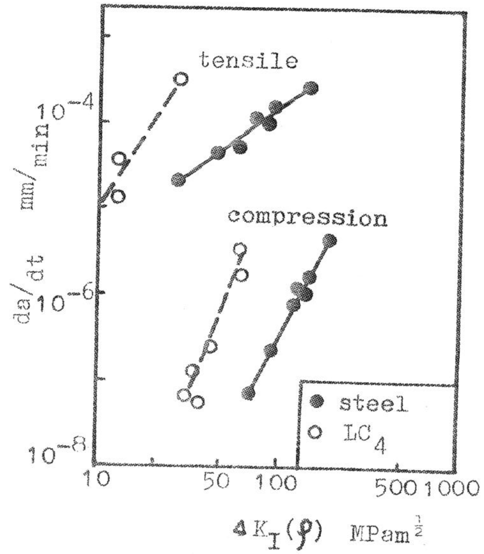


Fig. 6 Variation of da/dt with $\Delta K_I(\rho)$, $-\sigma_{min} = 0$