Abstract. Dilatometric study in maraging 300 steel was carried out to study the effect of heating rate on precipitation of intermetallic phases and martensite to austenite transformation. Solution annealed material were subjected to controlled heating-holding-cooling cycles. The martensite to austenite transformation splits into two steps at lower heating rates. The first step enhanced by slow heating rate, occurs through a diffusion process, while the second step, enhanced by a fast heating rate, occurs though a shear process. The extent of precipitation decreases with heating rate, suggesting that precipitation occurs primarily by a diffusional process.

1. Introduction

Maraging steels are strategic materials to the Brazil’s technological development due to their high strength combined with high fracture toughness, finding extensive applications in several areas, such as in aerospace and nuclear technologies [1]. Maraging refers to the ageing of martensite. The only transformation that occurs at ordinary cooling rates is martensite formation. The martensite without carbon is quite soft, but heavily distorted by a high dislocation density. Hardening and strengthening of these steels are subsequently produced by heat treating (ageing) for several hours at 480–510°C, caused by precipitation of intermetallic phases such as Ni_3X (X=Ti, Mo) and the formation of a more stable phase Fe_2Mo that demands higher exposure times. During this stage, the metastable martensite in the steels decomposes. Fortunately, the precipitation hardening occurs much more rapidly than the reversion reactions producing austenite and ferrite. Thus, substantial hardening can be produced before reversion occurs. Austenite reversion, or the prevention of it in most cases, is important to ageing, because austenite is a stable phase at room temperature for maraging steel compositions [2-4]. It is noteworthy that both diffusion and shear mechanisms can occur simultaneously during this transformation of austenite reversion. Previous studies have shown that these mechanisms can depend on the heating rates. Dilatometry has been largely used for studies of phase transformations on several types of steels, such as low-carbon steels and maraging steels [5,6].

The present work was carried out on maraging 300 steel using the dilatometric technique to study the effect of heating rate on both the precipitation and the martensite to austenite transformation.
2. Experimental Procedure

Samples from maraging 300 steel supplied in the solution annealed condition were machined to 4 mm diameter and 18 mm length cylindrical rods. The composition of this steel is listed in Table 1.

| Element | Ni   | Co   | Mo   | Ti   | Al   | C    | S    | P    | Si   | Mn   | Fe   |
|---------|------|------|------|------|------|------|------|------|------|------|------|
| wt %    | 19.00| 9.37 | 4.94 | 0.63 | 0.08 | 0.008| 0.002| 0.004| 0.06 | 0.01 | Balance |

Heating and cooling cycles were performed in the quenching Linseis-L75V 1400 RT dilatometer under argon atmosphere. For these tests, heating was carried out with heating rates of 10 and 20°C/min. Length increase (ΔL) and temperature (T) changes were measured during heating for each heating rate.

3. Results and Discussion

A typical dilatometric curve of the maraging 300 steel tested at a heating rate of 10 °C/min is shown in Figure 1.

![Dilatometric curve of heating and cooling for Maraging 300, heating rate of 10 °C/min.](image)

Uniform expansion continues until 500 °C when a small contraction starts to occur, indicating the start of precipitation at this temperature (P_s). This is followed by a small amount of linear expansion with increasing temperature to 595 °C (P_f). When the temperature is raised to 623°C, a large contraction appears in the dilatometry curve, which can be taken as the start of the austenite formation (A_s). At 720 °C, the contraction starts to slow down, until 801°C when the curve resumes linear expansion. Therefore, the austenite transformation ends at around 801°C (A_f). Complete solution is ensured by heating continuously to 900°C and holding at this temperature for 1 minute. During cooling to room temperature, there is drastic expansion at approximately 194 °C, owing to the sudden start and the rapid transformation from austenite to martensite, corresponding to the martensite start temperature (M_s). The martensite finish temperature (M_f) is about 62 °C. Thus, this maraging 300 steel should have a single-phase structure upon cooling to room temperature that is martensite.
Figure 2 presents the variation of the slope of dilatometric curves as a function of temperature to the heating rates of 10 and 20 °C/min for the maraging 300 studied.

![Figure 2](image_url)

**Figure 2.** Slope of dilatometric curves for maraging 300 at heating rates of 10 °C/min and 20 °C/min indicating the precipitation and martensite to austenite transformation.

It is observed from figure 2 that at the lower heating rate, the austenite transformation splits in two steps. At a lower heating rates, the martensite starts to transform to austenite by a diffusion process and at sufficiently high temperatures (>720 °C) the thermodynamic driving forces takes over, thus transforming the remaining martensite to austenite by shear mechanism. Since at high heating rates there is insufficient time for diffusion to take place, therefore the entire martensite transforms to austenite by a single step shear mechanism [5,6].

It’s also possible to observe from figure 2 that as the heating rate increases, the extent of precipitation decreases. This result indicates that precipitation in maraging 300 is primarily diffusion-controlled. For higher heating rates the time available for precipitation decreases leading to a smaller specimen contraction, due to the smaller volume fraction of precipitates formed during heating at higher heating rates [5,6].

4. Conclusions
The martensite to austenite transformation in maraging 300 steel shows a tendency to split into two steps as the heating rate is decreased. The first step of this transformation, enhanced by a slow heating rate, occurs through a diffusion process, while the second step, enhanced by a fast heating rate, occurs through a shear process. The extent of precipitation decreases with increasing heating rate, suggesting that precipitation occurs primarily by a diffusional process.

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