Title
OBSERVATIONS OP STRAIN-INDUCED MARTENSITE AROUND A CRACK

Authors
Gerberich, W.W.
Hemmings, P.L.
Zackay, V.F.

Publication Date
1968-10-01

OBSERVATIONS OF STRAIN-INDUCED MARTENSITE AROUND A CRACK

W. W. Gerberich, P. L. Hemmings, and V. F. Zackay

October 1968

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

DISCLAIMER

Submitted to Transactions of
the AIME

UCRL-18534
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

OBSERVATIONS OF STRAIN-INDUCED MARTENSITE AROUND A CRACK

W. W. Gerberich, P. L. Hemmings, and V. F. Zackay

October, 1968

OBSERVATIONS OF STRAIN-INDUCED MARTENSITE AROUND A CRACK

W. W. Gerberich, P. L. Hemmings* and V. F. Zackay

Inorganic Materials Research Division, Lawrence Radiation Laboratory
Department of Mineral Technology, College of Engineering
University of California, Berkeley, California

The strain-induced martensitic transformation may be used to attain desirable combinations of strength, ductility and fracture toughness. One of the parameters is the relative stability of the austenite. For example, it has been shown by Zackay, et al.[1] that the volume percent of strain-induced martensite is related to the combination of strength and elongation obtained. It has also been shown that the degree of transformation is an important factor in the crack propagation resistance of metastable austenitic steels.[2] Considering both tensile and crack-propagation tests, it was of interest to see if there was any functional relationship between the amount of strain and the volume of strain-induced martensite. Previously,[3] it had been shown that at room temperature, there was a relationship between uniaxial tensile strain and the volume percent of resulting martensite given by

$$V_{\alpha'} \simeq 1.2 \, (\epsilon)^{1/2} \tag{1}$$

The data were obtained by plastically elongating tensile samples to a certain strain and them measuring the field strength to determine the strain-induced ferromagnetic volume. This was accomplished for two conditions having yield strengths of 229 and 233 ksi. The nominal com-

---

*Present Address: Boeing, Seattle, Washington.

position of this material was 9 Cr - 8 Ni - 3 Mo - 2 Mn - 2 Si - 0.25C - 0.09N.

In evaluation of the strain-induced martensite at a crack tip,[2] the question arose as to whether Eq. (1) would also be valid under triaxial stress conditions. Tests were conducted on 1/2-inch thick plate material having a composition of 9 Cr - 8 Ni - 4 Mo - 2 Mn - 2 Si - 0.27C. It was found that sectioning, polishing and etching of fractured specimens could reveal the strain-induced martensite occurring at a crack tip. Care had to be taken to minimize the final polishing steps so as to avoid a smeared layer of strain-induced martensite. The method for taking metallographic samples from fractured crack-line loaded type samples is shown in Fig. 1. Observations of the strain-induced martensite occurring at room temperature and -196°C in 0.5-inch thick samples are shown in Fig. 2. It is seen that the martensite is most pronounced at the fracture surface where the strain is the highest. It is also evident that the martensite is concentrated along the maximum shear planes which occur at angles near 45°. Lineal analyses at 0.01 inch intervals for the room temperature test and at 0.005 inch intervals in the -196°C test were made to determine the volume fraction of martensite as a function of distance away from the fracture surface. These data were then compared to a theoretical estimate that was obtained in the following manner.

If the plastic strain distribution can be described and if Eq. (1) is also valid for conditions at a crack tip, then a relationship may be derived. The plastic strain distribution was assumed to follow that obtained by Hult and McClintock[4] for the longitudinal shear case, the tensile analogy of which has been shown to give a reasonable estimate of experimental strain distributions.[5] This is given by

$$\epsilon_{p_{\|}} = \left(\frac{R_p}{r} - 1\right) \frac{\sigma_{ys}}{E} \qquad (2)$$

where R_p is the plastic zone length, r is the distance away from the crack tip in the direction of crack prolongation, σ_{ys} is the yield strength and E is the modulus of elasticity. One deviation from Eq. (2) is necessary since the strain distribution in the vertical direction rather than in the direction of crack prolongation is desired. Considering an approximate circular zone, the half-height would be one-half the plastic zone length which would give

$$\epsilon_{p_{\perp}} = \left(\frac{R_p}{2r} - 1\right) \frac{\sigma_{ys}}{E} \qquad (3)$$

for an estimate of the strain distribution perpendicular to the fracture surface. Knowing R_p allows a description of $\epsilon_{p_{\perp}}$. Following Hahn and Rosenfield,[6] an estimate of the plane stress plastic zone length is given by

$$R_p = \frac{\pi K^2}{8 \sigma_{ys}^2} \qquad (4)$$

where K is the stress intensity factor.

There is one question as to whether this estimate is reasonable for the stress intensity values encountered in these 1/2 inch thick specimens. That is, the calculated and observed plastic zone sizes do not traverse the section thickness. However, the type of plastic deformation observed along shear bands does indicate a relatively plane stress situation as suggested by Hahn and Rosenfield.[6] Also, a calculation from Eq. (4) shows that the plastic zone lengths should be 0.173 inches for the room temperature tests with a K of 141 ksi-in.$^{1/2}$ and a σ_{ys} of 213 ksi; and 0.051 inches long for the -196°C test with a K of 81.5 ksi-in$^{1/2}$ and σ_{ys}

of 226 ksi. These represent half-heights of 0.0815 and 0.0265 inches which are close to the observed values of 0.070 and 0.030 inches taken from Fig. 2. Combining Eqs. (1), (3) and (4) give

$$V_{\alpha}' \simeq 1.2 \left[\left(\frac{\pi K^2}{16 \sigma_{ys}^2 r} - 1 \right) \frac{\sigma_{ys}}{E} \right]^{1/2} \qquad (5)$$

Comparing this estimate to the experimental observations for the room temperature test are shown in Fig. 3. Near the fracture surface it is seen that the predicted values of V_{α}' deviate from those observed by about a factor of 2. There would be an even larger deviation for the data obtained at -196°C. Inspection of Eq. (5) revealed that the coefficient, 1.2, rather than the exponent, 1/2, was in error. Adjustment of the coefficient in Eq.(5) was made to arrive at a reasonable fit to the data. Coefficients of 2 at room temperature and 6 at -196°C are seen to bring Eq. (5) into reasonable agreement with the data shown in Fig. 4. The fact that there was about three times as much strain-induced martensite per unit strain at -196°C as compared to room temperature is significant.

The tentative conclusions are (1) the effect of a partially triaxial stress distribution is to give more strain-induced martensite per unit strain than a uniaxial stress distribution and (2) that as M_s is approached, e.g. -196°C, the amount of strain-induced martenstie increases by as much as a factor of three.

Acknowledgements - This work was supported by the United States Atomic Energy Commission.

REFERENCES

1. M. D. Merz, G. R. Chanani, V. F. Zackay and E. R. Parker, "Tensile Properties of Lower-Carbon TRIP Steels," submitted to Trans. ASM for publication, 1968.

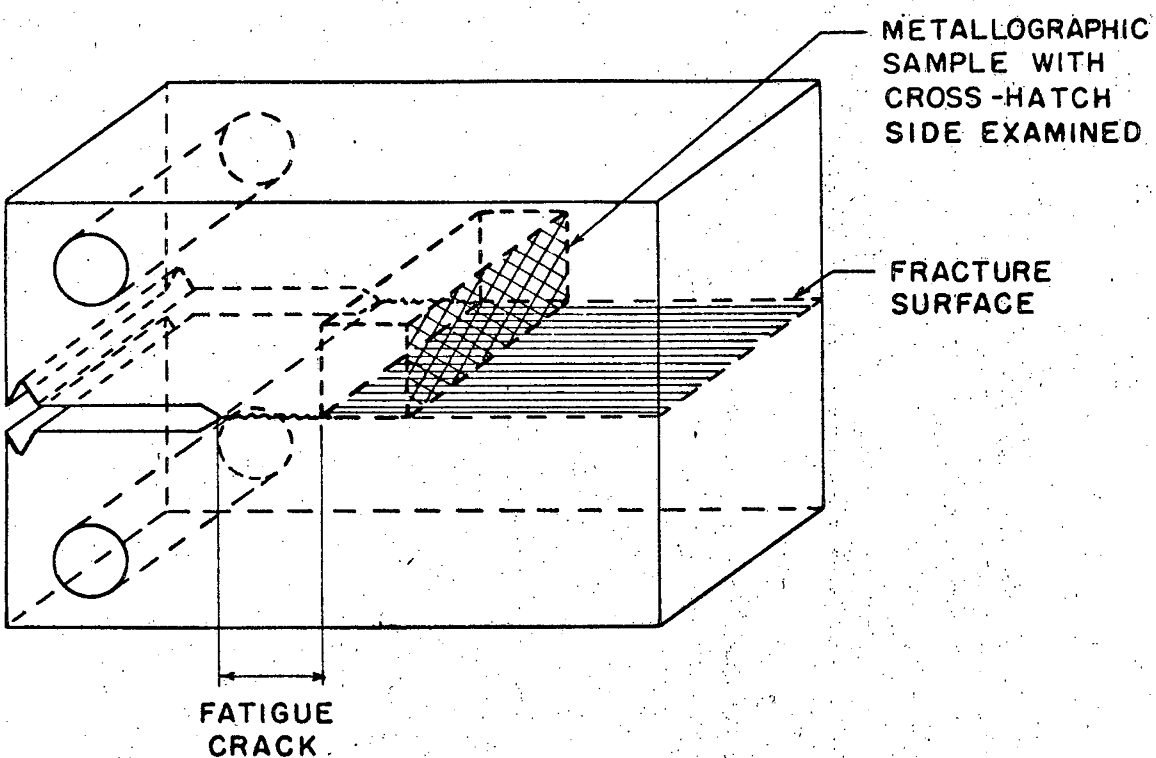
2. W. W. Gerberich, P. L. Hemmings, V. F. Zackay and E. R. Parker, "Interactions Between Crack Growth and Strain-Induced Transformation," to be presented at Second International Conference on Fracture, University of California, Berkeley, April 1969; UCRL-18467, September 1968.

3. B. De Miramon, "Quantitative Investigation of Strain-Induced Transformation Strengthening in Steel," M.S. Thesis, University of California, Berkeley; UCRL-17849, September 1967.

4. J. Hult and F. McClintock, Ninth International Congress of Applied Mechanics, 1956, Brussels, Vol. 8, p. 51.

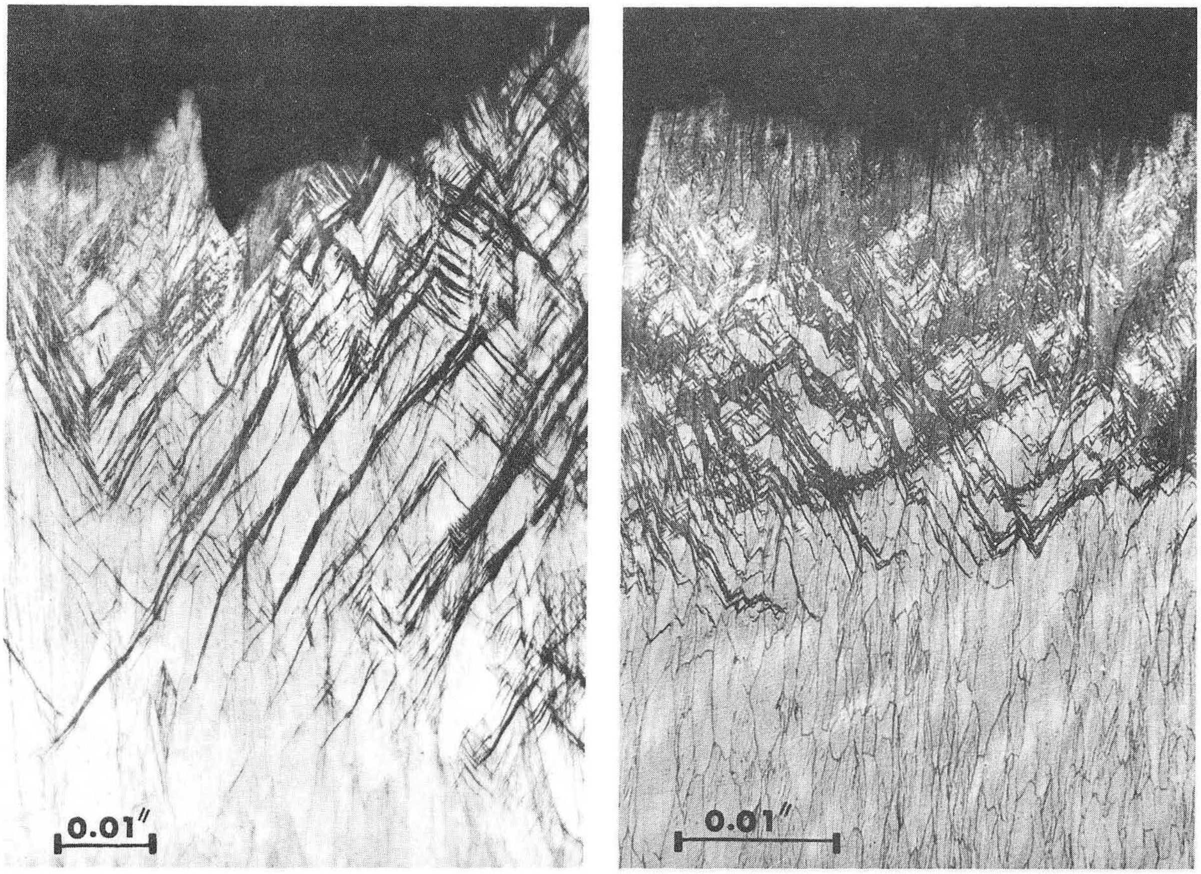
5. W. W. Gerberich, Experimental Mechanics, November 1964, p. 335.

6. G. T. Hahn and A. R. Rosenfield, Applications Related Phenomena in Titanium Alloys, 1967, ASTM STP 432, ASTM, Philadelphia, Pa.



XBL 6811-6141

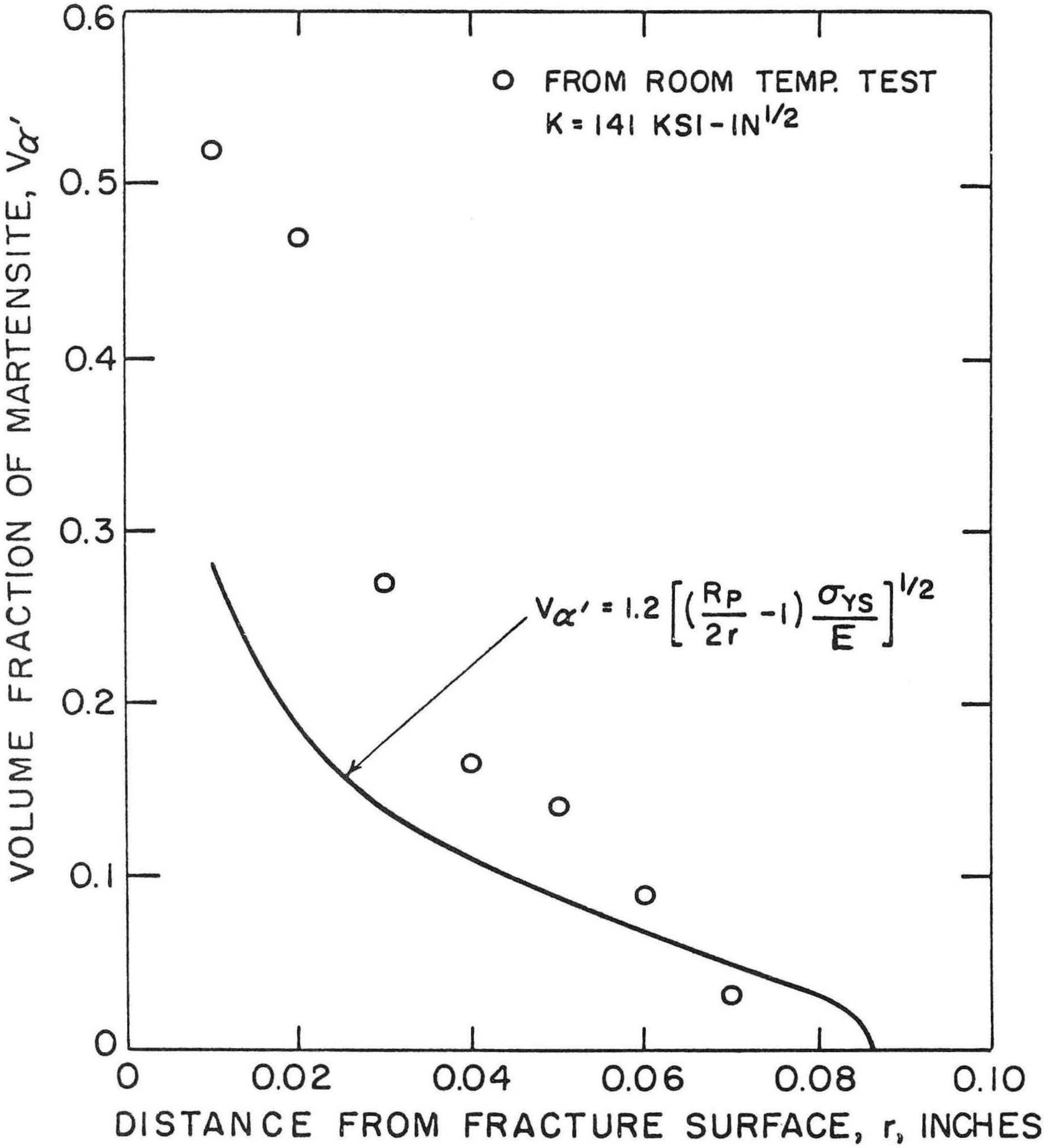
Fig. 1 Schematic of test specimen showing metallographic sectioning.



a) ROOM TEMPERATURE TEST. b) -196°C TEST.

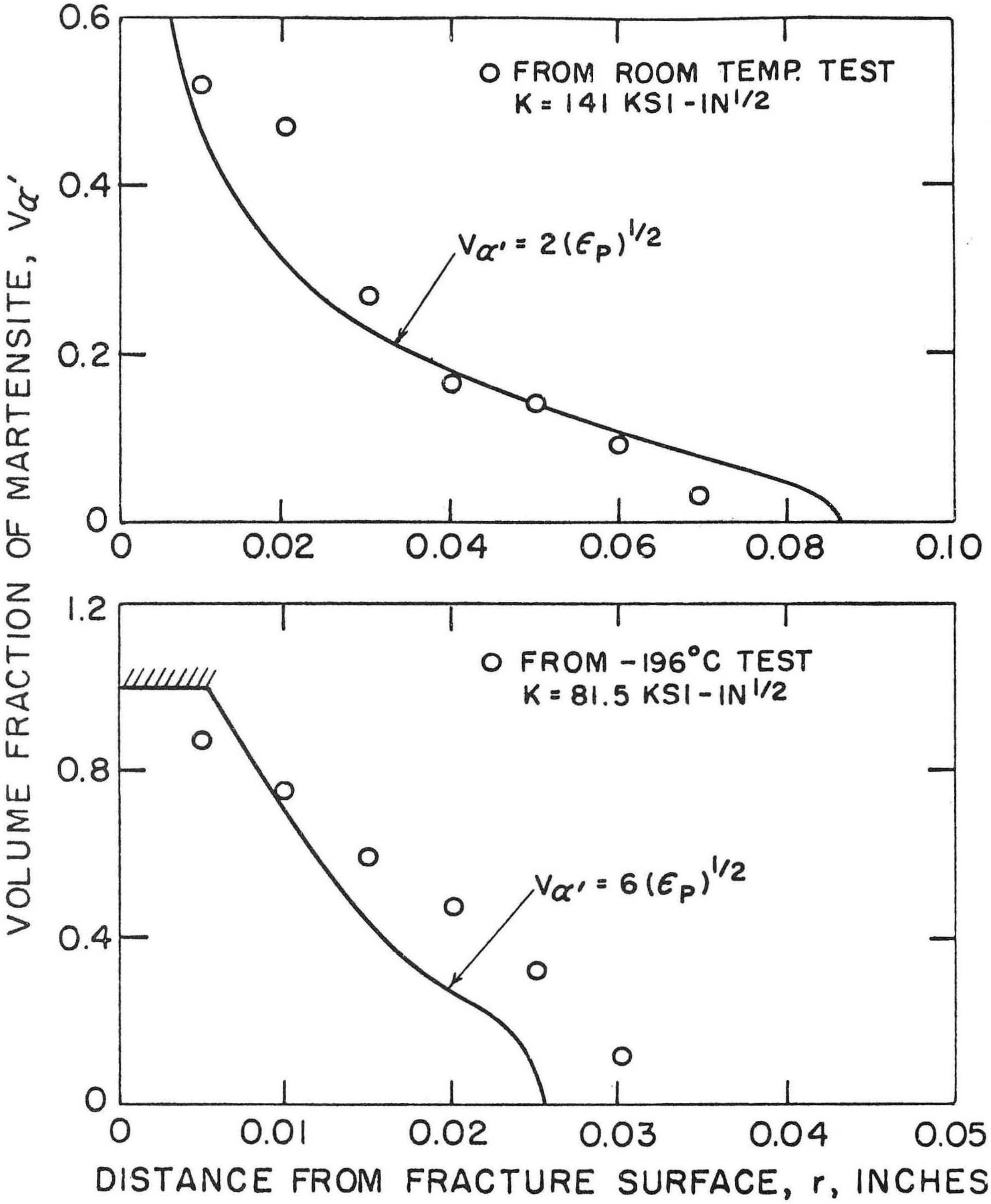
XBB 6811-6878

Fig. 2 Metallographic sections showing strain-induced martensite about fracture.



XBL 6811-6140

Fig. 3 Distribution of martensite about fracture compared to theoretical estimate based upon uniaxial behavior.



XBL 6811-6139

Fig. 4 Distributions of martensite about fracture compared to corrected estimates

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720