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Transformation-induced plasticity in Fe-17.20% Cr-7.34% Ni steel

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The characteristics of transformation-induced plasticity of Fe–17.20% Cr–7.34% Ni steel were studied. The maximum value of fracture elongation occurred at 20° C in the temperature range *Ms* (– 196° C) to *Md* (75° C), and this maximum elongation was brought about by the delay of necking. The percentage of α' martensite per unit tensile strain after the martensite transformation was then 2.20

1. Introduction

Mechanically induced α' martensite enhances the mechanical properties in metastable austenitic Fe–Cr–Ni alloys [1–3] and Fe–Ni alloys [2, 4], and the formation of α' increases the fracture elongation of the alloys. The increase of fracture elongation is thought to be brought about by the resistance of α' to incipient necking of the specimen [1]. Furthermore, it has been demonstrated that the increase is caused by the delay of the necking, and the appropriate value of percentage of α' in the specimen tensile strain in the case of the two-phase $(\alpha + \gamma)$ Fe–23.19% Cr–4.91% Ni alloy [5, 6] is found. It is intended to discover if the same result is found for Fe–17.20% Cr–7.34% Ni steel with γ phase. The present study is to clarify both the characteristics and cause of the transformation-induced plasticity in the steel.

2. Experimental procedure

The material tested was Fe–17.20% Cr–7.34% Ni steel and the chemical analysis in wt % was 0.10 C, 0.64 Si, 0.94 Mn, 0.024 P, 0.012 S, 7.34 Ni, 17.20 Cr, and the balance Fe. A 1.0 mm thick plate was cut into a 3.0 mm × 35.0 mm tensile sheet specimen, whose gauge length was 15.0 mm. The specimen was austenitized at 1100° C for 10 min in a vacuum furnace and furnace-cooled to room temperature, and had a mean grain size of 0.10 mm.

A tensile test was performed on an Instron testing machine operated at a crosshead speed of 0.5 mm min^{-1} in a test temperature range of – 196 to 200° C. The percentage of α', measured by X-ray analysis, and the tensile strain at which the α' martensite transformation began were obtained. The diffraction-planes, identified by CoK_α line, were $(1\,1\,1)_\gamma$, $(1\,1\,0)_{\alpha'}$ and $(2\,0\,0)_{\alpha'}$ diffraction-planes.

3. Results and Discussion

3.1. Temperature-dependence

Fig. 1 shows the variation of fracture elongation, yield strength and tensile strength with test temperature. The *Ms* temperature was ~ – 196° C and the *Md* was ~ 75° C in the Fe–17.20%Cr–7.34% Ni steel. Each value was a mean value of two to three points which were measured at the respective test temperatures. The maximum value of the fracture elongation appeared in the temperature range *Ms* (– 196° C) to *Md* (75° C), and occurred at 20° C. As already described by the authors, the appearance of the maximum fracture elongation (TRIP effect) depends on the delay of incipient necking and the appropriate value of α' per unit tensile strain in the case of the two-phase alloy

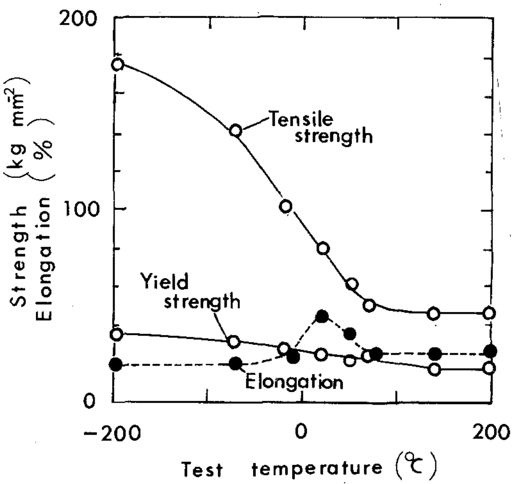

Figure 1 Temperature dependence of fracture elongation, yield strength and tensile strength in Fe–17.20%Cr–7.34%Ni steel.

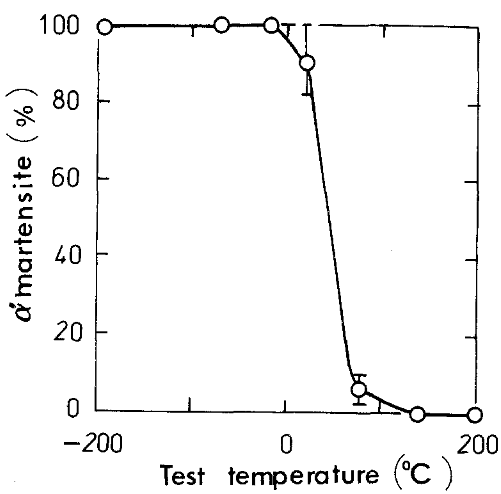

Figure 3 Effect of test temperature on the amount of α' lath martensite after a failure in Fe–17.20%Cr–7.34%Ni steel.

[5, 6]. The uniform elongation to necking was measured and the mean values obtained at -196, -72, -22, 20, 50, and 75° C were 15, 15, 20, 40, 28 and 20%, respectively. The value of the uniform elongation was therefore a maximum at 20° C. The maximum temperature of the fracture elongation was detected at $> 0°$ C, similarly to an Fe–15%Cr–13%Ni alloy [2] and an Fe–22.6%Ni–0.27%C alloy [7]. The yield strength increased smoothly as test temperatures decreased from 75 to $-196°$ C. The change with test temperature was not caused by an α' formation, but by a characteristic of the γ phase. That is, it was brought about by the increase of the yield strength of γ with decreasing test temperature [6, 8, 9]. The tensile strength increased with decreasing test temperature from 75° C to $-196°$ C, and this increase depended on the increase of α' in the specimen at a maximum loading of the stress–strain curve.

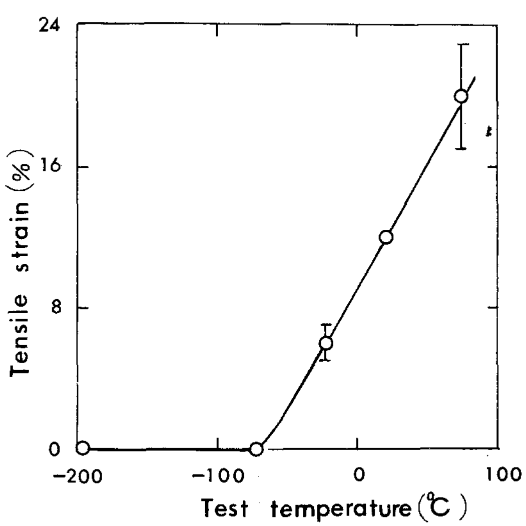

Figure 2 The tensile strain where the α' lath martensite forms during tensile straining at -196, -72, -22, 20 and 75° C in Fe–17.20%Cr–7.34%Ni steel.

3.2. The occurrence of α' lath martensite

When α' formed, ϵ martensite also occurred at low temperatures. The amount of ϵ was below 1.0% at -196 and $-72°$ C from X-ray analysis, and the ϵ was not detected at -22, 20, 75, 140 or 200° C. Fig. 2 shows the effect of increasing temperature on the tensile strain at which α' first forms. The α' is produced in deforming to $< 1.0\%$ strain at -196 and $-72°$ C. The mean strains at which the α' martensite transformation initiated were 6, 12, and 20% at -22, 20 and 75° C, respectively; they increased with the change of test temperatures from -22 to 75° C. Fig. 3 shows the effect of test temperature on the amount of α' in a fractured specimen. The amount of α' measured at -196, -72 and $-22°$ C was 100%, and all γ phase transformed to α'. The amounts at 20 and 75° C were 90% and 6% respectively, and the values at 140 and 200° C were 0%.

Fig. 4 shows the effect of test temperature on $\Delta M/\Delta\epsilon$. The value of $\Delta M/\Delta\epsilon$ indicates the ratio of the proportion of α' to the tensile strain after α' martensite transformation. This mean value decreased sharply with increasing test temperature

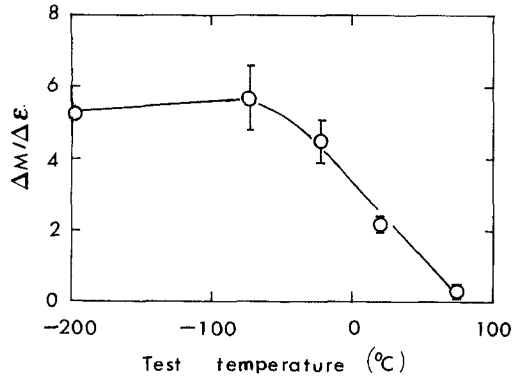

Figure 4 Effect of test temperature on $\Delta M/\Delta \epsilon$ in Fe–17.20%Cr–7.34%Ni steel. (The value of $\Delta M/\Delta \epsilon$ is the ratio of percentage of martensite present to the tensile strain after the martensite transformation.)

from − 72 to 75° C. At the temperature of maximum fracture elongation, 20° C, the value was 2.20, lower than the values obtained at − 196, − 72 and − 22° C. However, this value was larger than that at 75° C (0.29). The appropriate value was found when the elongation had a maximum value, and this result agreed with that observed by the present authors for the two-phase Fe–Cr–Ni alloy.

4. Conclusions

(1) The maximum elongation appeared at 20° C in the temperature range *Ms* (− 196° C) to *Md* (75° C). The yield strength increased smoothly and the tensile strength increased sharply, as test temperatures decreased from 75 to − 196° C.

(2) The tensile strain at which α' first formed increased with increasing test temperatures from − 196 to 75° C. The proportion of α' in a fracture specimen decreased from 90% to 6% as test temperatures increased from 20 to 75° C, and was 100% at − 196, − 72 and − 22° C.

(3) The maximum fracture elongation was obtained when the elongation at which necking was initiated was largest, that is at 20° C. The value of α' per unit tensile strain was then 2.20. This value was in good agreement with that obtained for the two-phase $(\alpha + \gamma)$ Fe–Cr–Ni alloy.

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References

1. J. P. BRESSANELLI and A. MOSKOWITZ, *Trans. ASM* 59 (1966) 223.
2. I. TAMURA, T. MAKI, H. HATO and K. ABRAI, *J. Japan Inst. Met.* **33** (1969) 1383.
3. A. ROSEN, R. JAGO and T. KJER, *J. Mater. Sci.* 7 (1972) 870.
4. P. C. MAXWELL, A. GOLDBERG and J. C. SHYNE, *Met. Trans.* 5 (1974) 1319.
5. T. NAKAMURA and K. WAKASA, *J. Japan Iron Steel. Inst.* **61** (1975) 2067.
6. K. WAKASA and T. NAKAMURA, *J. Mater. Sci.* **12** (1977) 1438.
7. S. SEO, T. MIYAZAKI, E. YAJIMA and K. MORITA, *J. Japan Inst. Met.* **37** (1973) 1172.
8. G. R. SPEICH and P. R. SWANN, *J. Iron Steel Inst.* **203** (1965) 480.
9. Y. TOMOTA, T. MAKI and I. TAMURA, *J. Mat.* (in Japanese) **22** (1973) 329.
10. C. J. GUNTER and R. P. REED, *Trans, ASM* **55** (1962) 399.
11. V. F. ZACKAY, E. R. PARKER, D. FAHR and R. BUSH, *Trans. ASM* **60** (1967) 252.

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