R-CURVES FOR MATERIALS WITH LARGE FRACTURE TOUGHNESS TO YIELD STRENGTH RATIOS

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Unless certain minimum size requirements are satisfied, cracking of sheet materials with high fracture toughness \( R \) and low yield stress \( \sigma_y \) is often complicated by generalised yielding in regions away from the crack tip. For materials with \( \sqrt{ER}/\sigma_y > 0.2\sqrt{m} \), these requirements become prohibitively large for most laboratory tests. To tackle this problem, various theories such as near tip strain, \( J \)-integral, crack opening displacement, and equivalent energy have been suggested as criteria for ductile fracture. Independently, Gurney, Mai, and Owen [1] have developed a new experimental technique involving the construction of an apparatus which reinforces laboratory size testpieces so that all irreversibilities caused by generalised yielding in parts remote from the crack tip are eliminated. Figure 1 shows the apparatus used in [1]. The webs of the channel section made of steels with high yield strengths (\( \sigma_y \approx 200 \text{ ksi} \)) are the reinforcements to the testpiece, and insofar as the load application arms (i.e., the flanges) remain elastic, valid fracture toughness values representing large scale brittle behaviour of the same material are determined unambiguously from the sector area method introduced by Gurney and Hunt [2].

The fundamental concepts of crack growth resistance curves (i.e., R-curves) and their use in prediction of critical cracking loads in sheet metals of various geometries have been described in ASTM STP 527. However, only R-curves for metal alloys with low and medium \( \sqrt{ER}/\sigma_y \) ratios are obtained. Although there is a need to extend the R-curve technology to more ductile materials possessing high toughness and low yield strength ratios, if the necessary testpiece size requirements are not met, valid R-curves will not be constructed. However, with the introduction of the Gurney apparatus, and the elimination of exceedingly large size testpieces, determination of valid R-curves for such materials in the laboratory is made possible. The present note discusses some preliminary results of valid R-curves for a 7075 aluminum alloy \( \sqrt{ER}/\sigma_y = 0.45\sqrt{m} \) and a thin warm mild steel \( \sqrt{ER}/\sigma_y = 0.7\sqrt{m} \) from experiments using the special test rig.

Using a beam on elastic foundation model for fracture analysis [1], it may be shown that (See Figure 1 with \( \epsilon = 1 \))

\[
\sqrt{ER} = K = \left[ \frac{\text{Sinh} (\lambda r) - \sin (\lambda r)}{\text{Sinh} (\lambda r) + \sin (\lambda r)} \right] M/\sqrt{It} \tag{1}
\]

where \( E \) is Young's modulus; \( K \), stress intensity factor; \( I \), second moment of web area; \( t \), thickness of fracture plane; \( M \), bending moment at crack extension; \( r \), length of unbroken ligament of testpiece and \( \lambda \), modulus of elastic foundation. The R-curve is determined by continuously recording the critical bending moment \( M \) as a function of \( \lambda r \). Since the test apparatus possesses good crack stability characteristics, it entails the complete determination of the R-curve for

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both the slow stable (sub-critical) and the continuous cracking regions.

Figure 2 shows the R-curve of 0.76 mm thick 7075 aluminum alloy. The Young's modulus and the yield stress for this metal are 73.5 GN/m$^2$ and 196 MN/m$^2$ respectively. It may be seen that in the slow stable growth region, the crack growth resistance rises gradually with crack extension. The variation of fracture toughness in the subsequent crack growth is probably associated with the effects of variation of crack speeds at the crack tip. A maximum toughness of 125 kJ/m$^2$ for the material has been obtained.

The feature of the R-curve for a thin warm mild steel with $E = 210$ GN/m$^2$ and $\sigma_y = 274$ MN/m$^2$ is shown in Figure 3. The negative $dR/dL$ behaviour of mild steel in the continuous growth region at room temperature is indicated by the instabilities on the R-curve. A maximum toughness of about 215 kJ/m$^2$ is recorded.

Due to the lack of published information on these two metals, no comparison of our R-curve results can be made. However, these results demonstrate the potential use of the Gurney apparatus for R-curve measurements of materials with large toughness and low yield strength.

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REFERENCES


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