Mechanical Behavior and Transformation Characteristics of Trip Steels

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I. INTRODUCTION

The strain-induced transformation of austenite to martensite in the recently developed high strength TRIP steels[1] is responsible for the enhancement of their tensile ductility. Further, the energy absorption due to the transformation ahead of a propagating crack gives rise to increased fracture toughness. The controlling parameters for achieving specific mechanical properties are the strength of the metastable austenite, the strength of the transformed martensite and the extent and rate of transformation of austenite to martensite. The present study is concerned with tension, notch tension, fracture toughness and fatigue crack propagation characteristics of several TRIP steels as a function of their processing history.

II. EXPERIMENTAL PROCEDURE

The chemical composition, processing history and material condition of the TRIP steels studied are given in Table 1. Fig. 1 shows the test specimen geometries used. In addition to mechanical testing, metallography and electron fractography was used to study microscopic fracture mechanism.

III. RESULTS AND DISCUSSION

A. Tensile Properties: The general shape of the engineering stress-strain curve for all materials studied is illustrated in Fig. 2. The yield strength of the materials tested was approximately the same, however, their tensile ductility varied from a high of 43% for steel A to a low of 10% for steel B_3. At peak elastic strain only about 2.5

vol.% martensite were formed. The martensite content of the Luder's bands, which generally grow until the entire test section is covered, is about 30 vol.%. From a simple model Weiss[2] obtains for the Luder's strain as a function of the amount of martensite in the Luder's band, ζ_L, the strength of the martensite, σ_m and the strength of the austenite, σ_γ

$$\varepsilon_L = \ln[1 + \zeta_L(\sigma_m - \sigma_\gamma)/\sigma_\gamma] \qquad (1)$$

The experimental results are in good agreement with the above predictions (ε_L measured = .18, ζ_L = .3, σ_m = 2,275 MN/m^2 and σ_γ = 1,379 MN/m^2, ε_L calculated = 0.19). Likewise, the strain hardening rate, and hence the strain at which necking takes place, is also affected by the strength differential of the two phases and the phase metastability of the austenite i.e.

$$\frac{d\bar{\sigma}}{d\varepsilon} = \frac{d\sigma_\gamma}{d\varepsilon} + \frac{d}{d\varepsilon}\,[\zeta(\sigma_m - \sigma_\gamma)] \qquad (2)$$

B. Notch Tension Properties: Fig. 3 shows the notch sensitivity of the TRIP steels in comparison with the ultra-high strength 300M and 250 grade maraging steels. The superiority of TRIP steels, especially in the presence of sharp notches, is quite evident. General yielding before fracture was visually observable in all notch tension specimens tested.

C. Fracture Toughness: The apparent plane strain fracture toughness values, K_Q determined were 4733Nmm$^{-3/2}$ for steel B_2 and 4872 Nmm$^{-3/2}$ for B_3. Metallographic examination showed that the plastic zone is well delineated by the region which has transformed to martensite and that this metallogrphically observable plastic zone size is in good agreement with the plastic zone size predicted from the crack tip stress field equations. Electron fractography revealed a mixed mode of fracture, i.e. ductile dimples in the austenite, wavy

slip in martensite and cleavage in martensite or alloy carbide particles.

D. Fatigue Crack Propagation: Fig. 4 shows the crack propagation rate, da/dN, as measured on the surface, as a function of the stress intensity factor range, ΔK, for the TRIP steels studied, for conventional high strength steels[3] and for a TRIP steel studied by Gerberich[3]. The fatigue crack propagation behavior conforms to the general observation, $da/dN = A.(\Delta K)^m$ with $m \simeq 3.7$. However it is lower than that obtained for conventional high strength steels. Metallography revealed that the extent of transformation to martensite in the vicinity of a fatigue crack is very small, i.e. there is little energy absorption due to transformation which may explain the low fatigue crack growth resistance of these materials. Furthermore, coarse grain structure and grain boundary carbide segregation in the austenite may also have contributed to these results.

IV. CONCLUSIONS

Composition and processing history of the TRIP steels studied have a pronounced effect on the tensile fracture ductility but little on their yield,tensile and notch tensile strengths, fracture toughness and fatigue crack propagation resistance. Yielding is inhomogeneous, the Lüder's strain being a function of the austenite instability and the strength differential of the two phases. In the fracturing process transformation plasticity causes significant energy absorption and hence a high fracture toughness. At lower strains, such as encountered in fatigue crack propagation, only little transformation occurred in the materials studied leading to a relatively low fatigue crack growth resistance.

REFERENCES

1. V.F. Zackay, E.R. Parker, D.Fahr and R. Bush, Trans. ASM,60,1967,252.
2. V. Weiss, Annual Pre-Congress Seminar, ASM, 1971, to be published.
3. W.W. Gerberich, SAE Paper No.690262,IAEC, Mich. Jan. 1969.

TABLE I

Material Designation	Alloy Composition	Condition	TRIP Processing
A	C-0.26, Mn-0.22, Si-0.20, Cr-11.96, Ni-7.95, Mo-1.94	Sheet 2.28 mm (0.09 in) Thick	80% warm roll 426C (800F), Cool to -196C (-320F) and hold 1 hr.
Heat 2321 Type I (B_1)	C-0.27, Mn-0.90, Si-1.88, Cr-8.80, Ni-8.5, Mo-4.0	Plate 7.62 mm (0.3 in) Thick	80% warm roll 426C (800F), Temper 350C (660F) 1 hr.
Heat 2322 Type I (B_2)	C-0.27, Mn-0.91, Si-1.84, Cr-8.81, Ni-8.73, Mo-4.07	Plate 7.62 mm (0.3 in) Thick	80% warm roll 426C (800F), Temper 350C (660F) 1 hr.
Heat 2322 Type II (B_3)	C-0.27, Mn-0.91, Si-1.84, Cr-8.81, Ni-8.73, Mo-4.07	Plate 7.62 mm (0.3 in) Thick	80% warm roll 426C (800F) 15% Cold work, Temper 350C (660F), 2 hrs.

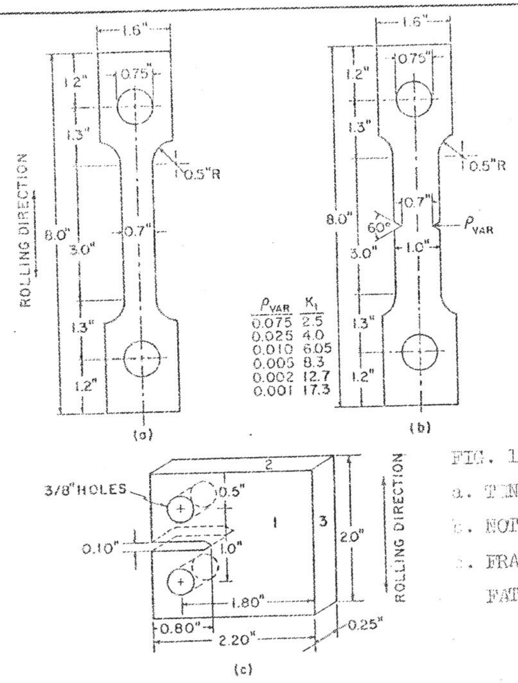

FIG. 1

a. TENSION

b. NOTCH TENSION

c. FRACT. TOUGH. AND FATIGUE

FIG. 2

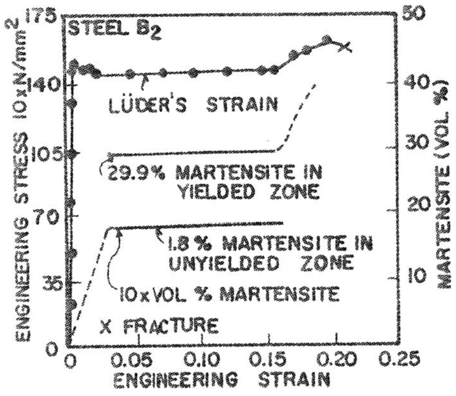

FIG. 3

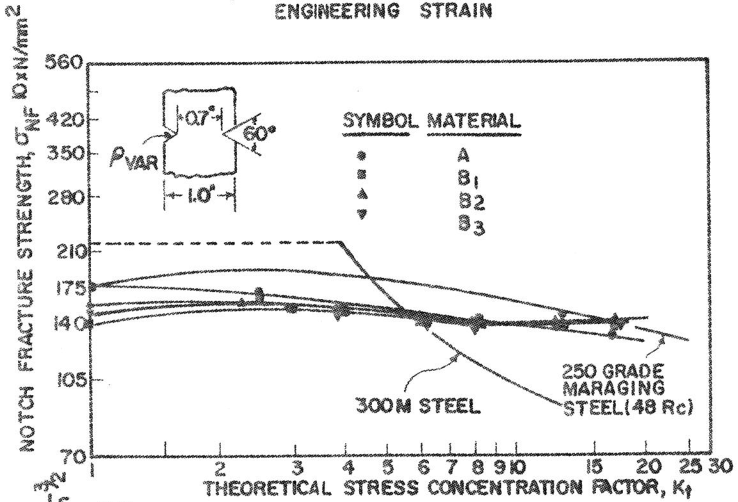

FIG. 4