The Effects of Local Plastic Strain on Crack Propagation

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Treatments of the effects of plastic relaxation on crack propagation are not entirely satisfactory for practical application or for consideration of the influence of particular metallurgical variables. These latter ends could be facilitated by a simple, mechanistically based appreciation of the problem. This paper presents the initial stages of attempts to develop such appreciation and to apply it to fatigue crack propagation under variable-amplitude cyclic stressing - the normal practical situation.

The work is divided into two parts. Part A considers plastic relaxation in the crack tip region; here, cleavage was studied because it is a clearly defined event which occurs when a precise criterion is fulfilled. Part B considers the effect of plastic relaxation at a fatigue crack on its propagation rate under high-amplitude cyclic stress.

EXPERIMENTAL DETAILS (A) Cleavage cracks were introduced by slowly loading sharply notched blanks (0.034 ins. thick) of cold-rolled steel (Mn 0.29, C 0.05 wt - %) at 77K. After load relaxation stopped the crack, tensile specimens (25 x 130 mms.) containing edge cracks 6 mms. long were spark-machined from the blank; the plastic zone formed at 77K was extremely small. In the tests, cracked specimens were subjected to preloads at various temperatures before tensile fracture at 77K. (B) Centre-notched OFC copper specimens were subjected to tension-compression fatigue between constant limits of (i) load, and (ii) crack-opening strain. Hysteresis loops of applied load against crack opening were autographically recorded. The specimens were strips with cylindrical grooves milled across their flat faces giving a waisted gauge length (32 mm x 2.5 mm minimum section). Crack lengths were measured on the specimen surface; macroscopically straight striations ran transversely across the fracture surface. The rates of propagation were compared at a standard crack length (overall) of 7.5 mms.

EXPERIMENTAL OBSERVATIONS (A) The effects of preload on the fracture load at 77K are best described in terms of a threshold load which decreases with increasing preload temperature (fig. 1). Preloads below the threshold do not affect the fracture load. Higher preloads increase the fracture load by an amount equal to that by which the preload exceeds the threshold.

When specimens were unloaded after prestrain the fracture loads were fairly uniformly reduced (fig. 2); after unloading from high preloads at 125K, the relationship was non-linear. Warming to room temperature after unloading from preloads below ambient temperature produced more complex changes in the relationships which are still under investigation.

Load/elongation traces did not reveal plastic flow at 77K before fracture. After preloads in the linear range of fig. 1, examination showed that cleavage originated very close to the original crack tip. Small regions of ductile fracture were only found near the end of the linear range. (B) Fig. 3 shows the variations of crack propagation rate with load amplitude, and with the amplitude of the plastic crack-opening strain (hysteresis loop

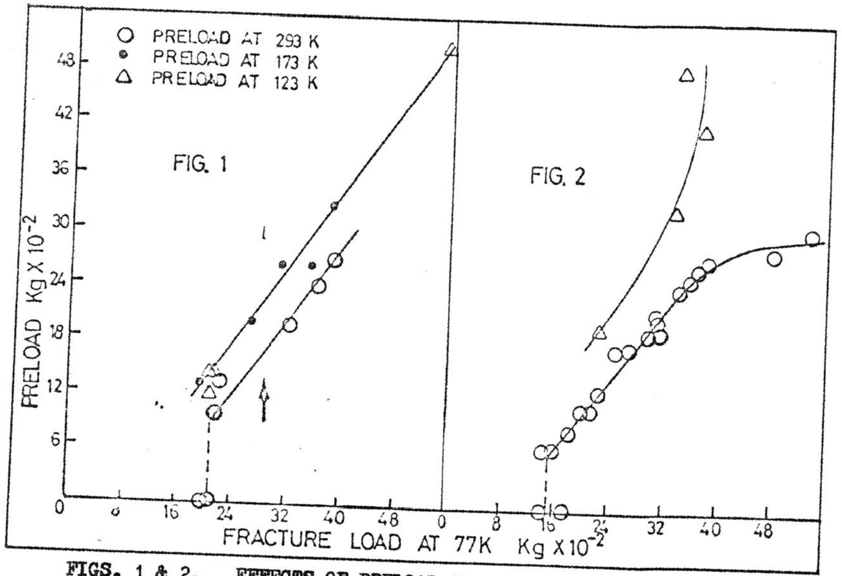
width) for two conditions of cycling and for two metallurgical conditions. The propagation rate follows a singular relationship with the plastic crack-opening strain, but separate relationships with the load amplitude.

DISCUSSION (A) The results of fig. 1 can be explained simply, as follows. The temperature-dependence of the threshold load suggests that significant local yielding begins at this load. Lower preloads thus do not affect the fracture stress. Higher preloads induce further plastic flow, during which the local stress in the yield zone remains at the yield value (ignoring work-hardening) and the excess of preload beyond the threshold is redistributed into previously elastic regions, i.e., away from the crack tip. The preload can thus be divided into two components, viz. (i) the threshold load, which provides the yield stress near the crack tip, and (ii) the excess (or remainder of the) preload, which does not contribute to the local stress near the crack tip.

On loading to fracture at 77K, component (ii) does not contribute towards fulfilling the local stress condition required for cleavage. Since the fracture loads after preload are always greater than those of specimens not subjected to preload by an amount equal to component (ii), the <u>local</u> condition for cleavage is unchanged. The <u>applied</u> loads at fracture differ because of different distributions of internal stress.

The condition for fracture appears to be one of local shear stress rather than normal stress because (i) the fracture load of specimens not subjected to preload is reasonably consistent with that for significant local yielding at 77K, as predicted from the temperature-dependence of the threshold load, (ii) the load redistribution described above occurs by plastic flow, which is controlled by local shear stresses and is insensitive to dilatational stress, and (iii) the fracture load/preload relationship remains linear through the gradual transition from plane strain to plane stress (arrowed in fig. 1) which decreases hydrostatic tension. A critical shear stress or local-yielding condition for cleavage suggests that the critical event is microcrack initiation near the crack tip or its "sharpening" by formation of a slip step at 77K.

Unloading after preload only changes the effect of preload if reverse plastic flow redistributes the internal stress; such flow tends to restore the original distribution. Any resulting Bauschinger effects could reduce the shear stress for yielding at 77K. Both effects would reduce the fracture load, although it is not clear why an almost uniform reduction occurs. Studies of unloading effects are continuing. (B) The correlation between propagation rate and amplitude of local plastic flow (fig. 3) is not surprising since it is generally accepted that, particularly at high amplitudes, fatigue cracks propagate by a mechanism involving local plastic flow. In constant-amplitude tests, the single relationship between cyclic stress intensity and local plastic strain correlates both parameters with the propagation rate. However, under variable amplitude conditions, fatigue softening and hardening continually modify the local stress/strain relationship and the propagation rate only correlates with the parameter mechanistically related to crack propagation.



FIGS. 1 & 2. EFFECTS OF PRELOAD ON PROPAGATION OF A CLEAVAGE CRACK AT 77K - (1) NOT UNLOADED, (2) UNLOADED, AFTER PRELOAD.

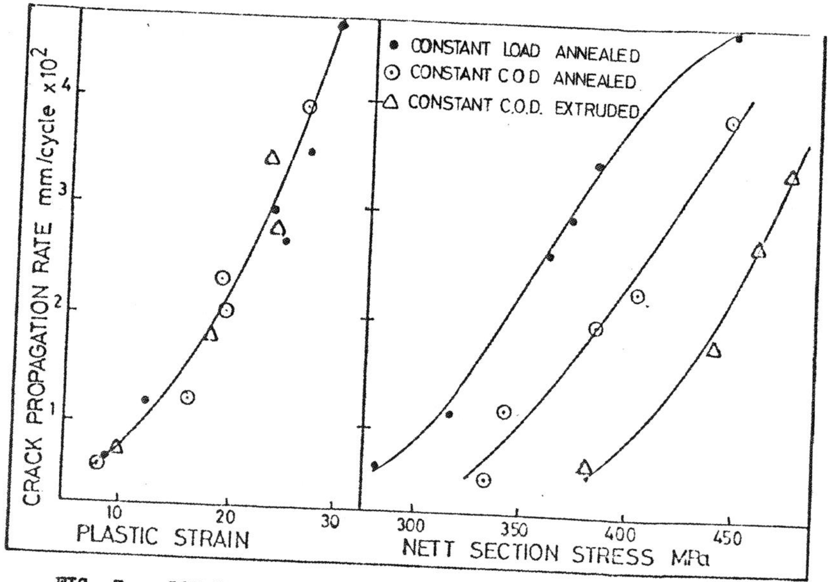


FIG. 3. LOW-CYCLE FATIGUE OF COPPER - PLASTIC STRAIN IS PLASTIC COMPONENT OF C.O.D.; NETT STRESS PROPORTIONAL TO ΔK.