RETAINED AUSTENITE IN SAE 52100 STEEL POST MAGNETIC PROCESSING AND HEAT TREATMENT

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Abstract

The application of magnetic fields as a method of reducing retained austenite in steel is based on the thermodynamic argument that paramagnetic austenite is destabilized in the presence of a large magnetic field. The goal of this study was to determine the effect of applying a magnetic field on the amount of retained austenite present at room temperature after quenching. After several post-quench delay times, samples of SAE 52100 steel were heat treated then subjected to a magnetic field of varying strength and time. X-ray diffraction was used to collect quantitative data corresponding to the amount of each phase present post processing. Stronger magnetic field strengths resulted in lower amounts of retained austenite for fixed application times. The results for applying a fixed magnetic field strength for varying amounts of time were inconclusive and suggest negligible dependence. When applying a magnetic field after a post-quench delay time, the analyses indicate that decreased delay times result in less retained austenite, which indicates that retained austenite becomes more stable with time after quenching. While it is apparent that applying a magnetic field after quenching will result in a lower amount of retained austenite, the exact relationship, linear or other, is presently inconclusive based on the data in-hand.

Introduction

Multiple researchers [1-3] have shown that the application of high or ultrahigh magnetic fields can alter the microstructure and phase transformations in medium and high carbon steels such as SAE 52100. Because of the high carbon content in SAE 52100, retained austenite can result from the heat treatment process. Since retained austenite can transform with a nominal 4% volume expansion into white martensite, lower amounts of retained austenite are usually sought in order to avoid any corresponding distortion and/or loss of fracture toughness in the final piece. Typically, a post heat treatment tempering cycle or a cryogenic treatment immediately following quenching will reduce the amount of retained austenite, but this is time-consuming and costly [4]. The application of a magnetic field as a method of reducing the amount of retained austenite in steel may overcome these difficulties and is based on the thermodynamic argument that paramagnetic austenite is destabilized in the presence of a large magnetic field.

Samples of SAE 52100 steel, which contain 1.45 wt% Cr and 1.0 wt% C, were studied to determine the relationship between applying a magnetic field post quench and the amount of retained austenite present at room temperature [5]. This project is a part of a larger, ongoing project investigating the application of a magnetic field during heat treatment and its influence on the iron-carbon phase-equilibria.

Experimental Procedures

A 32 mm diameter bore resistive magnet with a maximum magnetic field strength of 33T was used at the National High Magnetic Field Laboratory for the magnetic processing of the samples. The custom designed induction coil with a gas purge/quench system was used in the heat treatment of the samples and is described in [1, 3]. All samples were heated to 850° C and held for 30 minutes to insure full transformation into austenite. The samples were then quenched to 25° C using He gas. Magnetic fields with strengths ranging from 0T to 30T were applied post quench to the samples for varying times either immediately following the quench or after a wait time.

Table I lists the details of the experimental conditions for the x-ray measurements. Briefly, a 4-axis (Φ, χ, Ω, 2Θ) goniometer [6] was employed for phase identification using Θ-2Θ scans and near-parallel beam optics, which reduces sample surface displacement errors [7,8]. During scanning, the specimens were oscillated ±2 mm in plane to improve particle statistics. Specimen alignment was accomplished using a dial gauge probe, which was accurate to ±5 µm and a telescope. Here, the relative distance to the center of rotation is known, and the diffracting surface is positioned accordingly. Goniometer alignment was ensured by examining LaB_6 powder on a zero background plate. Jade software was utilized in the phase identification analysis [9]. In order to get a measure of the reproducibility, one sample was scanned 5 times in different locations/sets of grains. The amount of retained Austenite was then calculated and the standard deviation determined, which was assumed to be representative for all the samples.

Table I - Experimental conditions of the x-ray measurements PTS tube.

Parameter	Condition
Equipment	Scintag PTS goniometer Spellman DF3 series 4.0 kW generator Scintag liquid N_2-cooled Ge detector
Power	1.4 k; 40 kV, 36 mA
Radiation	Cr, λ = 2.28970 Å
Incidence slit divergence	0.5°
Receiving slit acceptance	0.25°; radial divergence limiting (RDL) Soller slit
Source to specimen distance	290 mm
Specimen to back slit distance	290 mm
Scans	0.02° 2Θ/step at 0.1 or 0.5 °/min

The amount of retained austenite was calculated using the ASTM standard for randomly oriented samples [10] where *R* is a scale factor associated with phases and materials used, *I* is the calculated integrated intensity total for the phase present, and *V* is the volume fraction of the phase. The austenite phase is represented by γ and the ferrite/martensite phase is represented by α.

$$\%\ of\ RA = (V_\gamma)\,100 = \left(\frac{\frac{I_\gamma}{R_\gamma}}{\frac{I_\gamma}{R_\gamma} + \frac{I_\alpha}{R_\alpha}} \right) 100$$

Since the samples contained “white” or untempered martensite, the tetragonal nature was evident by several split diffraction peaks.

Results / Discussion

In Figure 1, the percentage of retained austenite decreases as a function of magnetic field strength. The magnetic field was applied to all samples for 10 minutes immediately following the quench. The error bars shown in Figure 1, 2, and 3 represent the standard deviation determined as described above and was found to be 1.1%. While the magnetic field strength impacts retained austenite, more data is required to determine the exact relationship (e.g., linear).

Next, a 30T magnetic field was applied to the samples immediately following the quench for varying amounts of time. In Figure 2, the percentage of retained austenite appears to independent of the amount of time the magnetic field is applied. These results in conjunction with the results in Figure 1 indicate that it isn't how long the magnetic field is applied for, but the strength of field that has an effect of the amount of retained austenite present.

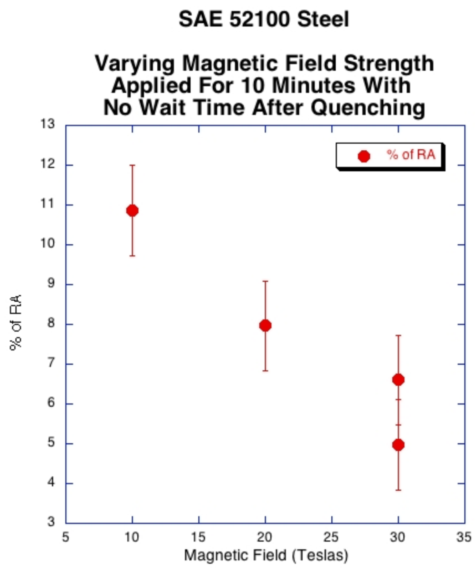

Figure 1

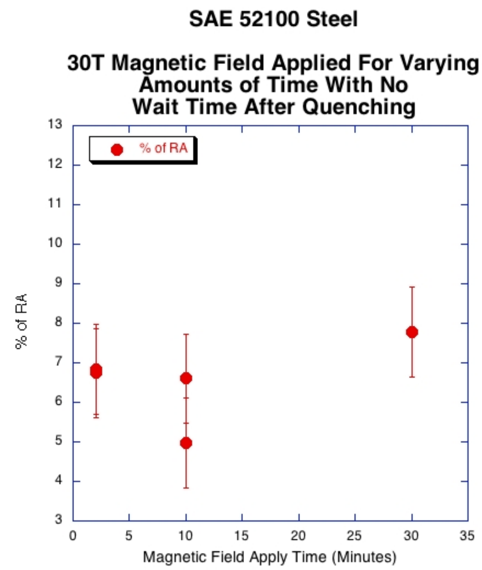

Figure 2

In Figure 3, the percentage of retained austenite is higher for longer wait times post quench until the magnetic field was applied. After waiting 0, 2 and 24 hours following the quench, a magnetic field of 30T was applied for 10 minutes to the samples. It is evident from the data that applying a magnetic field soon after the quench will lower the amount of retained austenite. Waiting 24 hours to apply a magnetic field post quench seemed to have little effect in lowering the retained austenite percentage. This indicates that the retained austenite is stabilizing over time and that once this happens, a magnetic field has less of an effect of destabilizing the paramagnetic austenite.

While examining the effect of applying a magnetic field on the tempering of an SAE 1045 steel [11], it was seen that the stronger the magnetic field, the less hardness loss occurred. This indicated that the magnetic field was hindering the tempering process. Because of this observation, hardness data was collected on the 52100 samples (see Figure 4). Here, a magnetic field of varying strength was applied for 10 minutes directly following the quench. Presently, it is unclear if the magnetic field has any effect on the hardness of the 52100 samples.

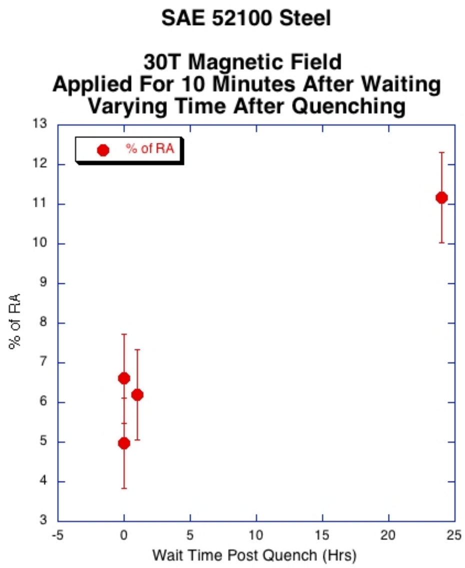

Figure 3

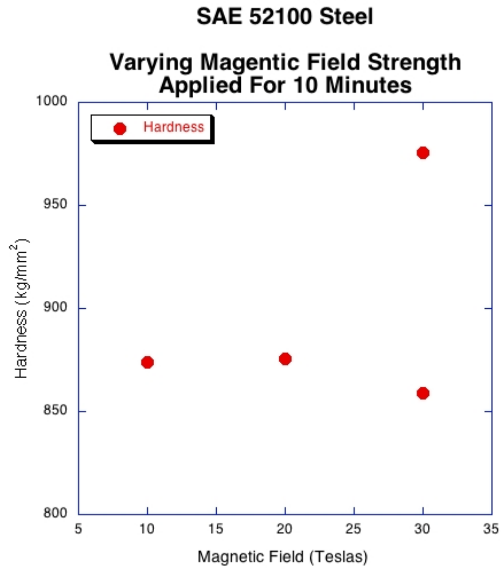

Figure 4

Summary / Conclusion

Applying a magnetic field after quenching results in lower amounts of retained austenite, and results indicate that austenite tends to stabilize with time in SAE 52100 steel. It is shown by the data that what is important is not how long the magnetic field is applied, but rather the strength of the magnetic field that is applied. Due to the fact that the austenite tends to stabilize over time, if magnetic processing is to be used as a viable method for retained austenite reduction, the field must be applied soon after the quench and therefore the magnet would need to be close by and ready to be used. The strength of a magnetic field seemed to have no effect on the hardness of the SAE 52100 steel.

The exact relationship, linear or other, of applying a magnetic field on the amount of retained austenite requires more data. This project is a part of a larger, ongoing project investigating the application of a magnetic field during heat treatment and its influence on the iron-carbon phase-equilibria.

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