OPTIMUM SIZE OF FATIGUE CRACKS PROMOTING THE EFFECT OF SUBSEQUENT UNDERSTRESSING

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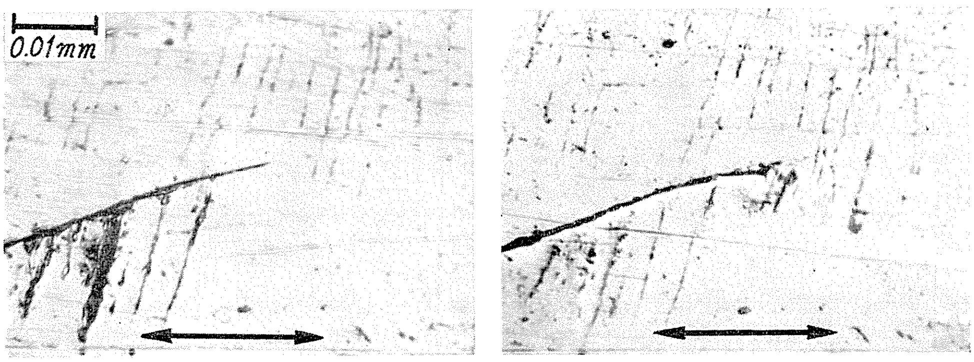
Abstract

A new conception different from the existing one is presented in connection with the effect of understressing. It maintains that the cracks initiated by an understressing improves the fatigue life of a specimen for a higher stressing and that this is attributed to the favourable change in shape at the tips of stationary cracks caused by the subsequent understressing.

A torsion fatigue test is made in connection with the new conception for the effect of understressing, presented by the authors in a previous paper[1]. The proposal is based on the experimental results on the stress distributions around the tips of fatigue cracks, stationary or progressive, measured by the electroplating method[2] and the similar results subsequently obtained by X-ray analysis[3].

It maintains that when the microcracks produced by a cyclic stressing are stationary, the favourable change in shape at the tips of cracks caused by a subsequent understressing, improves the fatigue strength of the material. The change in shape at the tips of cracks is illustrated in Fig. 1. As is shown in the figure, the tip of the stationary crack initiated by a high stressing, is rounded by a subsequent understressing. The fatigue strength of a material containing preliminarily the cracks as shown in Fig. 1 (b), is apparently larger than the one containing the cracks as shown in Fig. 1 (a), for a subsequent high stressing.

The effect often appears in low carbon steels submitted to understressing.



(a) (b)

FIG. 1. Change in shape at the tip of a stationary crack.
(a) Crack initiated by the stressing, $\tau=16.3$ kg/mm^2, $N=10^5$.
(b) After the subsequent stressing, $\tau=14.5$ kg/mm^2, $N=10^7$.

But when the fatigue cracks are always progressive as in aluminium alloys, little effect of understressing can be discerned. Furthemore, experimental results show that even in low carbon steels, when the amplitude of pre-stressing is so small as fatigue cracks cannot be produced in specimens, the fatigue strength of the pre-stressed steel is not improved at all as compared to new specimens. The existing conception that the diffusion of foreign atoms at the tips of cracks promoted by understressing, improves the fatigue strength of metals, is far different from the present one and cannot explain the matter satisfactorily.

In the present test, specimens of 0.16 percent carbon steel with the grain size of 0.036 mm, are examined. The endurance limit of the steel is 14.5 kg/mm^2, for torsion. The pre-stressing is given for specimens, in the manner as follows. First, specimens are submitted to a high stressing ($\tau = 16.3$ kg/mm^2) for a small number of cycles, N_1, to produce fatigue cracks preliminarily. Then, the surfaces of specimens are carefully examined for the initiation of cracks with a microscope. Next, those specimens are submitted to the understressing ($\tau = 14.5$ kg/mm^2) for the number of cycles of 10^7. The fatigue life, N_2, for the high stressing ($\tau = 16.3$ kg/mm^2), is examined for the specimens thus pre-stressed. The fatigue cracks which are produced in new specimens submitted to only the understressing, are generally very fine as shown in Fig. 2, even for the number of cycles of 10^7. Larger cracks, stationary or progressive, however, appear in the specimens, submitted to the high stressing even for a small number of cycles. This is favourable to examine how the size of cracks affects the effect of understressing.

The results are given in Fig. 3, where the abscissa represents the fatigue lives of the pre-stressed specimens, N_2/N_0. N_0 is the average value of the fatigue lives of new specimens for the high stressing and is 13.6×10^5 for the test material. The variation of the averaged value of fatigue lives, showing the effect for different pre-stressing, N_1, is illustrated by a curve in Fig. 4. When N_1 is small, the cracks produced by the high stressing becomes all stationary for the subsequent understressing and the favourable change in shape improves the fatigue life, N_2. As is shown in the figure, the effect of understressing appears most remarkably for the specimens which received the pre-stressing for $N_1 = 1.0 \times 10^5$, and the fatigue life increases considerably but it reduces abruptly when specimens are submitted to a slightly increased cycles of the high stressing. This indicates that the effect of the subsequent understressing is perceptively affected by the size of cracks produced by the initial pre-stressing, and there is the optimum size of crack which is most favourable to promote the effect of subsequent understressing, and when the size of crack increases over this limit,

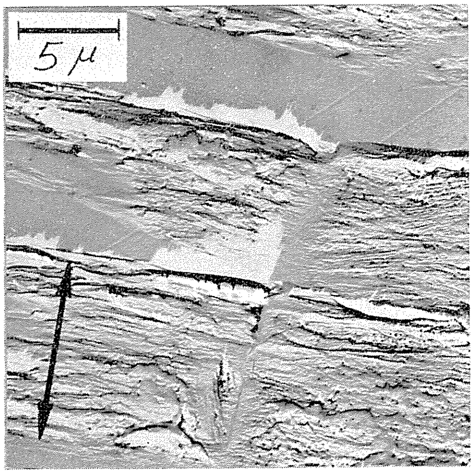


FIG. 2. Small cracks produced by the understressing for the number the cycles of 10^7. Arrow line represents the axial direction of the specimen.

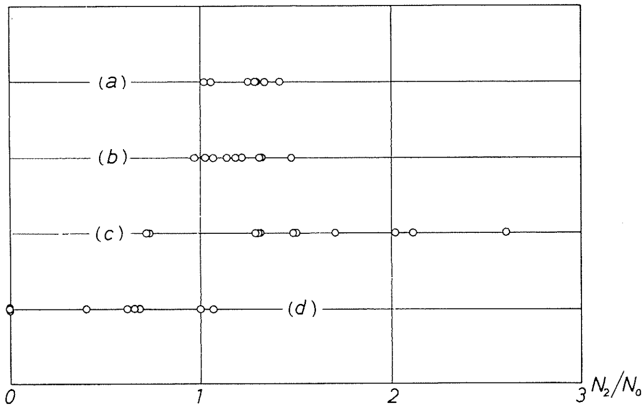


FIG. 3. Fatigue lives of pre-stressed specimens.
(a) $N_1=0$, (b) $N_1=0.5\times 10^5$, (c) $N_1=1.0\times 10^5$, (d) $N_1=5.0\times 10^5$.
Note: Three specimens were broken by the understressing for the cycles less than 10^7, in the test (d). The averaged value of N_2 is counted, assuming $N_2=0$ for those specimens, as is shown in the figure. Arrow line represents the axial direction of the specimen.

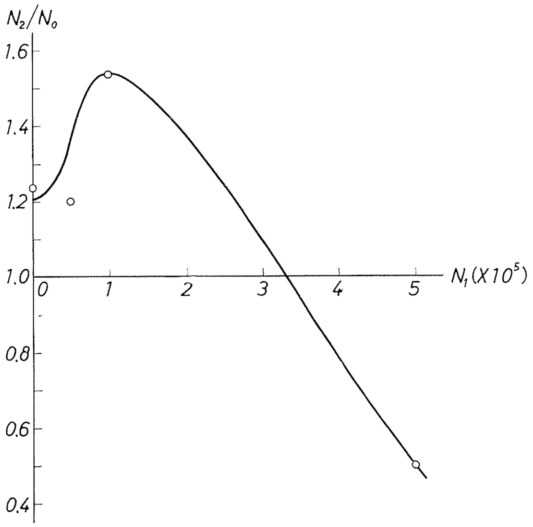
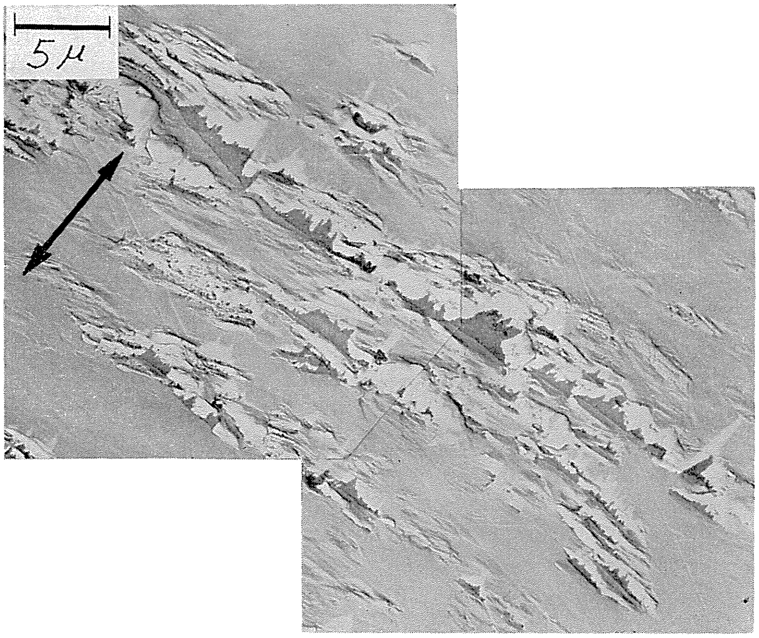
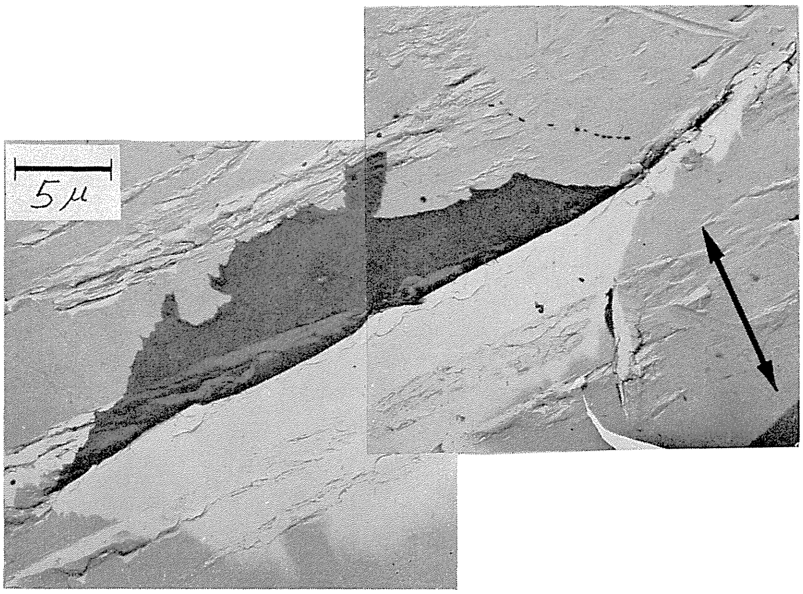


FIG. 4. The relationship between N_1 and N_2.

the crack becomes progressive even for the understressing, resulting in the rapid decrease of the average value of fatigue lives. For the pre-stressing of $N_1=1.0\times 10^5$, the average value of fatigue lives attains maximum, but the fatigue life of individual specimen becomes quite irregular, as is shown in Fig. 3 (c). It is interesting to note, however, that the effect of understressing is reduced abruptly when the size of crack increases from the optimum size, as is shown in Fig. 4. Consequently, for the specimens submitted to a pre-stressing which produces the cracks of optimum size, the irregularity in quality originally existing in individual specimen, reflects most intensely on the irregularity of the fatigue life. The existence of the optimum size of crack, of course, can be attributed to the microscopically high heterogeneity of the material and is deeply associated with



(a)



(b)

FIG. 5. Cracks of optimum size produced by the pre-stressing, $N_1 = 1.0 \times 10^5$.

the stepwise progress of fatigue cracks. It appears that the existing conception has been introduced ignoring this essential matter.

The micrographs of large cracks, produced in specimens by the pre-stressing ($\tau=16.3$ kg/mm^2), are shown in Fig. 5. The crack (b), which is presumed to be of the optimum size, almost agrees with the grain size of the steel. The comparison of the micrographs (a) to (b), however, reveals a difference in the depth of crack. The depth of the latter, Fig. 5 (b), almost attains 0.01 mm and this is the maximum depth for most progressive cracks of larger size which are produced for increased cycles of the pre-stressing. The fatigue life is also measured for specimens which have been submitted to a lower understressing ($\tau=10$ kg/mm^2) for the number of cycles of 10^7. By the pre-stressing, no crack is produced in the specimens since the stress amplitude is sufficiently small and the fatigue life for the high stressing is not improved as compared to new specimens. But for the specimens which contains fatigue cracks of optimum size, having been submitted to the pre-stressing, $\tau=16.3$ kg/mm^2, $N_1=1.0\times10^5$, the fatigue life is slightly improved by the subsequent pre-stressing, $\tau=10$ kg/mm^2 for the number of cycles of 10^7, namely the average value of fatigue lives of those specimens is $N_2/N_0=1.1$.

The tips of fatigue cracks are usually sharp at the very beginning of appearance as shown in Fig. 1 (a). Consequently, the cracks having sharp tips progress rapidly crossing obstacles in the directions of maximum shear when submitted to a subsequent high stressing. When submitted to an understressing, however, they progress more slowly and in most instances become stationary meeting with obstacles. Then, the piled energy supplied by the understressing of large number of cycles, causes the breakage around the tips of cracks where the stress concentrates, resulting in the enlargement of tip radius, as shown in Fig. 1 (b).

When the tip radius of a stationary crack becomes large enough, the secondary cracks will be produced by a subsequent stressing at n_1 rather than at n_2, in Fig. 6, and the cracks will progress in the directions of principal stresses, altering the direction of advance. The previous result for the twisted shafts containing small transverse holes[4] appears to hold this presumption. It is most interesting to note that the experimental results concerned with the directions of fractured surfaces can be explained satisfactorily by the reasoning.

Another cause for the effect of understressing, presumable from the results of hardness tests in ferite where initial cracks are usually produced, is the hardening of the metal at the tips of stationary cracks. The hardness of ferite is not affected surely by the understressing at room temperature but is affected slightly by the high stressing. This indicates that the hardening of the metal at the tips of stationary cracks where the stress highly concentrates, may be possible even when the test piece is submitted to the understressing macroscop-

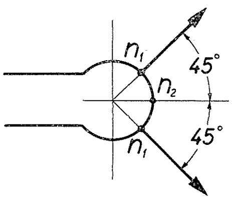


FIG. 6. The change in the direction of advance of fatigue cracks.

ically. This apparently promotes the fatigue strength of the metal and accelerates the enlargement in tip radius by subsequent understressing at the same time. It is concluded in either case that the effect of understressing is attributed to the stationary cracks produced in metals.

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