Fractography of a Metastable Austenite*

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A study of fracture development in Fe–31%Ni–0.1%C alloy has been made. Samples of this alloy, which show deformation-induced martensite transformation, were given pretreatments of shock loading and grain refining. Fine-grained samples showed higher microvoid density with decreasing deformation temperature. This was attributed to the existence of a large number of internal interfaces (martensite/martensite, martensite/austenite, and any remaining parent austenite boundary) in these fine-grained samples which may act as void nucleation sites. This trend was not so marked in preshocked samples because of their fast reaction kinetics. Thus both treatments, grain refining and shock loading, which affect the deformation-transformation behavior of the metastable austenite, also affected its fracture behavior.

Introduction

An important characteristic of a material's mechanical behavior is its fracture development. Several complex steels are known to have outstanding combinations of strength and ductility due to deformation-induced martensite transformation [1]. The present paper describes observations made by scanning electron microscope of the fracture surfaces of a simpler Fe–31%Ni–0.1%C alloy which also displays deformation-induced transformation when worked at appropriate temperatures [2]. The present results were considered significant since they are characteristic of specimens given pretreatments of shock loading and grain refining which strengthen the matrix but may affect differently the austenite stability [3, 4].

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Experimental Methods

The high-purity Fe–31%Ni–0.1%C alloy was received as 16-mm-diameter bars. They were transformed into 10-mm-thick strips, annealed for homogenization (18 hours at 1373 K and 667 × 10^{-9} N/m^2) and rolled down to 1 mm. Part of this material was machined in the form of flat tensile specimens (27 × 4 × 1 mm useful nominal gage dimensions) and given appropriate treatment (1373 and 1223 K) to develop large and smaller austenite grain size (S_v = 14.2±0.5 mm^{-1} and 29.6±0.9 mm^{-1} respectively, including annealing twins, where S_v is the total internal surface area per unit volume of material). The remaining material was also annealed to yield large grain, shocked (8 GPa and 2 μsec pulse duration), and machined carefully in the form of the tensile specimens. Shocking was achieved by impacting the specimen sandwiched between a cover plate and an anvil with a copper flyer plate projected by the detonation of a suitable plastic explosive. Details of this system and special procedures can be found elsewhere [5].

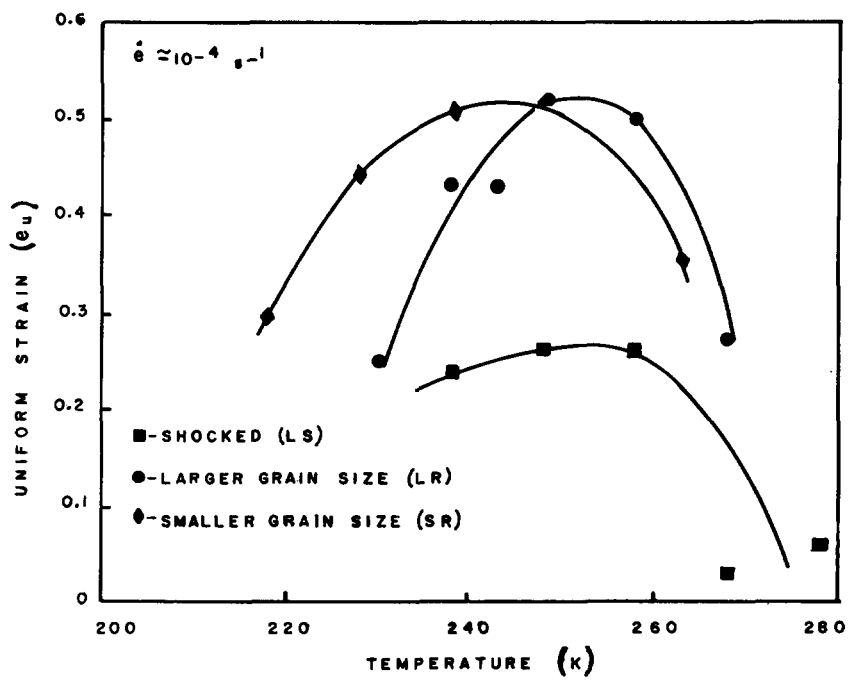


FIG. 1. Uniform elongation vs deformation temperature. Notice that, for all specimens, elongation is maximum at some intermediate temperature.

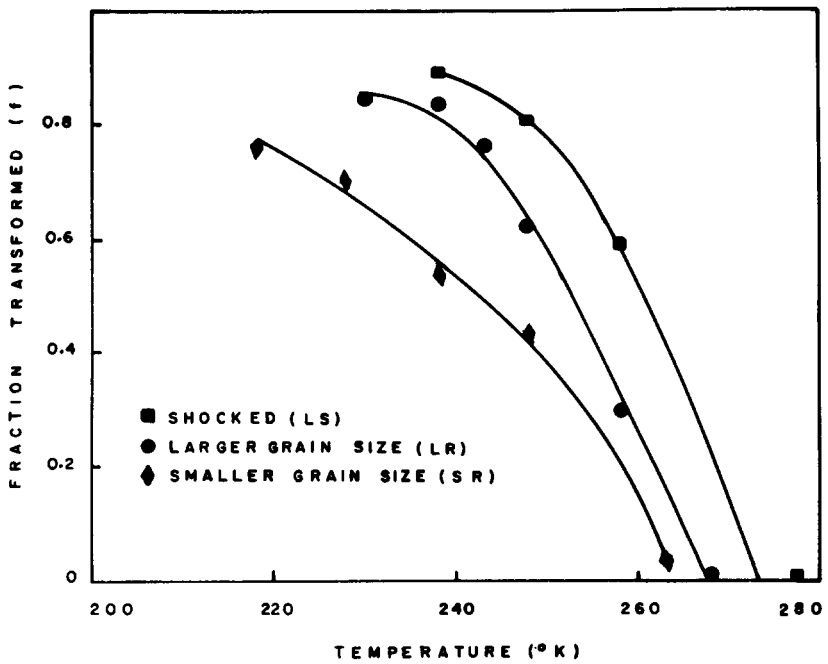


FIG. 2. Volume fraction transformed into martensite (f) vs temperature of deformation. Notice that, at any given temperature, f is the largest for the preshocked specimen.

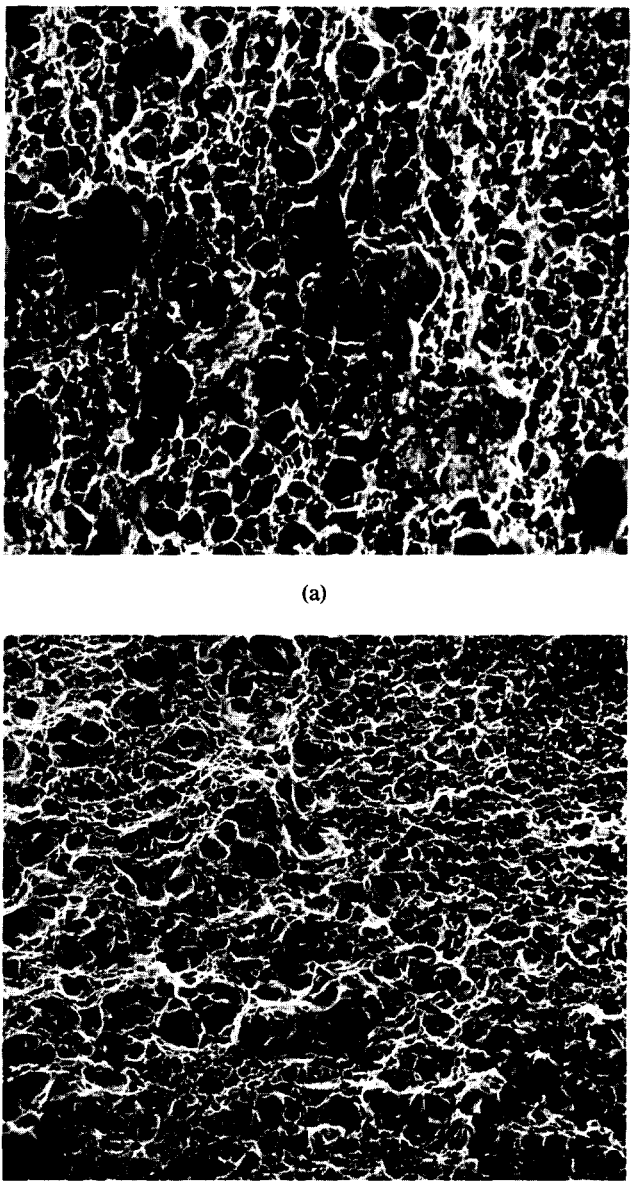
Mechanical testing was accomplished in an Instron TT-DM machine ($\dot{e} \simeq 10^{-4}\text{sec}^{-1}$) while the specimens were immersed in refrigerated ethyl alcohol baths controlled within ± 2 K.

Evaluation of volume transformed and internal surface area were done by the quantitative methods of point counting and line intercepts, respectively.

Fractographic observations were carried on with a JEOL-SMU/3 scanning electron microscope (SEM) operated at 25 kV and, in each case, the specimen was kept as close as possible at the same orientation relative to the beam.

Results and Discussion

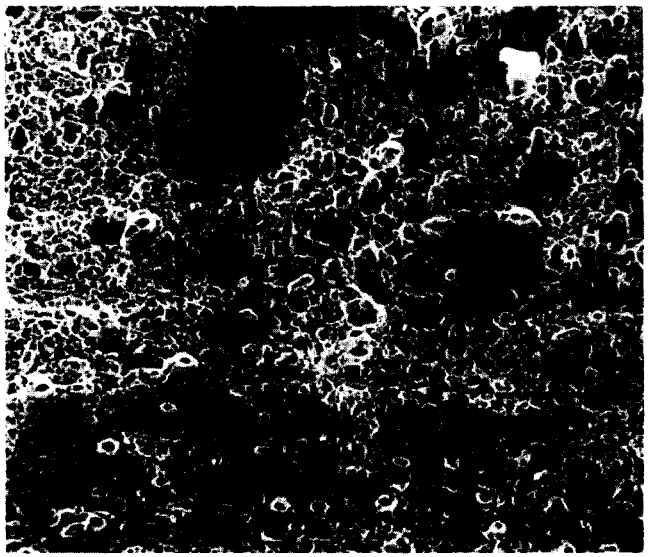
The alloy was found to display the typical behavior of metastable austenites deformed above but close to M_s. Uniform elongation was maximum at some intermediate temperature for all different specimens, Fig. 1. Analyses of the extent of transformation in the gage length,



(a)

(b)

FIG.3. Fractographs of fine-grained samples deformed at different temperatures. (a) 263K, (b) 248K.

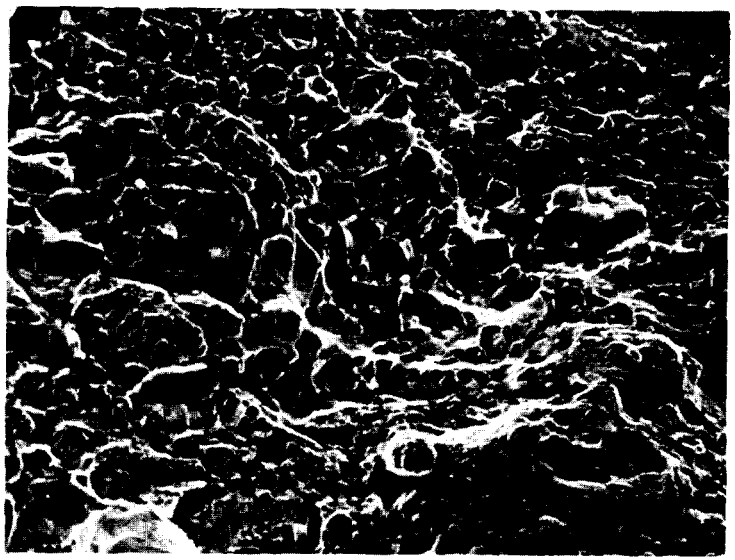


(c)

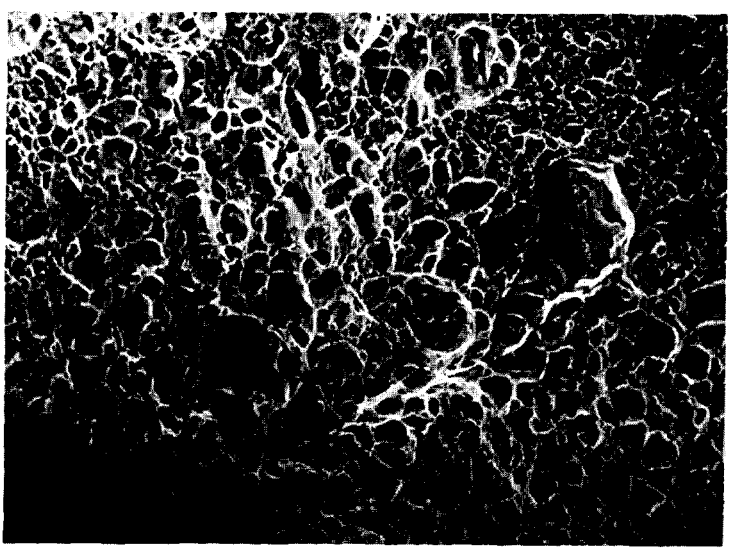
FIG. 3. (continued) (c) 228K. All 300×. Microvoid density increases with decreasing temperature.

excluding the fracture zone, by point counting allowed the construction of the curves of Fig. 2. It is clear from this figure that for a given temperature the amount of martensite was always larger in the shock-loaded specimens and smaller in the grain-refined ones. This supports the initial hypothesis about the opposite effects of two treatments on the austenite stability.

A series of SEM fractographs of fine-grained samples deformed at 263, 248, and 228 K is shown in Fig. 3(a), 3(b), and 3(c), respectively. One notes that the number of voids increases while the void size decreases with decreasing temperature of deformation. This is attributed to the existence of a high density of internal interfaces (martensite/martensite, martensite/austenite, and any remaining parent austenite boundary) in these fine-grained samples. These internal interfaces may act as sites for microvoid nucleation [6]. With decreasing temperature, the volume fraction transformed into martensite, f, increases (Fig. 2) leading to a larger number of internal interfaces and consequently increasing the possible void nucleation sites and thus leading to a larger

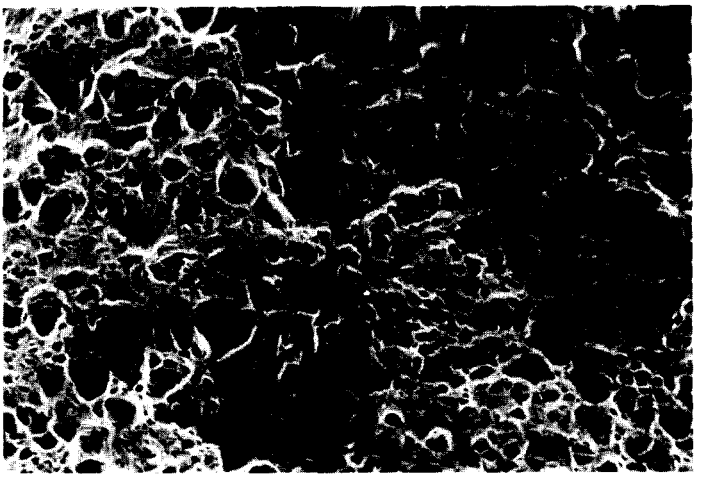


(a)

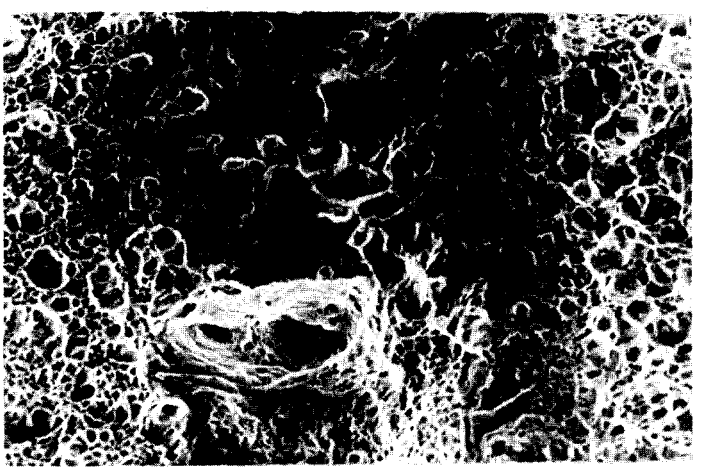


(b)

FIG.4. Fractographs of large-grained recrystallized samples deformed at (a) 268K and (b) 258K. Microvoid density increases with decreasing temperature but not as much as in Fig. 3. 300×.



(a)



(b)

FIG.5. Fractographs of large-grained preshocked samples deformed at (a) 268K, (b) 238K, showing that microvoid density increases slowly with decreasing temperature. 300× (cf. Fig. 3).

void density. This trend appears to be a general one. However, one would expect this to be more accentuated in fine-grained material than in a large-grained one (recrystallized or preshocked) because the former will result in smaller martensite plates and, therefore, more internal interfaces capable of nucleating voids. This is confirmed by fractographs

of large-grained recrystallized samples, shown in Figs. 4(a) and 4(b). Figure 4(a) is from a sample deformed at 268 K, while Fig. 4(b) is from a sample deformed at 258 K. Again one notices an increase in the quantity of voids and a decrease in the void size with decreasing temperature. In the large-grained preshocked samples there was also a difference in void size with decreasing test temperature. This is shown in Figs. 5(a) and 5(b), which are fractographs of samples deformed at 268 and 238 K, respectively. As expected, the trend is a bit less marked in the large-grained samples than in the fine-grained samples. Samples containing more or less the same fraction transformed at the onset of necking (e.g., at 238 K, Fig. 2) showed about the same void density, irrespective of the extent of the uniform deformation.

Conclusions

These fractographic observations indicate that both treatments, grain refinement and shock loading, which affect the deformation transformation behavior of the metastable austenite also affect the fracture development in the material, as should be expected, since the transformation would be the controlling factor for the mechanical response of this type of material.

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References

1. V. F. Zackay, E. R. Parker, D. Fahr, and R. Bush, *ASM. Trans. Quart. 60,* 252 (1967).
2. J. R. C. Guimarães, J. C. Gomes, and M. A. Meyers, unpublished results.
3. M. Umemoto and W. S. Owen, *Met. Trans. A* **5**, 2041 (1974).
4. S. Dash and N. Brown, *Acta Met.* **14**, 595 (1966).
5. M. A. Meyers, Ph. D. Thesis, University of Denver, 1974 (unpublished).
6. J. R. C. Guimarães and K. K. Chawla, *Microstructural Science,* Vol. 3 (P. M. French, R. J. Gray, and J. L. McCall, Eds.), American Elsevier, New York (1975), p. 123.

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