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Recrystallization study of the 348 stainless steel

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1. Introduction

The 300 steel series is used in several industrial segments. One important application of this steels are in primary circuit of pressurized water nuclear reactors, and in some cases, as nuclear fuel cladding [1-3]. During the fabrication, some austenitic stainless steels undergoes through a strain-induced martensitic transformation, which changes their microstructures and as consequence, their properties [4].
The stability of the austenitic phase under scientific debate, especially when these materials are subjected to environment of a nuclear reactor. One way to improve the resistance of these materials to irradiation damages are through the addition of alloying elements like, Co, Nb, Ti and Ta [5-6]. The 348 stainless steel receives the addition of Nb, Co and Ta to enhance the resistance to radiation induced precipitation, but these elements also could promote the precipitation of G phase in the strain-induced martensite [7]. This work intends to study the recrystallization process of the cold formed AISI 348.

2. Methodology

A 25 mm x 100 mm x 2 mm 348 strip was annealed according the manufacturer [8] instructions. The annealed samples were cold rolled in from 2 mm to 0.7 mm ($\varepsilon = -1.04$). 7 samples were taken from the cold rolled piece, then heat treated at 800°C during 2, 4, 8, 16, 32 and 64 minutes, followed by water quenching. The temperature was chosen based on Thermocalc simulations.
The heat treated samples were characterized by metallography, X-Ray diffraction (Cu Kα = 0,154 nm), Vickers micro hardness (HV1 – 15s) and scanning electron microscopy.
The metallography was carried out through conventional grinding and polishing. The etching was performed tow times: the firs using an aqueous solution of 10% oxalic acid at 6V for 60s to reveal grain boundaries and, after a new polish, a second etch using a modified version of the Vander Arend etching [9].
X-Ray diffraction patterns were acquired scanning in the $40° < 2\theta < 95°$ range, in a step size of 0,025° with a 2s time per step. The patterns were indexed and refined using the GSAS® [10] software. The micro hardness tests were performed in a Shimadzu HMV-2T micro hardness tester using a load of 1 kgf and 15s of indentation time. A TM-3000 SEM was used to aid the microstructural characterization.

3. Results and Discussion

Figure 1 presents the microstructure of 2 min sample, etched with Vander Arend (a) and with oxalic acid (b). The microstructure presents strongly deformed grains and a high quantity of strain-induced martensite. It is expected since the time is quite low, the 4, 8 and 16 minutes also presented similar microstructures, with a progressive reduction on the martensite area. The 32 and 64 samples did not react with the Vander Arend etch, even for prolonged etching times, indicating a low quantity of stain-induced martensite, Figure 2 presents the microstructures of these samples by SEM.

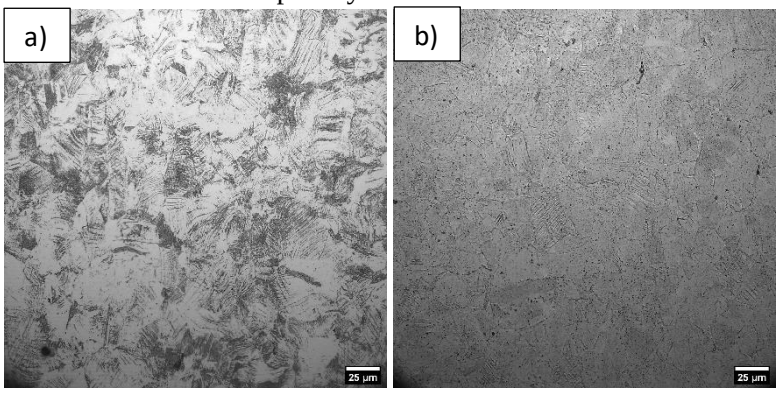

Figure 1 - Microstructure of the 2-minute sample etched with a)Vander Arend, b) oxalic acid.

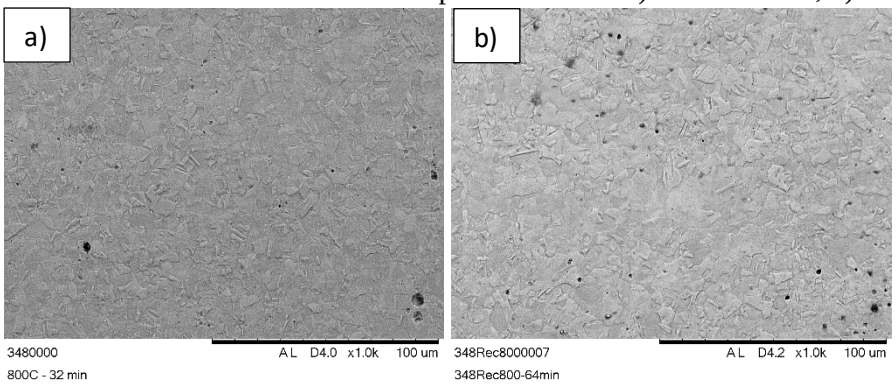

Figure 2 - Microstructure of the a) 32-minute sample and b) 64-minute sample.

The austenite recrystallization process competes with the martensite reversion, retarding the grain growth. Figure 3a presents the X-Ray diffraction patterns for all samples used in this work and Figure 3b presents the average grain diameter measured by intercept method. The martensite peaks are strongly reduced in the 32-minute and 64-minute sample, and it coincides with the average grain diameter reduction, so by comparing the average grain diameter with the intensity of the martensite peaks, it is clear that there is a correlation between the martensite volume fraction and the austenite recrystallization. The martensite reversion can occur by shearing or by diffusion, according to Tomimura [11], the kinetics of a shear controlled process is similar to a martensitic transformation, occurring almost instantly and the amount of reversed martensite is only function of temperature. Since there is a time dependence in the reversion, this process is probably controlled by diffusion.

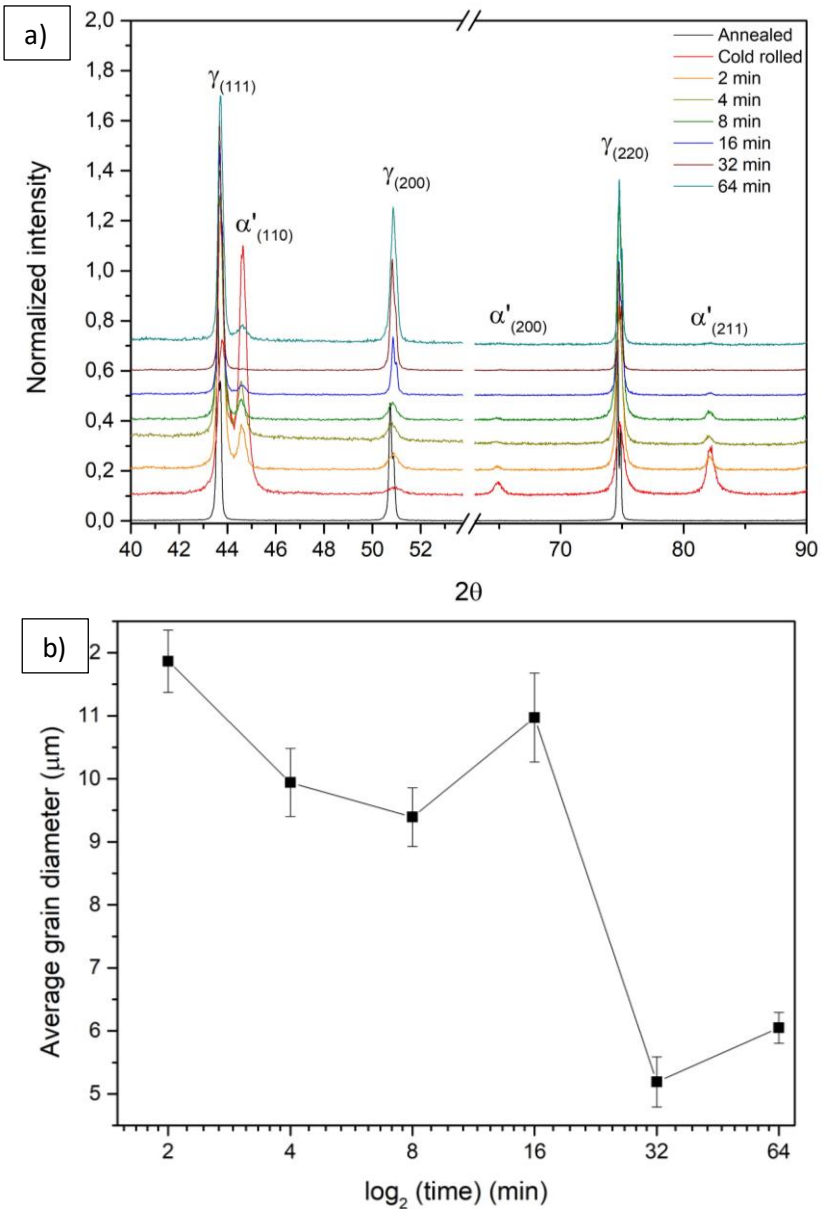

Figure 3 – a) X-ray diffraction patterns for the annealed, cold rolled and heat treated samples, and b) average grain diameter of heat treated samples.

4. Conclusions

The results allow to draw the following conclusions:

- The main mechanism of martensite reversion, at 800 °C, is diffusion.
- The competition between the martensitic reversion and the austenite recrystallization persists until the martensite volume fraction is below 5%, were the austenite begin to recrystallize.
- More studies are needed to evaluate if these mechanisms operate in different temperatures, and if the presence of stain-induced martensite increases of decreases the secondary phase precipitation.

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