AN ANALYSIS OF TIME DEPENDENT DUCTILE FRACTURE

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Application of energy rate line integral C* is being widely tried to describe time dependent crack growth in ductile materials[1,2,3], though other parameters like stress intensity factor[4], reference stress[5] and net section stress[6] could describe the phenomenon in some special cases. The J-integral approach having been developed for and applicable to only non-linear elastic materials implicitly assumes that the energy required for the formation of the crack is only the surface energy. However, in ductile materials that show plastic deformation at the crack front, the energy to be supplied for the crack growth is both the surface energy and the plastic energy, as the crack wades through the plastic zone. Doubt then arises as to how effectively C* can describe the crack growth in ductile materials. Fig. 1 shows the relation between da/dt and C*[2] which clearly indicates that there is no unique relationship between the two variables and it depends on the applied stress.

The energy supplied to the material as it creeps ($=P\dot{\Delta}$) is utilized not only for the crack extension but also for creeping of the rest of the material. What fraction of the energy supplied is used for crack extension and whether that fraction remains a constant or is a function of the crack length are to be clearly analysed, if the energy based approach is to be employed for creep crack growth. Fig. 2 shows the relation between da/dt and the modified J-integral J*[3]. Here again the data clearly indicate the load dependence of the relation.

When the deformation is localized near the crack tip, as it happens in a bending type of loading of a deep notched member, as shown in Fig. 3., an approach based on the COD rate near the crack zone may be successfully applied for the prediction of crack growth rate under creep conditions. In the case of a creep brittle material there will be very little crack tip deformation and the bending deflection, $\dot{\theta}$, or the COD rate, $\dot{\Delta}$, will be mainly due to the crack growth rate, $\dot{a}$, so that

$$\dot{\theta} \propto \dot{\Delta} \propto f[\dot{a}] \qquad (1)$$

In the case of very ductile materials, there will be a lot of crack tip deformation which will contribute to the deflection or COD rate. For a constant crack length, if the crack tip deformation takes place as shown in the figure, then

$$\dot{\theta} \propto \dot{\Delta} \propto f[\dot{\varepsilon}_{tip}] \propto [\sigma^{\alpha}_{tip}] \qquad (2)$$

In engineering materials, both crack tip deformation and crack growth will contribute to the COD rate, so that

$$\dot{\Delta} \propto f[\dot{a}][\sigma^{\alpha}_{tip}] \qquad (3)$$

As the crack grows σ_{tip} will increase. However, in ductile materials lot of crack blunting will take place. At high temperature relaxation at the crack tip will reduce the crack tip stress σ_{tip}. In such cases and for small crack length variations, σ_{tip} can be taken to be proportional to the applied bending moment so that

$$\dot{\Delta} \propto f[\dot{a}][M/M_0]^{\alpha} \qquad (4)$$

where M_0 is a constant.

EXPERIMENTAL

The materials investigated were (a) 6242 Ti alloy (a creep brittle material) and (b) 6061 Al alloy which shows good plastic deformation. Deep notched CT type specimens and large centre crack tension type specimens were used for the study. The load was applied through a pin joint which gave rise to bending type of loading on the ligament. The experiments were carried out at a specimen temperature of 275°C for Al alloy and 535°C for Ti alloy. The load point deflection and the crack growth with respect to time were measured with an accuracy of 0.01 mm. The experimental details are described elsewhere[7].

RESULTS AND DISCUSSION

In the materials tested, the Ti alloy showed very little plastic deformation at the crack tip and behaved like a creep brittle material. Such being the case, eqn. (1) is applicable to this alloy and the relation between $\dot{\Delta}$ and $\dot{a}$ is shown in Fig. 4. The relation does not depend on the load level. However, in the case of the aluminium alloy, there is lot of plastic deformation at the crack tip as the crack grows. The load point deflection rate (which is proportional to the COD rate) versus the crack growth rate shows a load dependence as given in Fig. 5. For a given da/dt, the deflection rate is a power function of the load with the exponent $\alpha=4$ in this case. Since the applied load induced a bending on the ligament, the bending moment was calculated and the relation between $\dot{a}$ and the parameter $[\dot{\Delta}/(M/M_0)^{\alpha}]$, according to eqn. 4, is shown in Fig.6., for the two types of specimen geometries used in this investigation. The data for both types of specimens fall on the same line on the log-log plot with a slope of 1.35 showing thereby the geometry independence of the parameter. The exponent α is an index of creep brittleness or creep ductility of the material. The value of α=zero for creep brittle materials where the deflection rate will be a function of the crack growth rate only. As the ductility of the material increases so will be the value of α.

This approach will be valid only when the load point deflection is contributed by crack growth and the crack zone deformation alone. If there is bulk deformation of the material then the approach has to be modified. However, in many practical applications, growth of a single dominant crack due to creep is likely to occur only under bending type of loading where there will be steep stress gradient and large crack tip deformation. In such cases the above COD based approach can be successfully applied, specially in the absence of any well founded crack growth criterion in ductile materials.

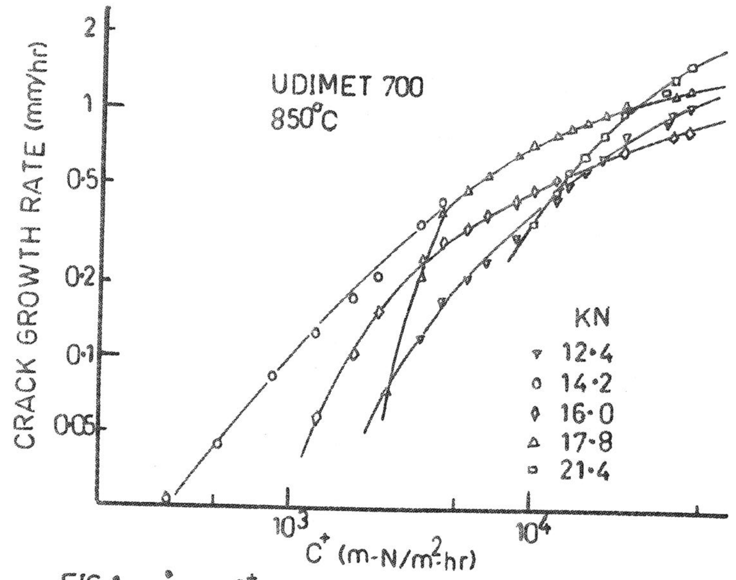


FIG.1. $\dot{a}$ vs C^*

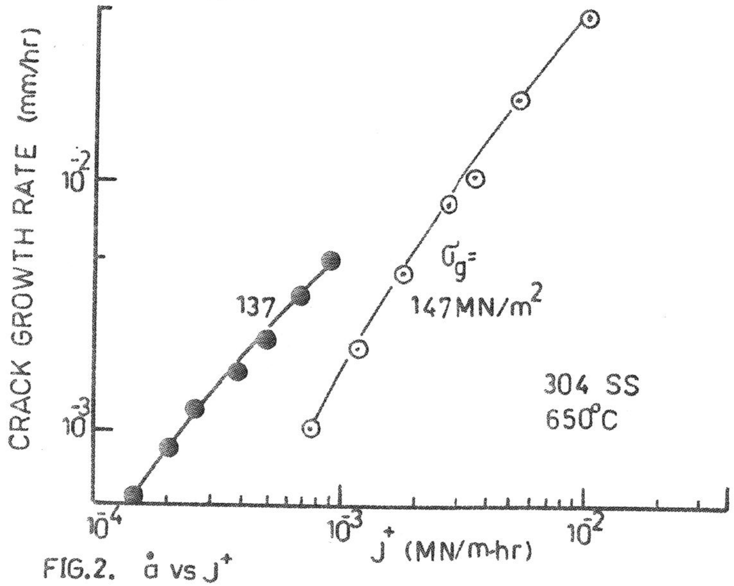


FIG.2. $\dot{a}$ vs J^*

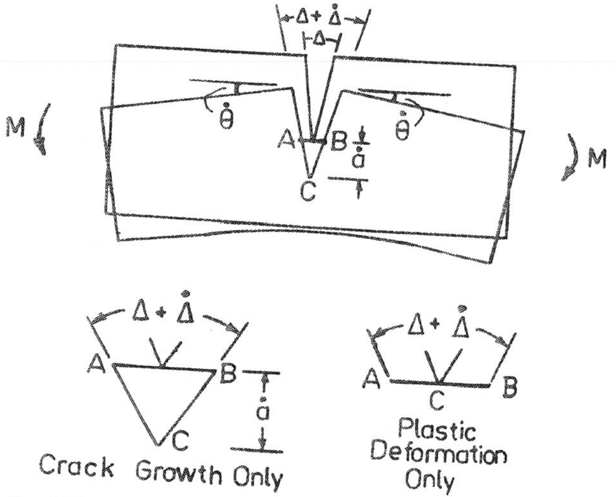
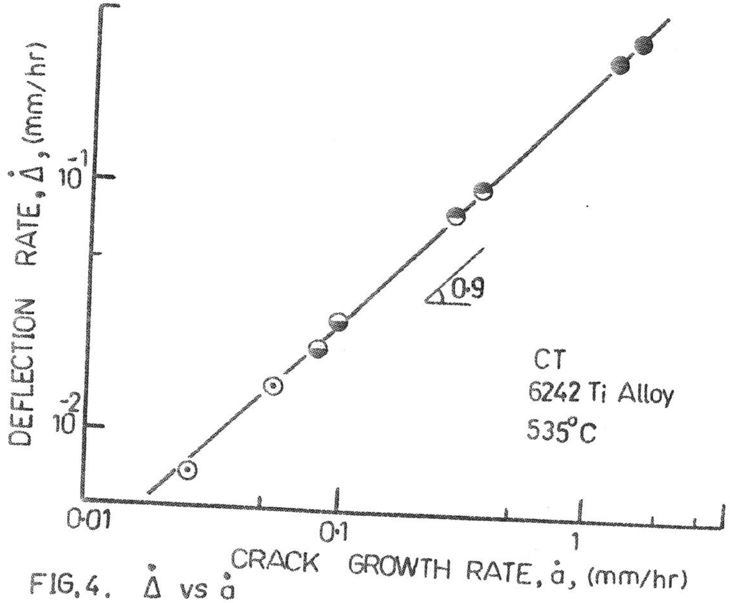


FIG.3. CONTRIBUTION TO DEFLECTION RATE.



FIG,4. Δ̊ vs ȧ

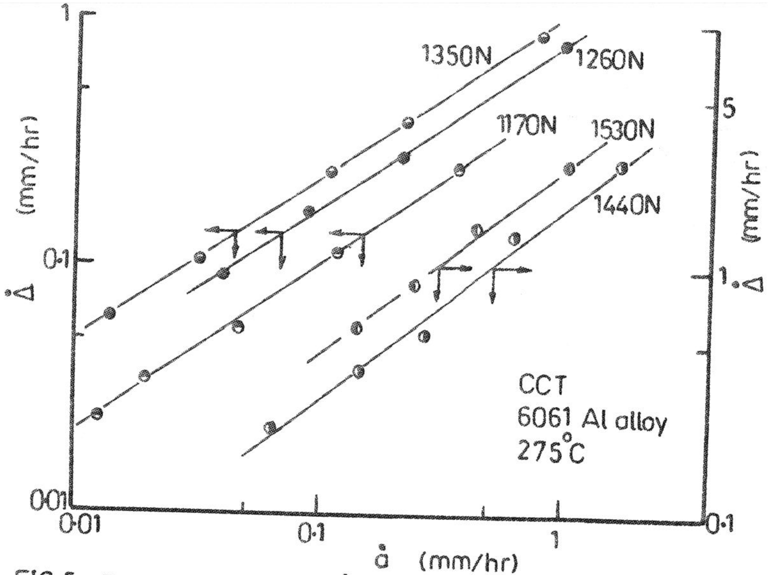


FIG.5. DEPENDENCE OF Δ̊ vs ȧ ON LOAD.

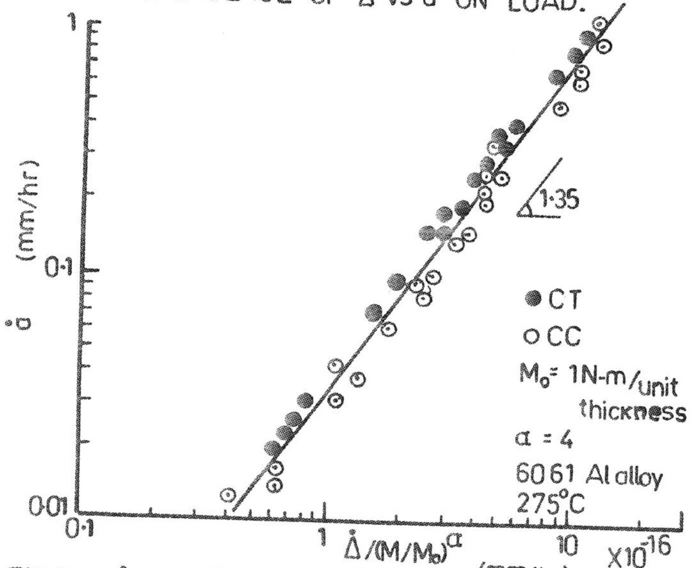


FIG.6. ȧ vs THE PARAMETER.

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