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A magnetic study of the maraging 350 steel

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Abstract

In this work the magnetic properties of a Ni–Co–Ti maraging steel grade 350 were measured in many processing conditions. The influence of the aging temperature is analyzed. Thermomagnetic analyses were also carried out to investigate martensite–austenite transformation.

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Keywords: Maraging steels; Magnetic properties; Thermomagnetic analysis

1. Introduction

Maraging steels are a family of age hardenable materials with extremely high mechanical strength and good toughness. Maraging 350 is one of the strongest grades of this family. In the as-quenched or solution-treated condition its microstructure consists of bcc martensite containing low carbon (0.02 wt% max) and high nickel (~18 wt%) and cobalt. The strengthening effect is produced by the precipitation of fine particles of Ni_3(Mo, Ti) and Fe_2Mo in the 450–650°C range [1]. The maximum hardness is obtained in the 480–520°C range, but accordingly to Ahmed et al. [2], the aging at 550–650°C may provide better toughness.

A maraging steel may be selected for magnetic devices where the combination of high strength and soft magnetic properties are required, such as in high-speed rotors. In the present work the magnetic properties of a maraging 350 steel were investigated as function of aging temperature in the 440–750°C range. The objective of this investigation was to determine the best treatment conditions for magnetic purposes. This paper also deals with the martensitic transformations ($M \rightarrow \gamma$ and $\gamma \rightarrow M$) of the maraging 350. This investigation was done by thermomagnetic analysis, following the same methodology applied for austenitic stainless steels [3].

2. Experimental

A maraging 350 steel (19.8%Ni, 10.7%Co, 4.7%Mo, 1.47%Ti, 0.98%Al, 0 > 0.007%C, %wt) was solution treated at 900°C. After this treatment the microstructure was completely martensitic (BCC). Aging treatments in the 440–750°C range were carried out in vacuum-sealed quartz tubes. In this work the duration of the aging treatments was fixed in 1 h. Some samples where cold rolled from 0.75 to 0.15 mm (true deformation = 1.61) before aging. The magnetic properties (coercive force (H_c), residual (B_r) and saturation (B_s) magnetization) were measured in a VSM EGG-PAR with maximum field of 600 kA/m and sweep time of 0.01 s. Thermomagnetic analysis and magnetic decay were performed in a thermomagnetic balance equipped with a resistance oven (LC-CNRS, Grenoble/France).

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3. Results

Figs. 1 and 2 show the behavior of the magnetization saturation (m_s) and coercive field (H_c) as function of aging temperature. The saturation magnetization starts to decrease at about 560°C and reaches a minimum value at 650°C (Fig. 1). This is attributed to the formation of austenite associated with precipitation reactions. Li and Yin [4] suggested that the austenite results from the partial dissolution of Ni_3(Mo, Ti) and Fe_2Mo formation. The Ni-rich austenite formed by aging in the 500–700°C range is stable at room temperature. The austenite formation also promotes the increase of H_c (Fig. 2). The cold rolling prior to aging does not change significantly the shape of the curves. However, a small decrease in the H_c values till 560°C (Fig. 2), and an increase of hardness and mechanical strength may be provided by plastic deformation before aging.

Fig. 3 shows the thermomagnetic analysis obtained with heating and cooling rates of 10°C/min. The start

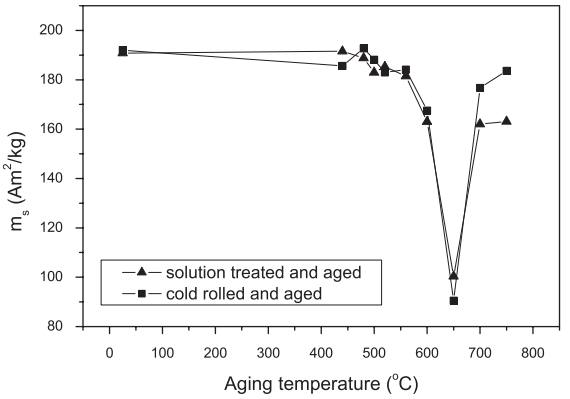

Fig. 1. Saturation magnetization vs. aging temperature.

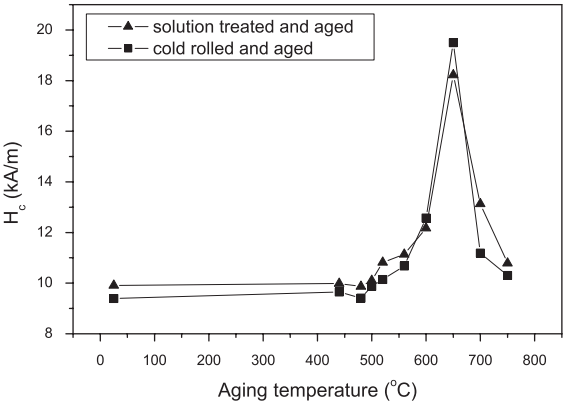

Fig. 2. Coercive field vs. aging temperature.

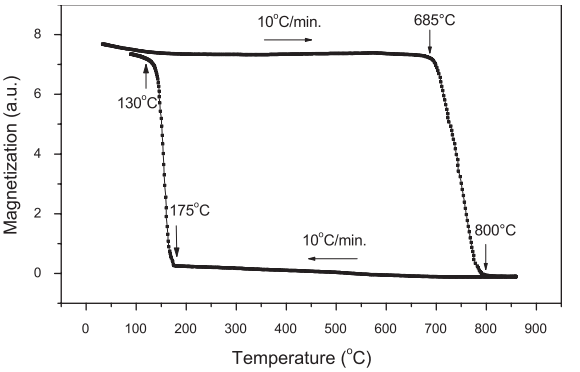

Fig. 3. TMA of the maraging 350 steel.

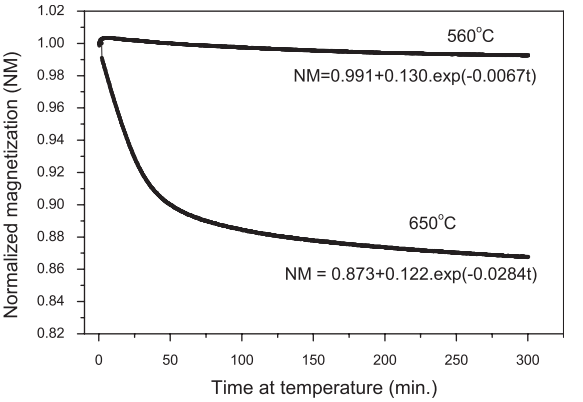

Fig. 4. Normalized magnetization vs. time curves.

(A_s) and final (A_f) temperatures of the martensite (M) to austenite (γ) transformation are 690°C and 800°C, respectively. The martensite start (M_s) and final (M_f) temperatures are 175°C and 130°C, respectively. The martensite reversion, however, can occur below the A_s point (690°C) during the aging treatment. The kinetics of the austenite formation during the aging can be studied by magnetic decay. Fig. 4 shows the normalized magnetization (NM) curves against time at 560°C and 650°C. The kinetics of martensite decomposition at these temperatures may be described by exponential decay laws (shown in Fig. 4).

4. Conclusions

The austenite formation between 560°C and 700°C promotes the increase of coercive force and the decrease of magnetization saturation. For magnetic purposes the steel may not be treated or used in this range. The

thermomagnetic analysis may be used to determine the starting and final points of the $M \rightarrow \gamma$ and $\gamma \rightarrow M$ transformations and to study the kinetics of martensite reversion.

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