Rapid Crack Propagation in Strips of Finite Width

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An important quantity in crack propagation studies is the energy dissipated by a crack moving steadily at a high velocity. A method for determination of this energy is the analouge to the static fracture toughness test i.e the energy released from the elastic field is calculated from observed load levels at fracture and then equated to the fracture energy. The situation in dynamic experiments is much more complex than in static cases and rather crude idealizations have to be made. Therefore only cases where a steady-state assumption appears realistic will be considered here. For this purpose a special specimen configuration is used.

Specimen and the energy-release rate

The specimen has the dimensions and loading conditions shown by the solid lines in fig.1. It is considered as a practical realization of the infinite strip configuration indicated by the dashed lines. The strip contains a semi-infinite crack propagating steadily with the velocity V. By using the path-independent integral for the energy-release rate (ref.[1]), it is easy to show that for the infinite strip

$$G_\infty = \frac{v_0^2 E}{h(1-\nu^2)} \qquad \text{plane stress} \qquad (1)$$

independent of V. E and ν are the elastic constants of the material.

In order to correct for the finite width in the x-direction, the static stress-intensity factor is calculated by a FEM-technique (ref.[2]). These calculations reveal that K_s is approximately constant between 0.3w to 0.7w. The following approximation for the energy-release rate is then made

$$G = G_\infty \left(\frac{K_s}{K_{s\infty}}\right)^2 \tag{2}$$

where $K_{s\infty}$ is the static stress-intensity factor for the infinite strip given by Rice [3]. The validity of eq.(2) is supported qualitatively by the experimental investigations performed by Bradley and Kobayshi [4].

Material and experimental details

Two materials were studied. The first was an austenitic stainless steel with a yield stress of 1340 MN/m^2 and a fracture toughness of 49 MN/m$^{3/2}$. The second material was common brass with a yield stress of 540 MN/m^2 and a fracture toughness of 97 MN/m$^{3/2}$. The specimens were manufactured from cold-rolled foils with a thickness of 0.05 mm for steel and 0.10 mm for brass. A state of plane stress can then be assumed to prevail.

In order to initiate fracture at different load levels an initial crack with a length between 10 to 25 mm was cut into the specimen. A special loading device with a very high stiffness was used so that the fixed grip conditions were fulfilled with good accuracy.

The propagation velocity was measured by an electric method developed by Carlsson [5].

Velocity recordings

The velocity recordings for the steel experiments are of two types. The first one (A) is characterized by a rather constant velocity during the main part of the fracture(fig.2) The second type (B) can be described as large oscillations about an approximately constant value (fig.3). Type (A) occurs when V/C_2 is less than 0.41 and type (B) in the higher velocity region. It was found that the velocity-oscillations can be ascribed to the tendencies for irregular propagation that appear at high velocities and/or loads.

The recordings for the brass experiments are all of the same type (fig.4). The acceleration period is rather long and in contrast to the steel experiments, the crack decelerates and hits the boundary with a low velocity. The period of constant velocity is short. It may also be noted that in all cases is the unstable growth preceded by a substantial amount of stable crack growth.

It appears from the above results that the steady-state approximation is only good for the type(A) steel tests. In order to obtain some meaningful comparison, the mean velocity over a 40 mm long interval in the central part of the specimen is calculated. This is done for all the tests, except for the type(B)-curves where the interval is chosen to cover a whole period of the oscillations.

The fracture energy

From the observed value of v_0 at fracture, G is calculated for each experiment. The mean-value over the above mentioned interval is then equated to the fracture energy γ_f. These results are plotted against the mean-velocity in fig.5 for both materials. Note that γ_f has been normalized with respect to the static value for each material and that V has been normalized with respect to the shear-wave velocity C_2. It looks as if the values fall on the same curve for both materials, but at present this is to be regarded as a coincidence. It was not possible to investigate a higher part of the curve for brass due to the limitations set by the above mentioned stable crack growth.

The scatter is remarkably low especially for the steel experiments. The results for the brass material can be improved by using larger specimens so that the constant velocity period becomes more pronounced.

It is now easy to explain the difference of the curves for steel and for brass. For brass the velocity is more sensitive to the current value of G than for steel.In fact K_s drops slightly as the crack approaches the boundary,and this decrease is enough to lower the velocity very much, while it hardly affects the velocity in the steel tests.

As seen from fig.5, γ_f increases rapidly with the crack velocity. Different explanations have been given for this behaviour. It has for example been proposed that the rate-dependence of the yield-stress should play a significant role in limiting the crack velocity (ref. [6]). It is however extremly difficult to measure such rate effects at the relevant strain-rates. For the present materials no such data are available so that any quantitative comparison with the theoretical models can not be made.

Another factor which might influence the fracture energy is the fracture surface roughening. It was found that this roughening increased with the velocity and was very marked for the type(B) steel tests. The roughening enlarges the effective fracture area and thus increases γ_f.

Acknowledgement

The investigation was made during the tenure of a grant from the Swedish Board of Technical Development. The author wants to express his gratitude for this grant.

References

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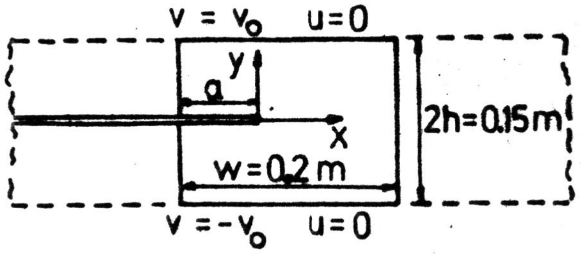

Fig.1. Idealized and real specimen

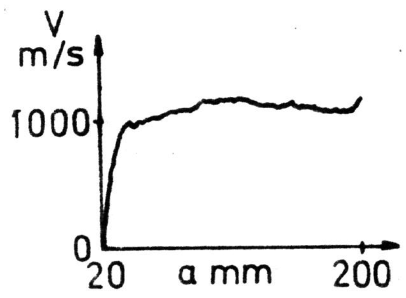

Fig.2. Steel type(A)

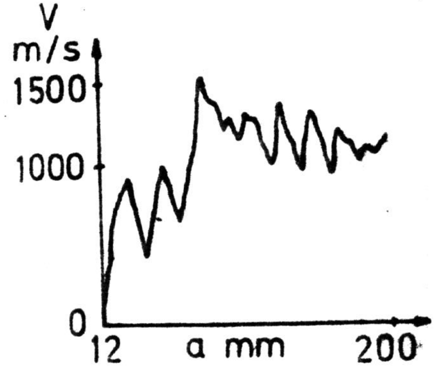

Fig.3.Steel type(B)

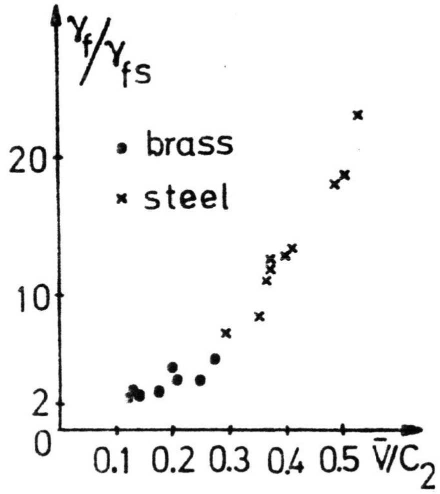

Fig.5. Fracture energy

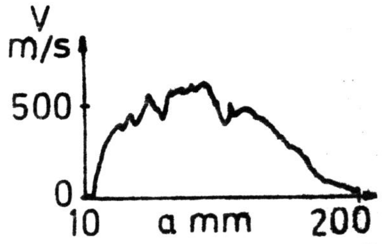

Fig.4.Brass