Correlation between Fracture Toughness and Stretched Zone Size

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1 INTRODUCTION

A stretched zone is formed at the tip of the fatigue crack in a fracture toughness specimen before fracture occurs. The stretched zone is visible on electron micrographs of the transition from the fatigue crack to the ductile dimple rupture. It consists of coarse wavy slip lines.

There has been some speculation as to the significance of the stretched zone. Spitzig [1] proposes that it is a measure for the process zone or ligament spacing in Kraffts [2] model. He concludes that the critical crack tip opening displacement (CTOD) is equal to the width of the stretched zone. Gerberich and Hemmings [3] decide that this is probably incorrect. Griffis and Spretnak [4] , Broek [5] , Brothers et al [6] and Wolff [7] consider the stretched zone a result of crack tip blunting (Fig.1). This implies that the dimensions of the stretched zone should be a measure of the CTOD at fracture.

It has been tried to correlate the width of the stretched zone with the critical CTOD, but not always successfully. Figure 1 shows that the apparent with $\bar{w}$ depends upon the angle of observation in the microscope and $\bar{w}$ is not always equal to the true width w. The figure also shows that w is not the relevant dimension of the stretched zone and that rather the depth d should be a measure of the critical CTOD. Large angle stereoscopic measurements are an excellent means to determine fracture surface topography [5,8] . This technique was used here to measure d and the results were correlated with the critical CTOD in fracture toughness tests.

Use was made of 14 fracture toughness specimens from an investigation by Van Leeuwen [9] . One specimen was of the 7075-T6 type, the others were taken from 7079 type aluminium alloy forgings. The forgings were heat treated to have widely varying fracture toughness properties. Replicas were made of the transition regions of all specimens and series of large angle stereoscopic pictures were taken at angles of + 18°, 0° and -18°. The dimension d was measured at several places in each specimen.

2 RESULTS AND DISCUSSION

Figure 2 presents an example of the results, obtained by stereo microscopy. The three micrographs at + 18°, 0° and -18° show the large parallax which can easily be measured to a reasonable accuracy. The series of three micrographs gives a good idea of the topography already. Topographic measurements made along four cross sections are also presented in figure 2. They show how d can be determined, although there are sometimes difficulties in the interpretation, since it is not always clear where the stretched zone begins and ends. In section III e.g. the part beyond N does not belong to the stretched zone; rather it is part of an extended void formed around inclusion J. The stretched zone is bounded by DHNR. Figure 2h gives a schematic outline of the topography. It shows that the magnitude of d is different in the four sections as a result of steps in the fatigue surface. Rapid tilting by hand of the specimen in the microscope allows direct observation of this topography. Then the microscopist can draw already a rough picture of the type of figure 2h, thus facilitating stereoscopic measurements in a later stage.

In view of the large variation of d through the specimen many measurements are required to obtain a reliable mean value of d. As outlined in figure 1 and by stereoscopy of matching fracture surfaces [5]. 2d should be equal to the critical CTOD, i.e. $2d = C\,K_{Ic}^2/E\sigma_{ys}$. The constant C in this equation is subject to doubt. It was taken at 0,4 here under the assumption that the effective yield stress is in the order of 2.5 times the unaxial yield stress due to the plastic constraint.

Mean values of 2d were plotted versus $0.4\,K_{Ic}^2/E\sigma_{ys}$ in figure 3. There appears to be a good correlation. Values of w as determined from the present measurements were plotted in figure 4. It is evident that d, rather than w is related to CTOD. A plot of w versus d in figure 5 indicates that on the average $w \approx 1.3\,d$, which means that the crack tip blunts to an angle of about 74° on the average. Of course, this angle will depend upon the orientation of local slip planes and therefore it will vary through a specimen and it will be different for different materials.

Blunting of the crack tip by slip takes place because a critical strain as well as a critical stress have to be build up before fracture by void initiation and coalescence can take place. This was amply discussed earlier [5,10].

3 CONCLUSION

There is a fair proof that the stretched zone represents the blunting of the crack before fracture. The width of the zone is not a good measure for the critical crack opening displacement, since there is no unique relation between w and d. The depth d of the stretched zone represents the crack opening displacement at fracture.

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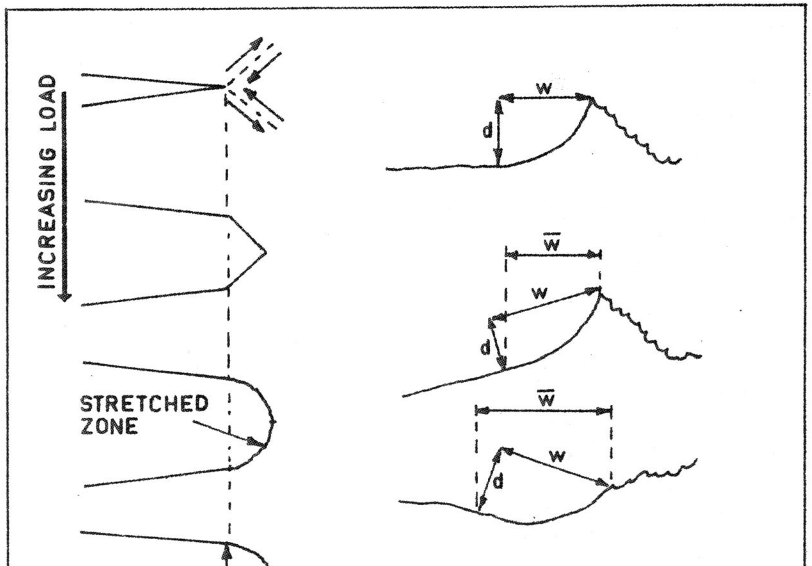

Fig.1 Crack tip blunting and stretched zone

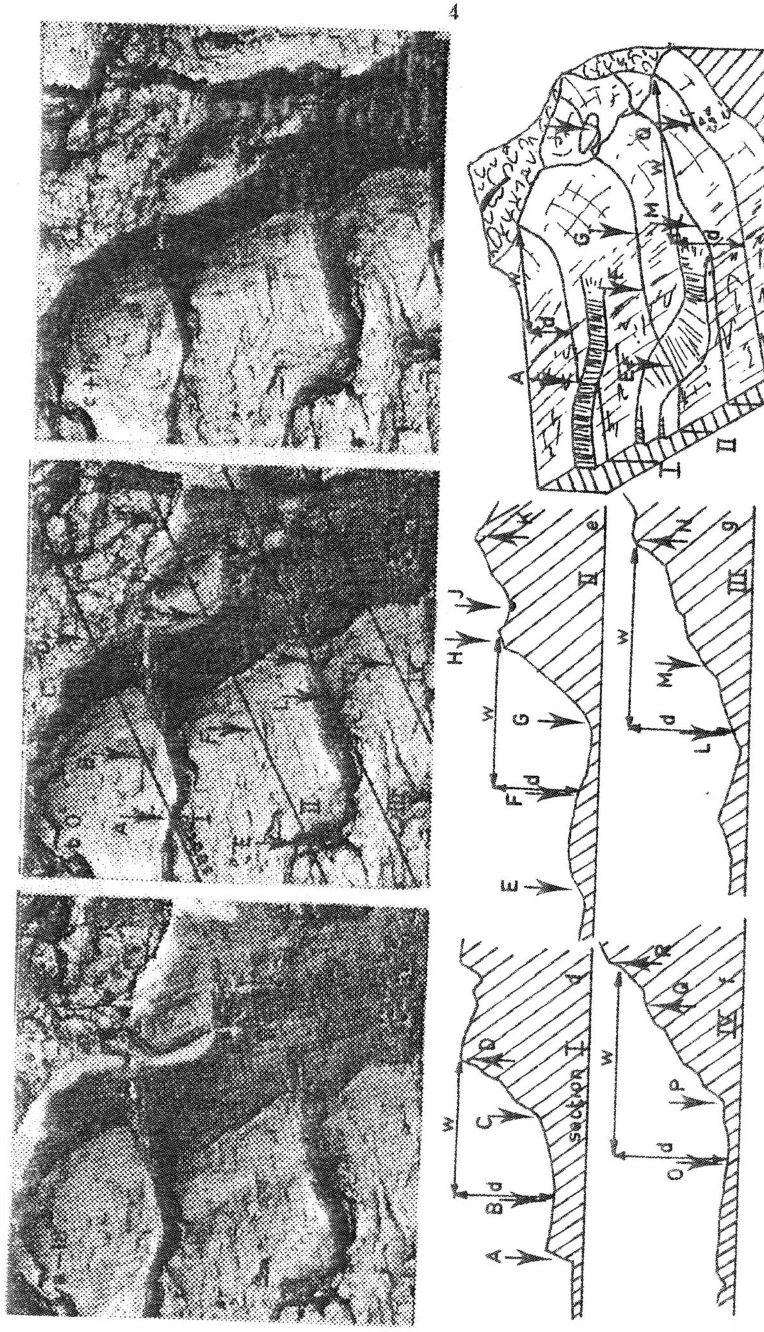

Fig.2 Topography of stretched zone

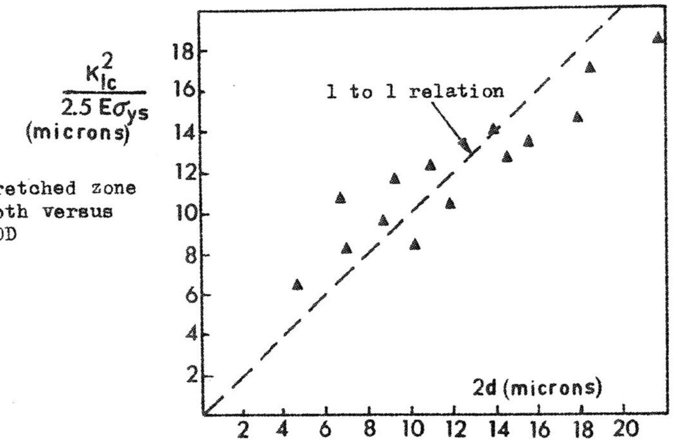

Fig.3 Stretched zone depth versus CTOD

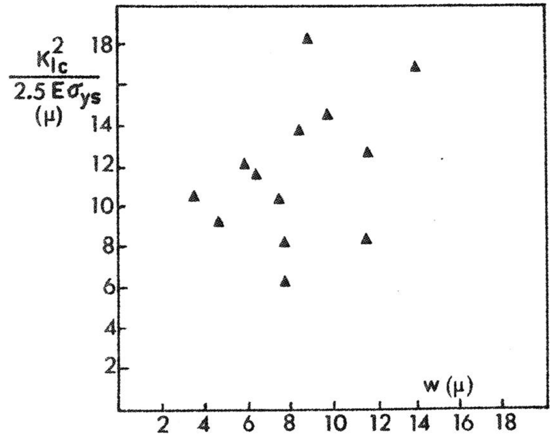

Fig.4 Stretched zone width versus CTOD

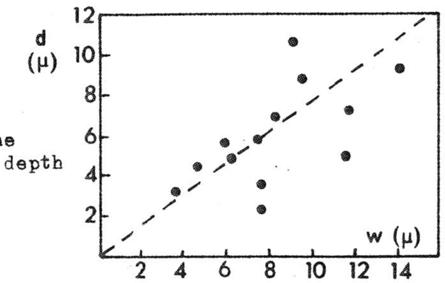

Fig.5 Stretched zone width versus depth