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Martensitic transformations in AISI 440C stainless steel

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Abstract

AISI 440C stainless steel possesses a low M_s temperature, which is far below room temperature. After subzero treatment in liquid nitrogen, the steel forms plate martensite with significant amounts of retained austenite. Dilatometric experiments with microstructural observation were performed to investigate the tempered martensite and the decomposed retained austenite during multiple tempering treatments. The results indicate that a complete transformation of retained austenite can be more easily achieved by multiple tempering cycles than by a single long-time cycle. The possible mechanism for the decomposition of retained austenite during multiple tempering cycles is attributed to the invariant-plane-strain of the prior martensitic transformation extending accommodation defects to the adjacent retained austenite, which favors further transformations in the subsequent tempering operations.

Keywords: Stainless steel; Tempered martensite

1. Introduction

For high-carbon iron–chromium stainless steels, the typical as-quenched structure is a mixture of twinned plate martensite and retained austenite. If the chosen tempering process for these types of steels ensures the eliminating of all the retained austenite and tempers all areas of martensite, an attractive combination of strength, toughness and size-stability in application can be obtained. The proper heat treatment process suggested [1] is to use (i) a subzero quench and (ii) a double tempering treatment with cooling to room temperature. Although the conventional tempering of martensite in as-quenched low-carbon steels can be divided into five distinct stages [2], the actual mechanism of tempering in these types of steels is still not clear.

There has been intensive research work on retained austenite and lath martensite in low-carbon alloy steels. However, little transmission electron microscopy research work has been carried out on twinned plate martensite with retained austenite in high-carbon alloy steels [3]. It is naturally very difficult to produce electron-transparent samples for TEM (because the high-carbon alloys are quite brittle), but TEM investigation continues to assume greater significance in research.

AISI 440C is a high-carbon grade in commercial martensitic stainless steels, and is widely used in many industries for manufacturing essential parts. In this work, dilatometric experiments were performed to investigate the tempering response in subzero-treated specimens of AISI 440C stainless steel. The resulting optical metallographs and transmission electron micrographs were examined to elucidate the microstructural evolution.

2. Experimental procedure

The as-received material was a commercial wrought AISI 440C stainless steel bar (with a diameter of 122 mm) produced by Gloria Material Technology Corporation through four-folded forging of a cast slab at 1130 °C and annealing at 870 °C for 8 h, followed by furnace cooling to ambient temperature. The chemical composition of the steel is listed in Table 1.

All the tempering thermal cycles in this work were performed on a Dilatronic III RDP dilatometer from Theta Industries, Inc. The dilatometer was interfaced with a computer workstation (PDP 11/55 central processor) for analyzing the resulting data. The software package (provided by Theta Industries, Inc) allows flexible and complete control to execute multiple tempering cycle experiments. The length, time and temperature information was recorded in microsecond intervals, and the level of vacuum could be maintained at 10^{-5} Torr (10^{-3} Pa) to protect the specimens from oxidation. Before the preparation of the

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Table 1
Chemical composition of AISI 440C stainless steel (wt.%)

Composition	Wt.%
Fe	Bal.
C	1.04
Cr	17.4
Mo	0.45
Mn	0.40
Ni	0.40
Si	0.38
Cu	0.05
Al	0.02
N	0.029
P	0.026
S	0.009

dilatometer specimens, the pieces of steel rod were machined from the half radius position of the original bar, and homogenized at 1200 °C for three days while sealed in a quartz tube containing pure argon, subsequently being quenched in water. After the decarburization layer had been removed, the specimens were then machined to 3 mm diameter cylindrical rods of 6 mm length. It has been noted that AISI 440C stainless steel has a much lower M_s temperature than room temperature, and that the homogenized specimens form mainly austenite with small amounts of undissolved carbides. In order to obtain a mixture of plate martensite with retained austenite, the homogenized specimens were therefore cooled by subzero treatment with liquid nitrogen (−196 °C). In this work, the tempering behavior of subzero-treated specimens was investigated. The subzero-treated specimens were heated at the rate of 20 K/s to the tempering temperature of 600 °C, held at 600 °C for 2 h, and then cooled at the rate of 20 K/s to ambient temperature; this was the first tempering cycle. The second tempering cycle was repeated after the first tempering cycle. For the purpose of comparison, a single stage tempering treatment at 600 °C for 4 h was also carried out.

The corresponding microstructures were examined by using optical microscopy (OM) and TEM. Both specimens were slit

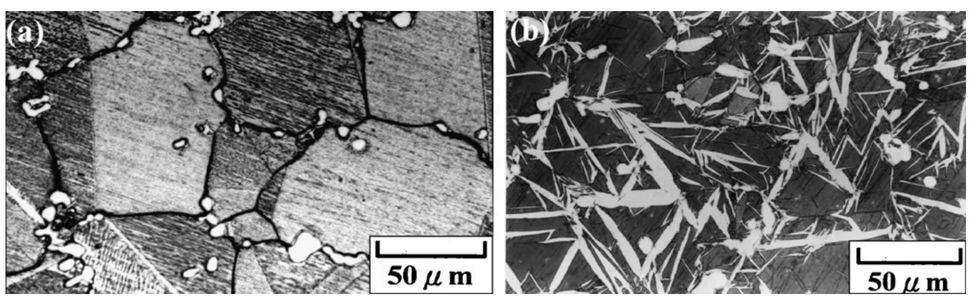

Fig. 1. Optical metallographs taken from (a) the as-homogenized sample; (b) the subzero-treated sample.

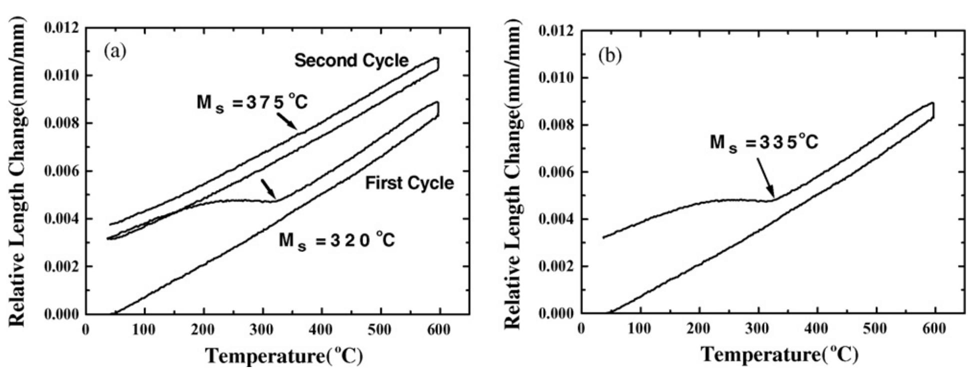

Fig. 2. Dilatometric curves.

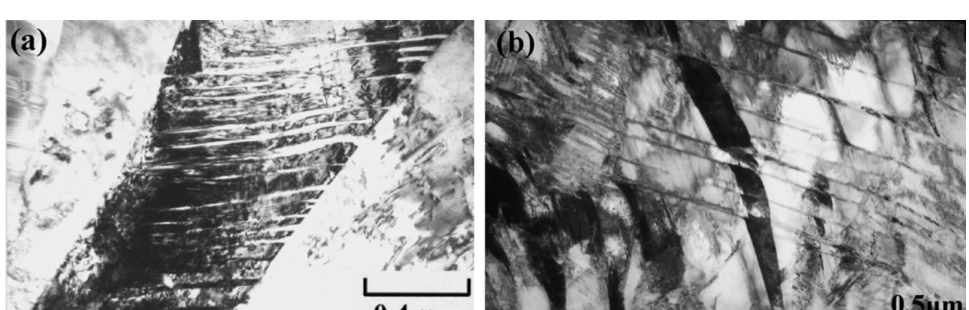

Fig. 3. TEM images showing accommodation defects within austenite.