UCRL-18015

cy. 2

University of California

Ernest O. Lawrence Radiation Laboratory

NOTCH TOUGHNESS VARIATIONS IN STEELS
WITH THE SAME TENSILE PROPERTIES

Y. Katz and M. D. Merz

December 1967

RECEIVED
LAWRENCE
RADIATION LABORATORY

LIBRARY AND
DOCUMENTS SECTION

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

UCRL-18015 cy. 2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Submitted to the Journal
of the Iron and Steel Institute

UCRL-18015
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract W-7405-eng-48

NOTCH TOUGHNESS VARIATIONS IN STEELS WITH THE SAME TENSILE PROPERTIES

Y. Katz and M. D. Merz

December 1967

NOTCH TOUGHNESS VARIATIONS IN STEELS WITH THE SAME TENSILE PROPERTIES

Y. Katz and M. D. Merz

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

Various authors[1,2] have attempted to make some quantitative correlation between uniaxial tensile properties (such as yield stress, work hardening rate, and ductility) and fracture toughness as measured in a notched specimen. The criterion for fracture is taken to be the attainment of a limiting value of stress or strain or energy at or near the crack tip. The predicted fracture toughness based on such models depends only on the mechanical properties as measured in a tensile test, i.e., materials with similar tensile behavior should have similar values of fracture toughness. The purpose of the present study was to investigate the relationship between fracture toughness and uniaxial tensile properties in a high strength steel and to study those microstructural features which might have a marked influence on this relationship.

Following the work of Raymond et al.[3] and Gerberich[4] a modified H-11 steel was chosen for the study. The composition is given as follows:

Fe	Cr	Mo	V	Mn	Si	N	C
bal.	4.85	1.34	0.50	0.22	0.84	0.30	0.21

Two separate processing treatments were used in the present study. One series of specimens was deformed by rolling 50% at three different temperatures (375°C, 410°C and 565°C) above the M_s temperature after austenitizing for 1/2 hour at 1050°C. A second series of specimens was isothermally transformed for 4 hours at the same temperatures. All specimens were double tempered for 2 + 2 hours at 565°C after the above treatments.

The tensile properties were determined with 1 in. gauge length sheet specimens. The fracture toughness was evaluated using 1 in. × 2 in. single edge notch specimens after Sullivan.[5] These were fatigue cracked prior to testing. Microstructural details of the crack path were investigated by bending the notched specimens and observing under a light microscope at high magnification.

The tensile properties of the two series are shown in Fig. 1. It can be seen that there is little variation in yield stress, tensile strength, elongation, and reduction in area within each series. Comparing the two series it can be seen that the material deformed 50% prior to transformations has higher values of yield and ultimate strength but that within a given series the tensile properties were essentially independent of processing temperature. The toughness values vary considerably within each series as is shown in Fig. 2. Figure 2 also shows the agreement between the present work and that of Gerberich et al.[3,4]

The fracture toughness of the material ausformed at 410°C is much higher than that for the other two deformation temperatures. Moreover the material deformed at 410°C fractures by an intermittent series of crack bursts and at ever increasing loads, whereas the other two cases fail in a brittle "catastrophic" manner once the crack is initiated at a relatively low stress. For the isothermal treatments the specimen processed at 410°C has the lowest toughness value. It was also observed that the fracture mode of the specimens isothermally transformed at 375°C and 575°C was very similar to that of the specimen ausformed at 410°C. Raymond et al.[3] attributed this behavior at the intermediate deforma-

tion temperature to the existence of two phases in the structure, i.e., low toughness tempered martensite and high toughness lower bainite. He suggested that the crack is arrested whenever it encounters the bainite.

It was felt by the authors that ausforming per se was not the source for the enhancement of toughness at a particular processing temperature since ausforming just raises the general strength level of steels. Rather, it is thought that the existence of lower bainite is responsible for the toughness peak. Examination of the TTT curve[6,7] shows that it is reasonable to expect bainite both when deforming at 410°C and when isothermally transforming at 375°C since ausforming should enhance the nucleation and growth of bainite and cause its appearance at a temperature higher than that when isothermally transforming. It is suggested that the isothermal 375°C treatment results in a two phase structure (tempered martensite and bainite) whereas the material deformed at 375°C is primarily tempered martensite. The material isothermally transformed at 410°C is tempered martensite and is therefore of relatively low toughness. The specimen isothermally reacted at 575°C contains pearlite which accounts for the low strength and high toughness observed.

Studies of the advancing crack tip revealed a marked difference between the material with high toughness (410°C ausformed, and isothermally transformed at 375°C and 575°C) and the material with low toughness (375°C and 575°C ausformed, and isothermally transformed at 410°C). Figure 3 shows a typical comparison between the crack in a material with high toughness and one in a specimen with low toughness. As can

be seen the crack in the tough material is very blunt with a relatively large crack opening displacement while the crack in the low toughness material is very sharp. Although not shown here, it was also observed that the crack for the brittle case followed the carbide-matrix interface.

A replication of the fracture surface (Fig. 4) of the material deformed at 410°C shows that alternate regions of cleavage and dimpled rupture occur, as postulated by Gerberich.[4] Presumably the dimpled rupture occurs in the bainite.

This study has emphasized the necessity of considering the micromechanics of fracture, with due consideration to the immediate microstructural environment of the advancing crack tip. A tensile test involves bulk behavior of the material whereas crack propagation involves the microscopic behavior in the vicinity of a crack and its stress field. Since fracture involves the propagation of a local defect, it is not surprising to find that local variations in structure (which will be averaged out in a tensile test) have a direct controlling influence on the fracture toughness. In the particular case studied here, the fracture toughness was enhanced by the presence of a tough second phase whereas the tensile properties were little affected.

ACKNOWLEDGMENTS

The authors wish to thank V. F. Zackay and W. W. Gerberich for their helpful suggestions. This work was supported by the United States Atomic Energy Commission.

REFERENCES

1. G. T. Hahn and A. P. Rosenfield, Sources of Fracture Toughness: The Relation Between K_{I_c} and Ordinary Tensile Properties of Metals, presented at ASTM Symposium, Los Angeles, California, 1967.
2. J. M. Krafft, Applied Materials Research, April 1964, p. 88.
3. L. Raymond, W. W. Gerberich and W. G. Reuter, Aerospace Report TR-669 (6250-10)-7 Aerospace Corporation, Los Angeles, May 1966.
4. W. W. Gerberich, Trans. ASM 59, 899 (1966).
5. A. M. Sullivan, Materials Research and Standards, Vol. 1, pp. 20-24, (1964).
6. D. Kalish, S. A. Kulin and M. Cohen, ASTM Special Technical Publication 370, (1965), p. 172.
7. G. A. Roberts, J. C. Hamaker and A. R. Johnson, Tool Steels, (ASM Publications, Inc., Metals Park, Ohio, p. 549).

FIGURE CAPTIONS

Fig. 1 Variation of tensile properties with ausforming and isothermal transformation temperatures.

Fig. 2 Variation of fracture toughness with processing or transformation temperature.

Fig. 3 Comparison of crack in tough material to that in brittle material. Note difference in magnification.

Fig. 4 Replication of fracture surface of material deformed at 410°C showing alternate regions of cleavage and dimpled rupture. Magnification: ×10,000

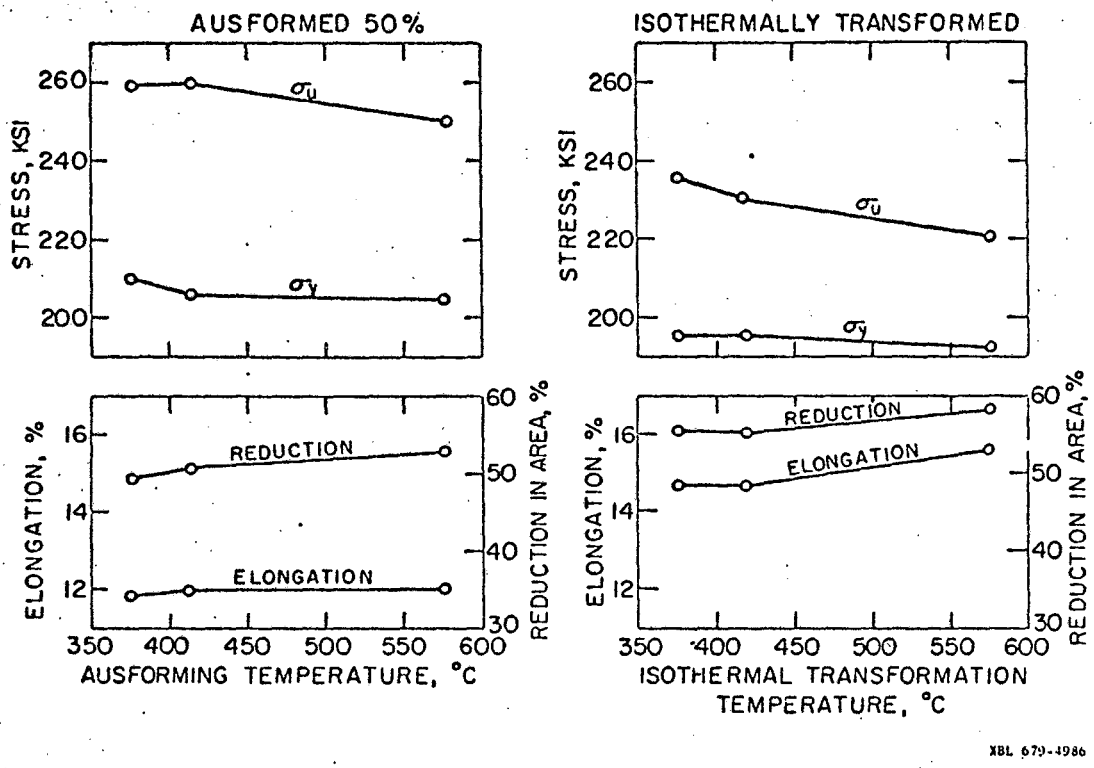
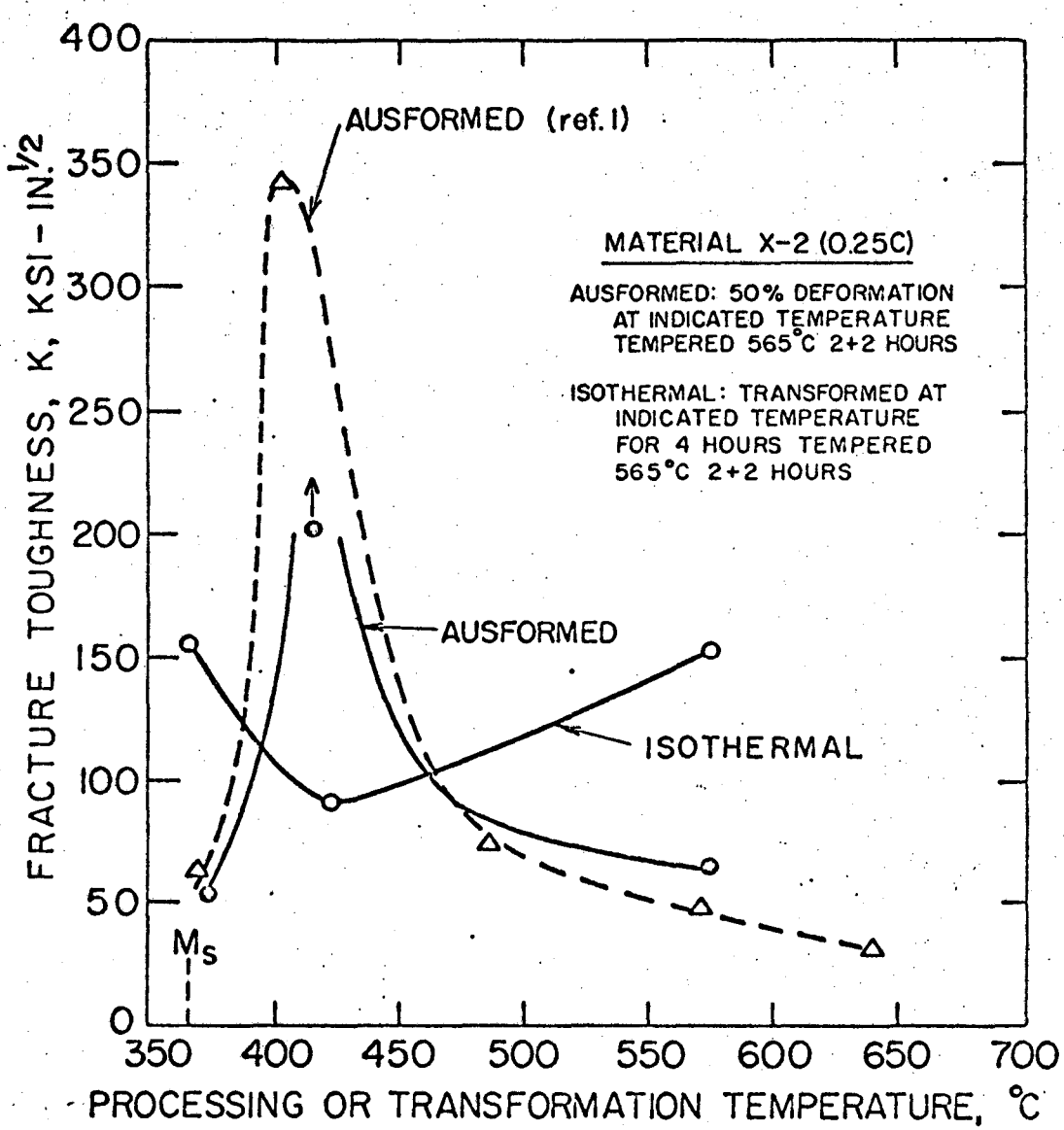

AUSFORMED 50%
ISOTHERMALLY TRANSFORMED
STRESS, KSI
260
240
220
200
σ_u
σ_y
ELONGATION, %
REDUCTION IN AREA, %
16
14
12
60
50
40
30
REDUCTION
ELONGATION
350 400 450 500 550 600
AUSFORMING TEMPERATURE, °C
ISOTHERMAL TRANSFORMATION TEMPERATURE, °C
XBL 679-4986

Fig. 1



XBL 679-4984

Fig. 2

XBB 670-5721

AUSFORMED AT 410°C 400X AUSFORMED AT 575°C 1600X

CRACKS IN AUSFORMED X-2

Fig. 3

XBB 679-5111-A

Fig. 4

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.