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LAWRENCE RADIATION LABORATORY
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A recent analysis (1) of the stretched region formed in fracture surfaces between the farique crack and overload fracture regions indicated that the regions could be related to the plane-strain fracture toughness, K_{IC}. Similar fractographic observations on a metastable-austenitic steel do not follow this relationship. From three separate specimens of this investigation, the stretched regiond were observed to be 2.7 to 7.6 μ in width. The corresponding values of stress intensity for the onset of crack growth were 121 to 153 ksi-in$^{1/2}$. This compares to the stretched regions (5-10μ) and K_{IC} values (51-65 ksi-in$^{1/2}$) observed by Spitzig (19) for a 0.45 carbon alloy steel. Thus, although the stretched regions were about the same in size, the stress intensity levels for the onset of crack growth were a factor of 2 to 3 different. The following discussion explores this discrepancy further.

Some previous observations (2,3) on these metastable austenetic steels, called TRIP steels, indicated some unusual fracture characteristics due to the strain-induced martensitic transformation occurring at the crack tip. From this standpoint, these steels are not desirable model materials with which to generalize about fracture surface marking. Nevertheless, the fracture surface markings were so clear that the stretched regions could be measured without ambiguity. This is important since the fatigue and

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and stretched regions were not well defined in the steels used by Spitzig (1). With the TRIP steels, fatigue striations, stretched regions and dimpled rupture were easily distinguished one from the other. One possible reason for this was that the particular heat evaluated did not transform to martensite at room temperature with plastic deformation. Thus, the fatigue precrack introduced at room temperature was in a face-centered-cubic austenite which gave relatively uniform striations.

MATERIAL, PROCEDURES AND RESULTS

The material processing consisted of forging at 2000°F, austenitizing at 2200°F for 2 hours, and rolling to a 75 percent reduction at 840°F. This produced 1/2-inch thick plate of the following composition: 13.5 Cr, 9.0 Ni, 3.0 Mo, 2.0 Mn, 1.0 Si, 0.20 C. Upon testing at room temperature, tensile specimens remained austenitic giving a yield strength of 181,000 psi, an ultimate strength of 196,000 psi and an elongation of 10 percent. Upon testing at -196°C, the strain-induced transformation was observed giving a yield strength of 258,000 psi, an ultimate strength of 322,000 psi and an elongation of 40 percent. As pertains to the fracture toughness, crack-line-loaded samples approximately 2.2 inches wide by 2.2 inches high were evaluated at room temperature and -196°C. With the aid of a crack-opening displacement gage to monitor load-displacement, the following stress intensity factors were calculated.

	Yield Strength ksi	Deviation from Linearity ksi-in$^{1/2}$	Maximum Load ksi-in$^{1/2}$
Tested at R.T.	181	153	213
Tested at -196°C	258	121	143

These values were calculated from the collocation solution provided by Srawley and Gross (4). The stress intensity value at the deviation from linearity in the load-displacement curve is reported since this represents the onset of gross plastic deformation and/or crack growth. Considering the stress intensity levels and the 1/2-inch thick specimens utilized, the room temperature data can only be considered as "apparent K_{IC}" since the plastic zone was fairly large compared to the thickness. From the resulting fracture surfaces, electron fractography was utilized to examine the transition region between the fatigue precrack and the overload fracture.

FRACTOGRAPHIC OBSERVATIONS

Two typical fractographs of the stretched region are shown for each of three specimens in Fig. 1. In 1(a) and (b), replicas taken from the transition region of a specimen tested at room temperature clearly show three regions starting from bottom to top: fatigue striations, stretched region, and shear dimples representing overload fracture. Similar markings were observed in the two specimens tested at -196°C, typical results being shown in Figs. 1(c) through (f). A slightly different procedure was used for the last two fractographs in that the fracture surface was slightly etched before the replicas were taken. It may be noted that the etching, which more severely attacks martensite, brought out a region of martensite fracture in Fig. 1 (f) which is quite different than the shear dimples observed in the austenite.

Four to seven separate fractographs were taken of each transition region allowing a reasonable estimate of the stretched region. Spitzig (1) has indicated that these may be related to the fracture toughness through either Krafft's (5) process zone size or the crack-tip displacement. As these two theoretical estimates give similar numerical results, only the crack-tip displacement will be considered here which, for plane strain, is given by (6)

$$2\nu_c = \frac{K^2}{2\sigma_{ys}E} \tag{1}$$

The suggested relationship (1) between stretched region and stress intensity used K_{IC} in Eq. (1). For comparison, the K at the deviation from linearity was utilized in Eq. (1) since this represents an estimate of "apparent K_{IC}". As will be shown, this does not show any correlation to the stretched regions in this investigation. It was surmised that some other factor might be controlling the size of this region. If one considers that this stretching process might occur over a region of highly dislocated material, then it would seem that the fatigue precracking operation may be an appropriate parameter. That is, the crack-tip displacement occurring during fatigue might control the subsequent size of the stretched region. Therefore, a calculation of $2\nu_c$ was also made based upon the fatigue-cracking stress intensity which ranged from 45.6 to 47.3 ksi-in$^{1/2}$. The resulting observations and calculations of stretched regions are given in Table 1. It is obvious that the estimates obtained from the fatigue-cracking value of K match the observations best. Thus, it is possible in this steel that the stretched region is controlled by the fatigue-precrack operation.

One further comment about the observations in Table 1 is in order. Although the stress intensity values for fatigue cracking, for linear deviation and for maximum load were nearly identical in specimen 2 compared to 3, the average stretched regions differed by a factor of two. It is possible that the etching, which was used exclusively in specimen 3, might have brought up some sub-surface markings which tended to narrow down the actual stretched region. Further confirmation that etching resulted in narrower stretched regions was obtained from an additional fractograph taken after etching specimen 1. The observed stretched region in this fractograph was 3.6μ as compared to 5.9 - 9.5 μ for all others.

In summary, it appears that the stretched region in these metastable austenitic steels may be related to the stress intensity level used to fatigue precrack the sample. The authors make no claim that the present observation is any more nearly valid than the previous one by Spitzig (1). Because of the limited data and the unusual fracture characteristics accompanying TRIP steel fracture, it is not reasonable to generalize this finding. However, because of the variance between those two findings, additional fractographic observations on a wide variety of materials would seem to be in order before any conclusions can be drawn. Thus, it seems that an orderly investigation of this phenomenon should be undertaken to determine if these stretched regions are a consistent fracture surface marking relatable to the loading conditions.

Acknowledgement

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Table I. Comparison of Stretched Regions to Crack-Tip Displacements

Test Temperature	Observed Stretched Region		Calculated Crack-Tip Displacement, $2\nu_c$	
	Range, μ(a)	Average, μ	For Fatigue, μ	For Linear Deviation, μ
Spec. 1 R.T.	(7) 3.6 - 9.5	7.6	5.2	55
Spec. 2 -196°C	(6) 2.3 - 10	6.5	4.8	24
Spec. 3 -196°C (b)	(4) 2.3 - 3.0	2.7	4.9	29

(a) Number of fractographs observed in ( ).

(b) Fracture surfaces slightly etched before replicas were taken.

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FIGURE CAPTION

Fig. 1 Fractographic observations of stretched regions in TRIP steels tested at room temperature (A,B) and -196°C (C-F).

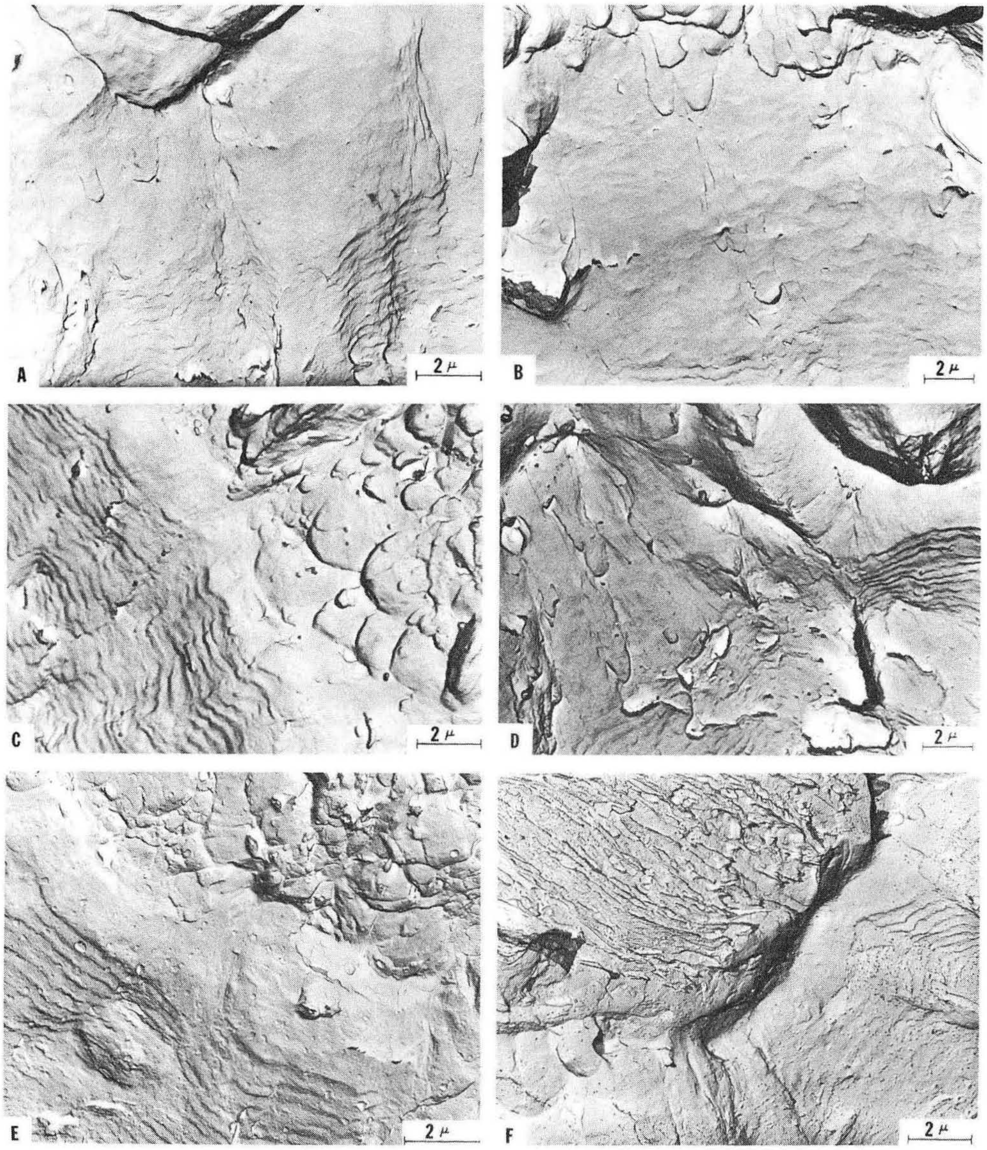

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Fig. 1

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