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Influence of Cold Rolling on Austenite Formation in Plain Low-Carbon Steel Annealed in Intercritical Region

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1- Introduction

Due to crashworthiness performances and their good balance between strength and formability, dual-phase steels (DPS) are widely used in the automotive industry. DPS are characterized by hard martensite islands embedded in a softer ferrite matrix; and their microstructural features are mainly determined by the condition of austenite forms at the intercritical temperature. Therefore, a fundamental understanding of austenite formation is necessary for controlling and optimizing DPS microstructures.

A lot of studies have been conducted on the formation of austenite in the intercritical region for both hot-rolled and cold-rolled steels. The effect of intercritical annealing parameters such as heating rate, intercritical annealing temperature, and holding time were taken into account. Since the level of cold rolling has a main influence on the kinetics of austenite formation as well as its nucleation and growth, in the present work, the effect of the level of cold rolling as well as intercritical annealing temperature on the evolution of austenite condition and final microstructure has been studied.

2- Experimental

A sheet of a medium carbon steel 4.6 mm in thickness was used in this study as the starting material. The chemical composition of this steel is given in Table 1. Samples with the size of 80×15 mm were cut from the sheet and were then cold rolled by 50% and 70% reduction in thickness using a laboratory rolling mill with the roll diameter of 57 cm and the peripheral speed of 40 revolutions/min. The cold rolled samples were intercritically annealed at 740 ºC and 780 ºC for 30 s to 10 min followed by quenching into an ice brine solution. In order to investigate the microstructural evolution as well as the effect of controlling parameters on the nucleation and growth processes of austenite (martensite at room temperature) formation, the samples were quenched at various time intervals during intercritical annealing; and after being etched with 3% Nital solution as well as 10% sodium meta-bisulfite aqueous solution, the microstructure of the steel samples was examined using the scanning electron microscope (SEM) (type Leo 1450VP). The ferrite grain size and the size of martensite islands and cementite particles as well as the volume fractions of martensite and cementite phases were measured using Clemex image analysis software.

Table 1 Chemical composition of the steel in weight percent

Fe	C	Mn	Si	P	S	Cr	Ni
Bal.	0.165	1.15	0.411	0.018	0.01	0.035	0.066

3- Results and Discussion

Microstructural observations for 70% cold rolled specimen indicate that recrystallization of deformed ferrite grains completed prior to austenite formation. Spheroidization of cementite lamellae inside pearlite colonies can also be observed in the microstructure (Fig. 1). Fig. 1 and Fig. 2 represent that austenite (martensite at room temperature) nucleates mainly at cementite aggregates located along ferrite grain boundaries and its growth continues until complete consumption of the aggregates.

For the case of 50% cold rolled specimen, recrystallization of ferrite grains is completed prior to austenite formation. According to Fig. 3a, it can be said that cementite lamellae inside pearlite colonies were partially spheroidized prior to austenitization. Austenite nucleates mainly at ferrite-pearlite interfaces and then sweeps pearlite colonies (Fig. 3a).

The model predictions for austenite formation at 740°C for the three kinds of specimens have a reasonable agreement with the experimental results (Fig. 4). As can be seen in Fig. 4, austenite forms at higher rate in 75% cold rolled specimen than in unrolled and 50% cold rolled specimen. The observed trend can be attributed to the change of microstructure as a result of cold rolling.

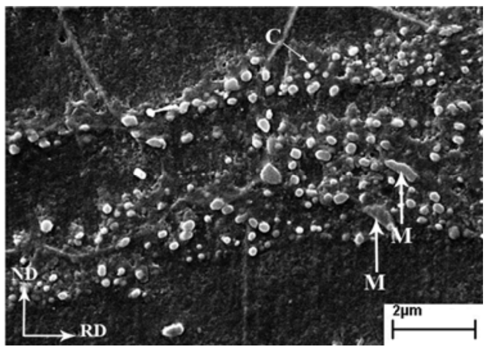

Figure 1 SEM micrograph of the microstructure of 70% cold rolled specimen after intercritical annealing at 740 °C for 2 min (M and C represent martensite and cementite phases, respectively)

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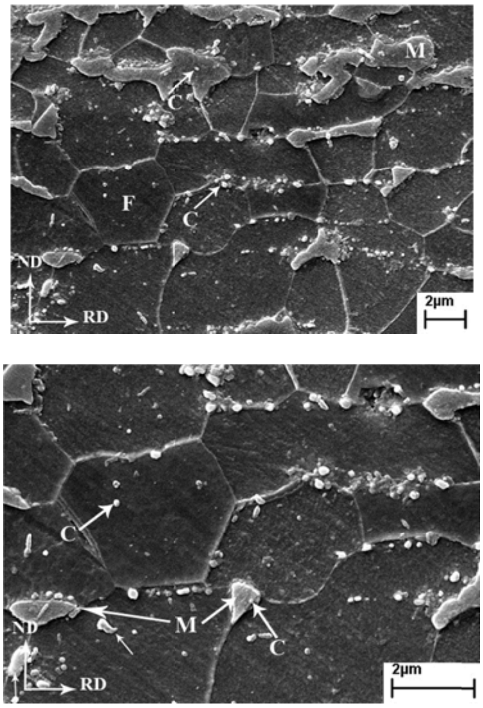

Figure 2 SEM micrographs of the microstructure of 70% cold rolled specimen after intercritical annealing at 740 °C for 3.5 min (M represents martensite phase)

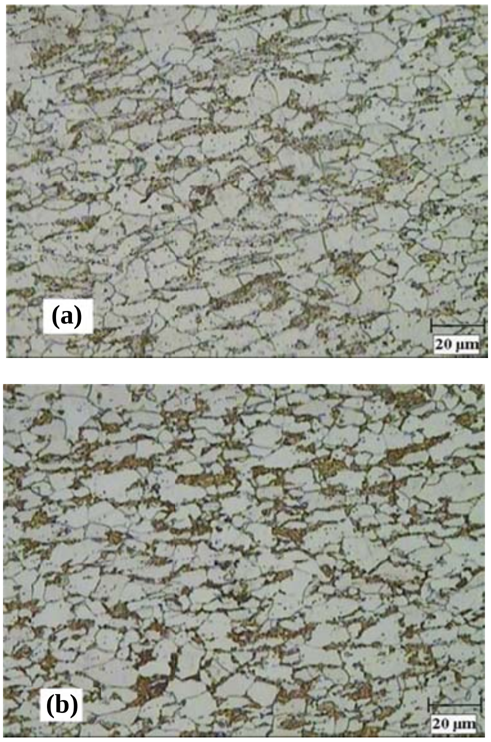

Figure 3 Optical micrographs of the microstructure of 50% cold rolled specimen after intercritical annealing at 740 °C for: a) 2.5 min, b) 4 min

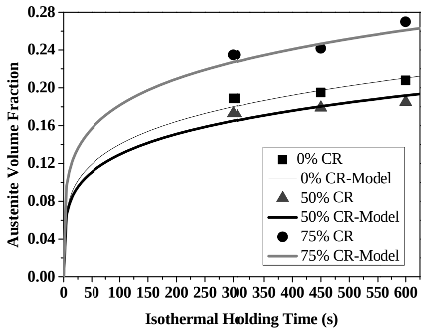

Figure 4 The kinetics of austenite formation during intercritical annealing at 740 °C

4- Conclusions

The results showed that cold rolling and other processes occurring during the formation of austenite significantly influence the initial microstructure and the nucleation and growth of austenite phase. In undeformed and 50% cold rolled specimens, austenite formed from the pre-existing pearlite colonies. However, in the 70% cold rolled specimens, cementite spheroidization within the deformed pearlite colonies caused austenite to form from a microstructure consisting of cementite particles embedded in a matrix of ferrite. In this situation, nucleation and growth of austenite phase took place mainly on the grain boundaries of ferrite matrix. Furthermore, it was found that the temperature of intercritical annealing treatment has a strong effect on the kinetics of austenite formation.