**Title**
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LAWRENCE RADIATION LABORATORY
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# A METASTABLE AUSTENITE WITH PLANE STRESS FRACTURE TOUGHNESS NEAR 500,000 psi-in$^{1/2}$

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Recent tests on one high-strength metastable austenitic steel have shown it to possess an unusual combination of properties. This nominal 11Cr - 8Ni - 2Mo - 0.4Mn - 0.27C steel had a yield strength of 210,000 psi, an ultimate strength of 235,000 psi and an elongation of 47 percent. The major difference between this alloy and some other metastable austenites[1] was in the ease of the strain-induced phase transformation which may be described by the coefficient, m, in

$$V_{\alpha'} = m\varepsilon^{1/2} \quad (1)$$

where $V_{\alpha'}$ is the amount of the martensitic phase and $\varepsilon$ is the strain. Since the alloy content was 3 - 5 percent less, the value of m at room temperature was as much as a factor of two greater than m for those alloys reported previously.[1] While the alloys of the previous investigation had plane stress fracture toughness, $K_c$, values in the range of 200,000 to 320,000 psi-in$^{1/2}$, the present result showed $K_c$ values to range from 405,000 to 495,000† psi-in$^{1/2}$ with the average value being 440,000 psi-in$^{1/2}$. Keeping in mind that these results were obtained on 3-inch wide single-edge notch specimens, the plastic zone traversed the remaining plate width and so the results can only be considered as rough estimates. Nevertheless, no plastic zone correction term was utilized in the

† Part of what seems to be scatter is attributable to an adiabatic heating effect which is a function of crack velocity and hence testing speed.[2]

calculation and so this material possibly has a $K_c$ greater than 500,000 psi-$in^{1/2}$ which must be considered very tough for a 210,000 psi yield strength steel. To clear up any ambiguity, we currently are running some tests on 7-inch wide plates to obtain better $K_c$ estimates.

To account for the high toughness obtained in this class of steels, it was originally proposed[1] that at the tip of a crack, the invariant shear of the phase transformation was a more efficient energy dissipator than other plastic deformation processes. To see if the present result could be accounted for simply by the increased amount of phase transformation, a calculation similar to what was done before[1] was made. For example, the contribution of the invariant shear strain, $\varepsilon_{IS}$, may be given by

$$U_{IS} = \frac{\pi}{8} B \int_0^{R_p} m \varepsilon_{IS} \sigma_{\alpha'} \left(\frac{\sigma_\gamma}{E}\right)^{1/2} \left[\frac{R_p}{r} - 1\right]^{1/2} r \, dr \qquad (2)$$

for an elliptically shaped zone where B is the thickness, $R_p$ is the plastic zone length, and $\sigma_{\alpha'}, \sigma_\gamma$ are the flow stresses for martensite and austenite. Further calculations allowed the total energy to be given by $U_p \sim 4020\, R_p^2 B$ Lb/in$^2$. From measurements of the plastic zone height and the relationship between the length and height, a value of $U_p$ as a function of crack length was determined as shown in Fig. 1. At the point of crack instability, $\partial U_p/\partial a$ was roughly 6400 Lb/in which, from $K \sim [(\partial U_p/\partial a)\, E]^{1/2}$ gives a stress intensity of 440,000 psi-$in^{1/2}$. As the actual measured value for this specimen was 415,000 psi-$in^{1/2}$, it would indicate that the high toughness achieved in this alloy is directly attributable to the large value of m, since $\partial U_p/\partial a$ is directly proportional to m. Thus, it would appear that a relatively simple method for achieving excellent combinations of strength and toughness might be to make metastable austenites as unstable as possible, thereby giving relatively large values of m.

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## REFERENCES

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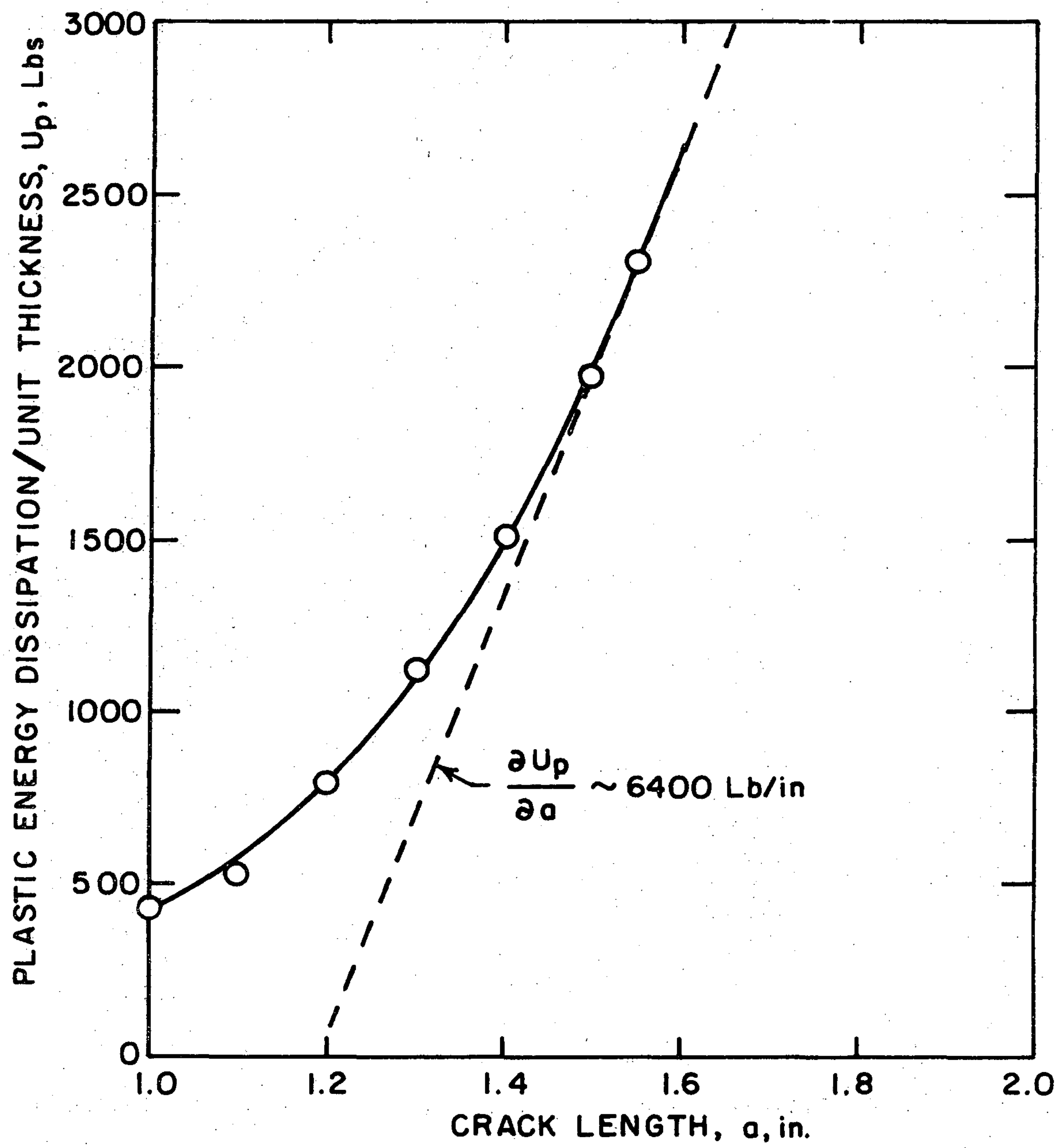


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Fig. 1. Plastic Energy Dissipation as a Function of Crack Length.