

UNCLASSIFIED

AD 407 556

DEFENSE DOCUMENTATION CENTER

FCR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

AD No. 407 556
DDC FILE COPY
407 556
SSD-TDR-63-127

63-4-1

Scale = 2
REPORT NO.
TDR 169(324)

1

Effect of Stress on the Lüders Band Velocity in Low Carbon Steels

4 JUNE 1963

Prepared by HANS CONRAD
Materials Sciences Laboratory

Prepared for DEPUTY COMMANDER AEROSPACE SYSTEMS

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

Inglewood, California

DDC
JUN 25 1963
TISIA B

LABORATORIES DIVISION • AEROSPACE CORPORATION
CONTRACT NO. AF 04(69

\$ 1.10

SSD-TDR-63-127

Report No.
TDR-169(3240-11)TN-9

EFFECT OF STRESS ON THE
LÜDERS BAND VELOCITY IN LOW CARBON STEELS,

Prepared by
Hans Conrad,
~~Materials Sciences Laboratory~~

AEROSPACE CORPORATION
El Segundo, California

Contract No. AF 04(695)-169

4 June 1963,

7 p.

Prepared for
DEPUTY COMMANDER AEROSPACE SYSTEMS
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Inglewood, California

ABSTRACT

The Lüders band propagation rate, $\dot{s}_{sub L}$, in low carbon steel can be considered to obey the relation,

$$\dot{s}_{sub L} = \dot{s}_{sub gen} \exp \left[- \frac{H(\tau_{av}^*)}{RT} \right]$$

where $\dot{s}_{sub gen}$ is approximately a constant, and $H(\tau_{av}^*)$ is the activation energy of the process, and represents a decreasing function of the effective stress, τ_{av}^* (given by the difference between the applied stress and the long-range internal stress). Available data on the effect of stress on Lüders band velocity is correlated on the basis of this relationship. The fact that the activation volume derived from this correlation is independent of structure, and is the same as that for dislocation mobility and other deformation phenomena in iron and steel, suggests that the rate-controlling mechanism is thermally-activated overcoming of the Peierls-Nabarro stress.

EFFECT OF STRESS ON THE LÜDERS BAND VELOCITY IN LOW CARBON STEELS

In a recent paper, Butler [1962 (Ref. 1)] indicated that the Lüders band velocity, $\dot{s}_L$, in low carbon steel could be expressed by the relationship originally proposed by Fisher and Rogers [1956 (Ref. 2)]:

$$\dot{s}_L = A - \frac{B}{\sigma} \quad (1)$$

where σ is the applied tensile stress, and A and B are material constants that depend on the structure i.e., on grain size, carbon content, and heat treatment. Eq. (1) is based on an analysis by Fisher [1955 (Ref. 3)] of the thermally-assisted tearing of dislocations from an interstitial atmosphere. On the other hand, Hahn [1962 (Ref. 4)], proposed an empirical relationship of the form

$$\dot{s}_L = \left(\frac{\sigma}{\sigma_0} \right)^m \quad (2)$$

where m and σ_0 vary with structure. None of the above authors has provided an explanation of the role that structure plays in the propagation of a Lüders band.

From a consideration of the dynamic aspects of the plastic deformation of iron and steel, Conrad [1961 and 1963 (Refs. 5, 6, and 7)] has suggested that the strain rate $\dot{\epsilon}$ is given by

$$\dot{\epsilon} = \nu \exp \left[-\frac{H(\tau^*)}{kT} \right] \quad (3)$$

where ν is a frequency factor that includes: the number of places where thermal activation may occur, the strain per successful thermal fluctuation, and an entropy term. $H(\tau^*)$ is the enthalpy (energy) of activation, which is a decreasing function of the effective shear stress, τ^* , given by the difference

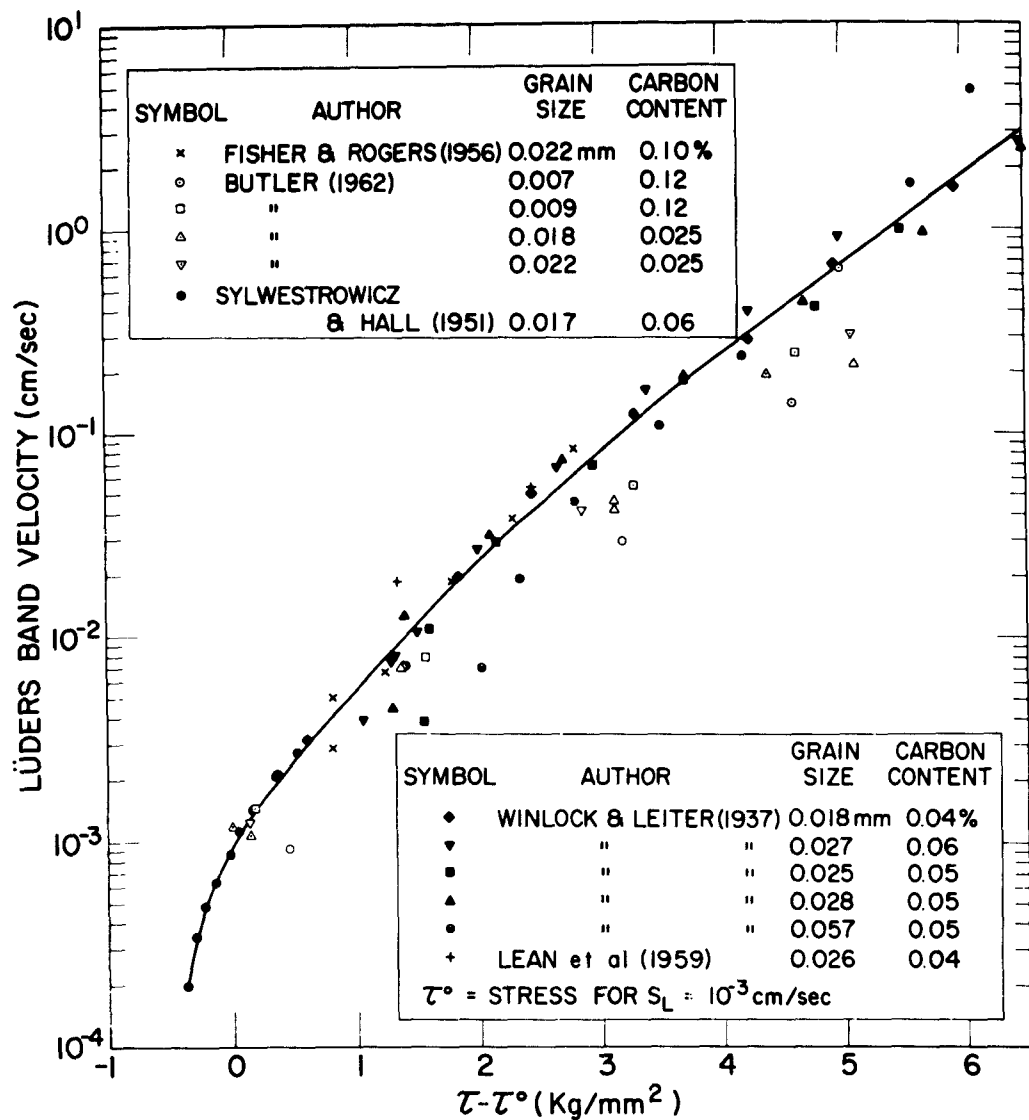


Fig. 1. Effect of Stress on Lüders Band Velocity at 300°K in Low Carbon Steel

between the applied stress¹, τ , and the long-range internal stress, $\tau\mu$ (proportional to the shear modulus, μ). τ^* is also termed the thermal component of the stress, and is a function of the temperature and the strain rate. $\tau\mu$ is

termed the athermal component, is a function of the structure, is independent of strain rate, and varies with temperature only as the shear modulus varies with temperature. To eliminate the athermal component of the stress in any consideration, some reference stress, τ^0 , referred to a fixed temperature and strain rate, is subtracted from the applied stress, τ ; that is,

$$\tau(T, \dot{\epsilon}) - \tau^0(T, \dot{\epsilon}_0) = \Delta\tau^*(T, \dot{\epsilon}) \quad (4)$$

Assuming that the propagation of a Lüders band is controlled by the same dislocation mechanism that controls the plastic strain rate following the yield point elongation [Conrad 1961 (Ref. 5)], then

$$\dot{s}_L = \dot{s}_0 \exp\left[-\frac{H(\tau^*)}{kT}\right] \quad (5)$$

where $\dot{s}_0$ is approximately a constant. If the velocity is plotted versus the quantity, $\tau - \tau^0$, all of the data on the effect of stress on Lüders band velocity at constant temperature would be expected to lie on one curve. That this is the case is shown in Fig. 1². Here, τ^0 is taken as the stress that gives a Lüders band velocity of 10^{-3} cm/sec at 300°K .

Rearranging Eq. (5) and differentiating with respect to stress, one obtains

$$-\frac{dH}{d\tau^*} = kT \left(\frac{\partial \ln \dot{s}_L}{\partial \tau^*} \right)_T = v^* \quad (6)$$

¹For the b.c.c. metals one can assume that $\tau = 1/2 \sigma$.

²The Lüders band velocity was calculated from the data of J. Winlock and Leiter, 1937 (Ref. 8). Sylwestrowicz and Hall [1951 (Ref. 9)], and Lean, Plateau and Crussard, [1959 (Ref. 10)] from the well-known relationship $\dot{s}_L = (\dot{\epsilon}l)/(n\epsilon_L)$ where l is the specimen length, n is the number of Lüders bands (assumed to be two) and ϵ_L is the Lüders strain.

where v^* is termed the activation volume. In Fig. (2) it is seen that the activation volumes obtained by graphical differentiation of the curve of Fig. (1) are in good agreement with those obtained from other data [Conrad 1961 and 1963 (Refs. 5, 6, and 7)] on the plastic flow of iron and steel. In Fig. 2 it is assumed that $\tau^* \approx 0$ at $\dot{s}_L = 10^{-4}$ cm/sec.

The above indicates that the effect of stress on Lüders band velocity can be described by Eq. (5), and that, as postulated previously (Ref. 5), the same dislocation mechanism is controlling during Lüders band propagation as during homogeneous plastic flow. Furthermore, for the steels considered,

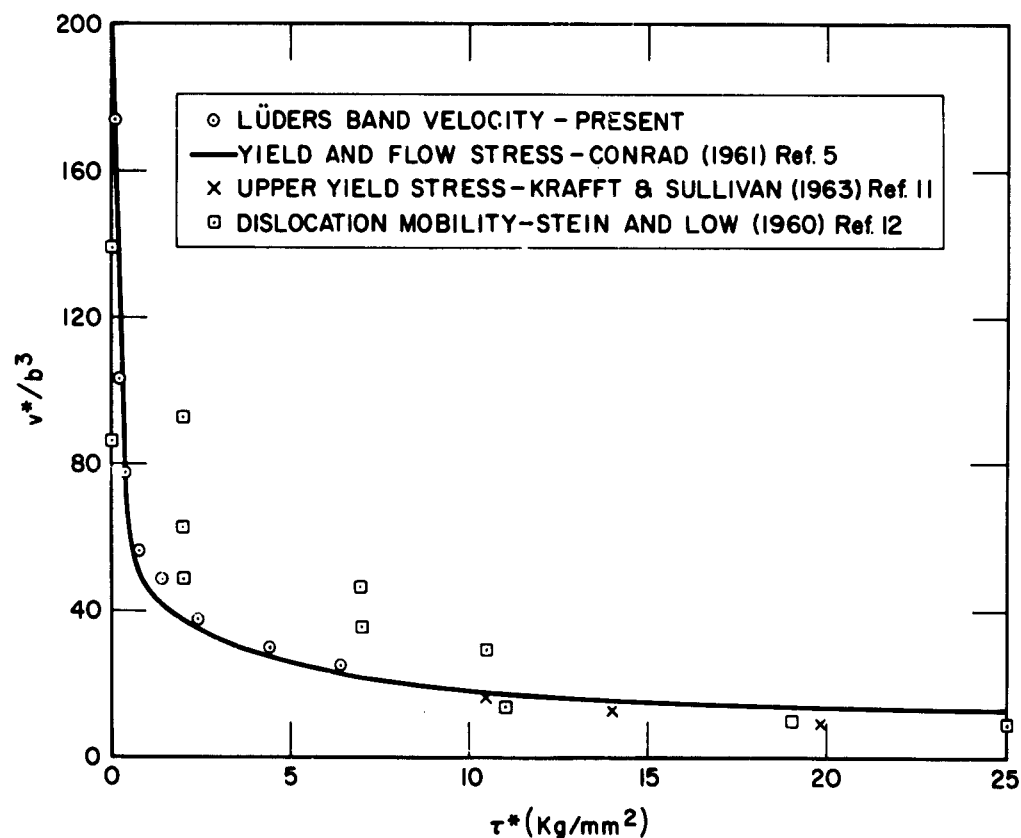


Fig. 2. Variation of the Activation Volume, Divided by the Burgers Vector Cubed, with Stress for Iron and Steel

(the effect of structure (strain, grain size, carbon content, etc.) is principally through the long-range stress fields opposing the motion of dislocations, rather than through any direct effect on the controlling mechanism. This and other work (Refs. 5, 6, and 7) suggest that the rate-controlling mechanism during the yielding and flow of iron and steel at low temperatures ($T < 0.2T_m$) is thermally-activated overcoming of the Peierls-Nabarro stress.

REFERENCES

1. J. F. Butler, J. Mech. Phys. Solids 10, 313 (1962).
2. J. C. Fisher and H. C. Rogers, Acta Met. 4, 180 (1956).
3. J. C. Fisher, Trans. Am. Soc. Metals 47, 451 (1955).
4. G. T. Hahn, Acta Met. 10, 727 (1962).
5. H. Conrad, J. Iron and Steel Inst. 198, 364 (1961).
6. H. Conrad, Iron and Its Dilute Solid Solutions, Interscience, Inc., New York (1963), p. 315.
7. H. Conrad, Yielding and Flow of Body Centered Cubic Metals at Low Temperatures, Report No. TDR-169(3240-11)TN-5. Aerospace Corporation, El Segundo, California (7 March 1963). Also in Proceedings of the NPL Symposium on Relation Between Properties and Structures of Metals, Teddington, England, January 1963 (to be published).
8. J. Winlock and R. W. E. Leiter, Trans. Am. Soc. Metals 25, 163 (1937).
9. W. Sylwestrowicz and E. O. Hall, Proc. Phys. Soc. (London) 64B, 495 (1951).
10. J. B. Lean, J. Plateau, and C. Crussard, Mem. Sci. Revise Metall. 56, 427 (1959).
11. J. M. Krafft and A. M. Sullivan, Trans. Am. Soc. Metals 56, 160 (1963).
12. D. F. Stein and J. R. Low, J. Appl. Phys. 31, 362 (1960).

Aerospace Corporation, El Segundo, California. EFFECTS OF STRESS ON THE LÜDERS BAND VELOCITY IN LOW CARBON STEELS, prepared by H. Conrad. 1 June 1963. [12] p. incl. illus. (Report TDR-169(3240-11)TN-9;SSD- TDR-63-127) (Contract AF 04(695)-169) Unclassified report The Lüders band propagation rate, $\dot{s}_L$, in low carbon steel can be considered to obey the relation $\dot{s}_L = \dot{s}_0 \exp[-H(\tau^*)/kT]$ where $\dot{s}_0$ is approximately a constant, and $H(\tau^*)$ is the activation energy of the process, and represents a decreasing function of the effective stress, τ^* (given by the difference between the applied stress and the long-range internal stress). Available data on the effect of stress on Lüders band velocity is correlated on the basis of this relationship. The fact that the activation volume derived from this correlation is independent of structure, and is the same as that for dislocation mobility and other deformation phenomena in (over)	UNCLASSIFIED
--	---

Aerospace Corporation, El Segundo, California. EFFECTS OF STRESS ON THE LÜDERS BAND VELOCITY IN LOW CARBON STEELS, prepared by H. Conrad. 1 June 1963. [12] p. incl. illus. (Report TDR-169(3240-11)TN-9;SSD- TDR-63-127) (Contract AF 04(695)-169) Unclassified report The Lüders band propagation rate, $\dot{s}_L$, in low carbon steel can be considered to obey the relation $\dot{s}_L = \dot{s}_0 \exp[-H(\tau^*)/kT]$ where $\dot{s}_0$ is approximately a constant, and $H(\tau^*)$ is the activation energy of the process, and represents a decreasing function of the effective stress, τ^* (given by the difference between the applied stress and the long-range internal stress). Available data on the effect of stress on Lüders band velocity is correlated on the basis of this relationship. The fact that the activation volume derived from this correlation is independent of structure, and is the same as that for dislocation mobility and other deformation phenomena in (over)	UNCLASSIFIED
--	---

Aerospace Corporation, El Segundo, California. EFFECTS OF STRESS ON THE LÜDERS BAND VELOCITY IN LOW CARBON STEELS, prepared by H. Conrad. 1 June 1963. [12] p. incl. illus. (Report TDR-169(3240-11)TN-9;SSD- TDR-63-127) (Contract AF 04(695)-169) Unclassified report The Lüders band propagation rate, $\dot{s}_L$, in low carbon steel can be considered to obey the relation $\dot{s}_L = \dot{s}_0 \exp[-H(\tau^*)/kT]$ where $\dot{s}_0$ is approximately a constant, and $H(\tau^*)$ is the activation energy of the process, and represents a decreasing function of the effective stress, τ^* (given by the difference between the applied stress and the long-range internal stress). Available data on the effect of stress on Lüders band velocity is correlated on the basis of this relationship. The fact that the activation volume derived from this correlation is independent of structure, and is the same as that for dislocation mobility and other deformation phenomena in (over)	UNCLASSIFIED
--	---

Aerospace Corporation, El Segundo, California. EFFECTS OF STRESS ON THE LÜDERS BAND VELOCITY IN LOW CARBON STEELS, prepared by H. Conrad. 1 June 1963. [12] p. incl. illus. (Report TDR-169(3240-11)TN-9;SSD- TDR-63-127) (Contract AF 04(695)-169) Unclassified report The Lüders band propagation rate, $\dot{s}_L$, in low carbon steel can be considered to obey the relation $\dot{s}_L = \dot{s}_0 \exp[-H(\tau^*)/kT]$ where $\dot{s}_0$ is approximately a constant, and $H(\tau^*)$ is the activation energy of the process, and represents a decreasing function of the effective stress, τ^* (given by the difference between the applied stress and the long-range internal stress). Available data on the effect of stress on Lüders band velocity is correlated on the basis of this relationship. The fact that the activation volume derived from this correlation is independent of structure, and is the same as that for dislocation mobility and other deformation phenomena in (over)	UNCLASSIFIED
--	---

UNCLASSIFIED	iron and steel, suggests that the rate-controlling mechanism is thermally-activated overcoming of the Peierls-Nabarro stress.	UNCLASSIFIED
--------------	---	--------------

UNCLASSIFIED	iron and steel, suggests that the rate-controlling mechanism is thermally-activated overcoming of the Peierls-Nabarro stress.	UNCLASSIFIED
--------------	---	--------------

UNCLASSIFIED	iron and steel, suggests that the rate-controlling mechanism is thermally-activated overcoming of the Peierls-Nabarro stress.	UNCLASSIFIED
--------------	---	--------------

UNCLASSIFIED	iron and steel, suggests that the rate-controlling mechanism is thermally-activated overcoming of the Peierls-Nabarro stress.	UNCLASSIFIED
--------------	---	--------------