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ROLE OF RETAINED AUSTENITE ON THE TOUGHNESS OF STEELS WITH AND WITHOUT CARBON

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ABSTRACT

The presence of retained austenite suppresses the ductile-brittle transition temperature of the 9Ni steel (containing 0.1 pct carbon) in both impact testing and fracture toughness testing. However, in an interstitial-free Fe-8Ni-2Mn-0.25Ti steel, the benefit of retained austenite is seen only in impact testing, and little improvement in fracture toughness is observed. The stabilities of retained austenite in both alloy systems are compared in terms of chemical compositions and strain rate. The implications on the role of retained austenite are discussed.

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INTRODUCTION

Among a series of high strength ferritic steels studied in this laboratory, commercial 9Ni steel (1) and 8Ni (2) laboratory steels pose a rather interesting case. The introduction of retained austenite suppresses the ductile-brittle transition temperature (DBTT) of the carbon-containing (0.1 wt %) 9Ni steel to below the liquid helium temperature (1) in both impact and fracture toughness testings. However, in the interstitial free 8Ni steel the benefit of retained austenite appears only in the impact testing; only a slight improvement in fracture toughness is observed as will be shown in the following sections. The available data on these two steels and 6Ni (3) and 12Ni (4) steels lead us to believe that the beneficial effect of the retained austenite is intimately connected with its mechanical stability, at least in these intermediate nickel steels. In the following, recent experimental data on 9Ni and 8Ni steels will be compared and the effect of retained austenite will be discussed.

EXPERIMENTAL PROCEDURED AND RESULTS

Chemical compositions of the commercial 9Ni steel and 8Ni laboratory steel are shown in Table 1. Detailed procedures for specimen preparation, heat treatment, cryogenic Charpy impact and fracture toughness testing, and other techniques are described elsewhere (1,2). A thermal cycling technique was employed to form a microstructure of ultra-fine grains ($\sim 1\mu$ size) in both steels before final tempering. For 9Ni steel, the conventional double normalize and temper (NNT) procedure (ASTM A353) was also used to produce typical commercial microstructure of $\sim 10\mu$ sized grains.

In Table 2 the Charpy impact energy (C_v) and fracture toughness (K_c) values of 9Ni steel at testing temperature of liquid nitrogen (LN$_2$T) and liquid helium (LHeT) are listed for different heat-treating conditions. As a measure of fracture toughness, the maximum stress intensity factor K_c values are used unless otherwise noted, since the valid plane-strain condition could not be fulfilled. In Fig. 1, impact energy (C_v) and fracture toughness (K_{IC}) for 8Ni steel under tempered (2BT) and untempered (2B) conditions are plotted against the testing temperature.

Comparison of C_v and K_c or K_{IC} reveals almost an identical behavior between the variation of impact energy and toughness as a function of testing temperature in 9Ni steel, but not in 8Ni steel. Thus in 8Ni steel, the K_{IC} values should be used as a fundamental measure of toughness rather than C_v values. In the case of grain-refined 9Ni steel, C_v values at LN$_2$T and LHeT before and after tempering clearly show that the DBTT is lowered below LHeT in consequence of retained austenite introduction. This observation is reinforced further by the very high fracture toughness value measured at LHeT.

DISCUSSION

It has been suggested that the retained austenite may serve as a sink for deleterious elements in the matrix, that it may act as a shock-absorber or crack-blunter, and that it may refine the microstructure. These roles are in turn influenced by several closely related factors such as volume fraction, shape, size, thermal and mechanical stability against the transformation to martensite on cooling and deforming at low temperatures, morphology of the martensite after the transformation, and chemical compositions.

The volume fraction of retained austenite in 9Ni steel under different heat-treating conditions is listed in Table 2. In 8Ni steel it is $\sim$5%. The higher volume fraction in the grain-refined 9Ni steel did not lead to the lower yield strength indicating no effect on the toughness. The shape and size of austenite grains observed in transmission electron microscopy were essentially the same in both 9Ni (1) and 8Ni (2) steels.

The stability of retained austenite and after-transformation morphology are actually determined by the chemical composition of the retained austenite and strongly influenced by the microstructure of the matrix. The retained austenite in 9Ni steel should be thermally more stable than in 8Ni steel since carbon is a far more efficient austenite stabilizer than Ni and Mn. The retained austenite in 9Ni was shown to have an estimated composition of 0.4% C, 19% Ni and 3% Mn and an austenitic steel of the same composition has the M_s point below LN_2T (5). The absence of carbon in 8Ni steel would lend to the M_s point higher than LN_2T. But when cooled to even LHeT, the amount of retained austenite in these two steels remained unchanged. This remarkable stability seems due to the stabilization effect of the grain refinement (6).

Evidences for mechanical stability are more difficult to obtain. In maraging steels (7), fracture toughness showed a sharp drop at a temperature near that of which the retained austenite first became mechanically unstable. Haga (8) observed in 6Ni steel that stable austenite does not transform at LN_2T even in the immediate vicinity of fracture surface and that some austenite islands are divided by twinned martensite which indicates a partial transformation of austenite due to crack arrest. The importance of the after-transformation morphology of retained austenite depends on whether inherently brittle or rather ductile martensite is produced from the austenites in front of the moving crack. Thus the presence of carbon could be a source of concern in these nickel steels since a high carbon content in highly nickel-enriched retained austenite would lead to brittle twinned plate martensite. On the other hand, the absence of carbon could harm the thermal and mechanical stability of retained austenite. Therefore the effect of retained austenite on toughness seems to be determined by an interplay of stability and after-transformation morphology.

Finally, the discrepancy in C_v and K_{IC} of 8Ni steel may be due to strain-rate effects. The exact nature of the strain rate effect is not clear. In case of 12Ni steel (4), a 1000 times faster cross-head speed led to a substantially lower fracture toughness and failed to detect the influence of retained austenite. In maraging steels, by a 100-fold faster cross-head speed, the fracture toughness was increased in the austenite-bearing alloys ($\gamma > 40\%$ by volume) while decreased in fully martensitic alloy.

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Table 1. Chemical Compositions (wt. pct).

Steels	Ni	C	Mn	Ti	N	S	P	Si	Fe
9Ni	9.18	0.060	0.60	--	--	0.002	0.010	0.21	Balance
8Ni	8.03	0.001	1.97	0.17	0.001	0.006	0.006	--	Balance

Table 2. Cryogenic impact energy and toughness of 9Ni steel.

		Testing Temperatures		Retained Austenite Sub zero treated at LN_2T (vol. %)
		LN_2T	LHeT	
Grain-refined	C_v ft-lb	40	--	0
Grain-refined and tempered	C_v ft-lb	137	128	10-15%
	K_c ksi$\sqrt{in}$	183	140	
Unrefined (NNT)	C_v ft-lb	125	75	<5%
	K_c ksi$\sqrt{in}$	180	72*	

*Valid K_{IC} value.

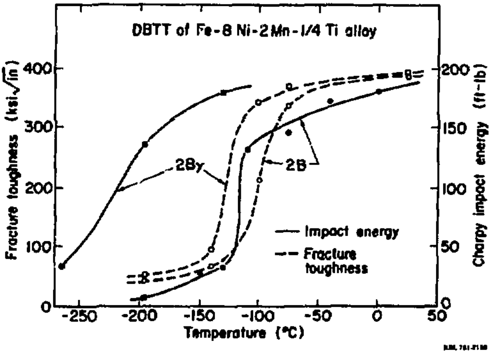

Fig. 1. Temperature variation of fracture toughness and Charpy impact energy in 8Ni steel.