THE EFFECT OF THE GRAIN SIZE ON THE CRITICAL DEPTH FOR THE EVALUATION OF LONG-LIFE FATIGUE STRENGTH USING THE CRITICAL DEPTH CRITERION

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INTRODUCTION

Most fatigue cracks of mechanical parts initiate in stress concentration zones where the material is simultaneously submitted to a complex state of stress gradient. when calculating notched parts for example submitted to multiaxial stresses, the mechanical engineer is faced with two problems : first he must have a long-life fatigue criterion for the material submitted to the complex stress state, allowing a forecast of behaviour from monoaxial fatigue testing results (under tension, rotating bending, etc...). Then he must be able to introduce into this criterion the concept of stress gradient which, as it is well known, influences considerably fatigue behaviour. A great deal of research has been done on both aspects of this problem [1], but there has been until now no general criterion available to take simultaneously into account the stress gradient and the multiaxial stress state.

CRITICAL LAYER CRITERION

FLAVENOT and SKALLI [2] have presented research work aiming at establishing the fundamentals of a general criterion. Analysing results of fatigue tests on notched specimens, they have been able to illustrate the use of critical depth characterizing the microstructural state of the material.

This new parameter should be representative of the elementary volume acting during the damage process at fatigue crack initiation. Integrating this concept into a fatigue criterion under multiaxial stresses gives a general criterion which agrees well with experimental data. For example DANG VAN criterion is written as follows :

$$\tau_a + \alpha P_{max} < \beta \qquad \text{(DANG VAN)} \quad (1)$$

Where τ_a is the local shear stress in the most unfavourable oriented plane, and Pmax the maximum hydrostatic stress of the fatigue cycle. DANG VAN criterion can be used with some modifications in the case of general loading (non proportional).

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In the new criteria, in order to take into account the physical mechanisms of crack initiation, particularly shearing of the crystallographic planes in a grain of metal, the mean values of the shear stress $\bar{\tau}_a$ and the mean value of the hydrostatic stress Pmax are used. These mean values are averaged over the volume element from the surface to twice the critical depth (layer thickess)which is an intrinsic caracteristic of each material. The value of the critical depth will be different according to the material concerned. The critical depth depends upon the microstructure (the grain size for example). The grain size of the metal can play a different role in slip motion, crack nucleation, and crack growth stages of the fatigue process. The scope of this paper is the grain size effect on the values of critical depth. A low-carbon steel (XC10 grade steel) is used for this study. Three differents kinds of microstructure were obtained by heat treatment.

RESULTS

For each grain size, two fatigue limits at 10^7 cycles was determined for two different mean stress and stress amplitude using unnotched specimens and tension-compression loading. The straight line which expresses the "behaviour law" of the material for a given grain size, can be obtained using the DANG VAN criterion. Then we plot the calculated mean values ($\bar{\tau}_a$,Pmax) for a notched specimen (Kt = 3) at some definite distance from the surface (depth) which depends on the material (grain size) and for which the experimental data for notched and unnotched specimens are regrouped align themselves along a single straight line, whatever the specimen geometry. Fig.1 shows the modified DANG VAN diagram for differents grain size of the material at their "critical depth". The Fig.2 shows the results of the ratio K = CD (critical depth)/GS (grain size) as a function of the grain size. It can be seen that when the grain size increases the ratio K decreases. This presumably is because short cracks can soon be retarded by grain boundaries for the small grain size. So for a smaller grain size material, the length of the short cracks must be a bigger proportion in relation to the grain size to cross the "wall" formed by the grain boundaries.

CONCLUSIONS

As it was well known, this study shows that the grain size has a significant influence on the fatigue limit. Besides this work shows that the critical depth criterion used for taking the stress gradient in notches into account is a parameter which clearly depends on the microstructure of the materials. The critical depth is different for different grain size of the same XC10 grade steel. The ratio K = CD (critical depth)/GS (grain size) is not constant (K = 0,5) as assumed by certains authors [3]. A detailed study of the role of the grain size in the slip notion, crack nucleation and growth stages of the fatigue process is required for a better understanding of the physical signification of the "critical depth" concept.

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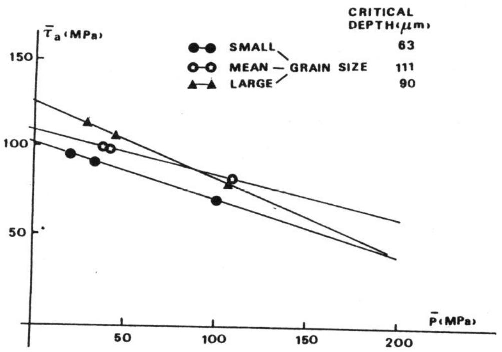

Fig 1 DANG VAN diagram for three grain size of a XC10 grade steel at their critical depth.

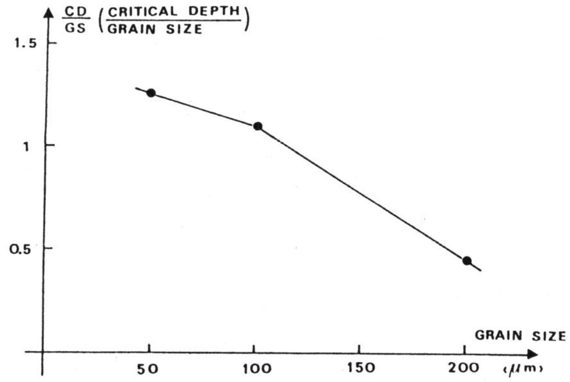

Fig 2 Ratio of CD (critical depth)/ GS (grain size) as a function of the grain size of the material.