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Deformation induced precipitation in an industrial Ti microalloyed dual phase steel

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Abstract

This study evaluated the influence of plastic deformation during hot strip rolling in the size of TiN precipitates in an industrial Ti microalloyed dual phase steel. TiN is usually used for pinning austenitic grain boundaries during recrystallization and its efficiency depends on factors such as size of the precipitates and Ti precipitated fraction. During the slab reheating process, there occurs a partial dissolution of TiN precipitates that subsequently reprecipitates during the hot rolling process. However, this reprecipitation preferentially takes place at crystalline defects which act as nucleation sites. These sites increase with the amount of applied plastic deformation, resulting in smaller precipitates, due to the partial dissolution of larger particles or due to reprecipitation in the nucleation sites. Results indicate a reduction of about 28 % in the average size of the precipitates for samples extracted from hot bands (with deformation) and, therefore, a significant reduction in austenitic grain size, when compared with samples extracted from slabs (with no deformation).

Keywords: Dual-phase steel, precipitation, TiN and deformation.

1. Introduction

Steels are amongst the most important and useful of engineering materials because of their wide range of mechanical properties and low cost (Puskhareva, 2009). In recent years, the technological advances in the automotive industry are focused on reducing weight, a very relevant issue due to the increasing requirements for fuel-efficiency, which are related to energy savings and environmental restriction regulations. In order to provide a steel-based solution that fulfills the automobile industry's requirements, a great effort is being made to develop and apply a new class of steel, the so-called advanced high strength steels (AHSS), which combine good formability with high mechanical strength, to reduce the thickness of different parts of the automotive body in white (BIW) without performance losses and ensuring passenger safety (Tsipouridis, 2006).

The application of AHSS, exhibiting both high strength and excellent formability, offers the unique option of combining weight reduction using thinner gauges of sheet material, providing improved passive safety, optimized environmental performance and manufacturing feasibility at affordable cost. Among of steels classified as AHSS, however, one in particular has been widely studied for some years and is potentially very attractive for the automobile industry: dual phase steels.

Basically, dual phase (DP) is a class of high strength low alloy steels characterized by a microstructure consisting of martensite and ferrite. On the basis of the ferrite-martensite microstructure alone, any further increase in strength can only be obtained by an increase in the volume fraction of martensite. This, however, might be done at the expenses of ductility and elongation. Another way to increase strength of such steels is to add dispersoid-forming elements, such as titanium, to the steel melt which would form small precipitates and hinder dislocation movement in ferrite (Saikaly *et al*., 2001).

The objective of this work, therefore, was to study the effects of deformation during hot rolling on the precipitation of titanium nitride (TiN) in an industrial Ti microalloyed dual-phase steel, adopting two different soaking times in the reheating furnace.

2. Materials and experimental procedure

The chemical composition of industrial microalloyed dual-phase steel studied is shown in Table 1.

C	Mn	Si	Ti	Cr	N	Others
0.15	1.9	0.23	0.02	0.25	0.005	< 0.01

Table 1
Chemical composition of industrial micro-alloyed dual-phase steel studied (wt %).

In order to study the effects of deformation during hot rolling on the precipitation of TiN, the analysis was done either on an industrial sample (with deformation) or on a sample obtained by simulation (no deformation), both of them extracted from slabs (simulation) or hot bands (industrial) of the same heat at the steel shop. Furthermore, two different soaking times in the reheating furnace were adopted. Samples obtained from slabs as casted were reheated in a box furnace until 1235°C, following the industrial reheat cycle for the two soaking times, and then brought into water.

The parameters of simulation and industrial process are given in Table 2.

Process	Characteristic	Values
Reheating Furnace (Simulation) and Hot Rolling (Industrial)	Discharging temperature	1235°C
	Soaking time	< 200min (Short)
		> 260min (Long)
	Reheating rate	6 °C/min
Hot Rolling (Industrial)	Slab thickness	225 mm
	Transfer bar thickness	28 mm
	Hot band thickness	2.80 mm
	Finishing delivery temperature	850°C
	Coiling temperature	550°C

Table 2
Parameters of simulation and industrial process.

The study of the microstructure was performed on a JEOL Scanning Electron Microscope (SEM) with Nital 2% metallographic etching. Austenite grain size after reheating was obtained using reagent (picric acid-2g, ferric chloride-2g and 100ml of water) and examined by optical microscopy. Qualitative and quantitative analysis of TiN precipitates were performed using carbon extraction replicas and analyzed under a JEOL Transmission Electron Microscope (TEM) using bright field image. The amount of Ti present as TiN was obtained by a methodology that consists in extracting the precipitates of a sample through electrochemical dissolution, obtaining the total precipitation by weight difference and analysis of the Ti in TiN precipitates.

3. Results and discussion

The results of qualitative and quantitative analysis of TiN precipitates of the samples extracted from slabs (no deformation) for the two different soaking times are shown in Figure 1. Quantitative analysis showed that 73% of total Ti (0.02%) were precipitated as TiN. Samples submitted to the long soaking time showed larger average TiN precipitate size, ranging from 69.4 to 104.1nm as well as a large particle size distribution. This occurs due to the occurrence of titanium nitride (TiN) precipitates coarsening through its partial dissolution during soaking in the reheating furnace and subsequent precipitation. These results are according to the referenced literature (Soto et al., 1999; Mohallem, 2013;Voorhees, 1984). Differences in TiN precipitate size reveal larger austenite grain size in the slab sample after long time soaking reheating furnace simulation when compared to short time soaking (figure 2). The variation of the austenitic grain size occurs because TiN is typically used to inhibit austenite grain coarsening by pinning austenite grain boundaries (Cuddy;Raley, 1983; Gladman, 1999). However, according to Korchynsky (1993) and by calculations performed by several authors, for this to occur effectively the size of the precipitates must be smaller than 50nm, and the greater the size of the precipitate, the less effective the anchorage growth of austenitic grain.

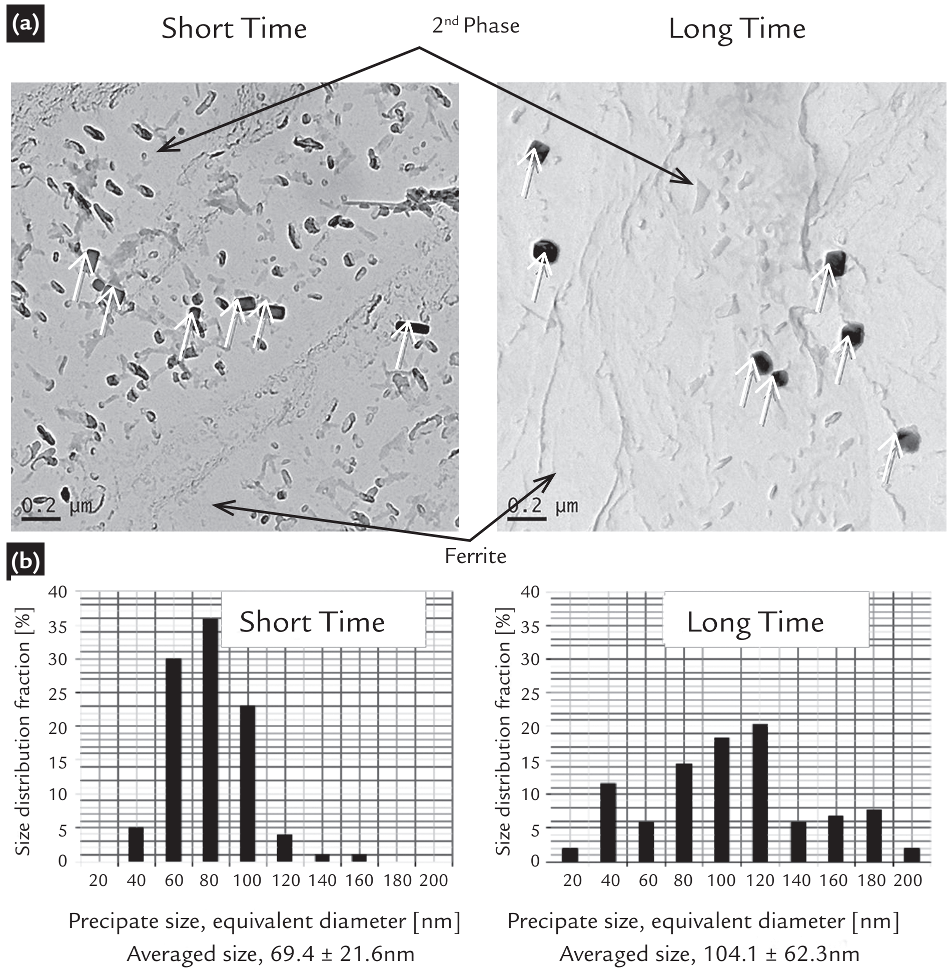

Figure 1
Carbon extraction replica characterization by TEM (a) and particle size distribution (b) of samples extracted from slabs (with no deformation) for two different soaking times: short (< 200min) and long (> 260min). The TiN precipitates are marked by white arrows.

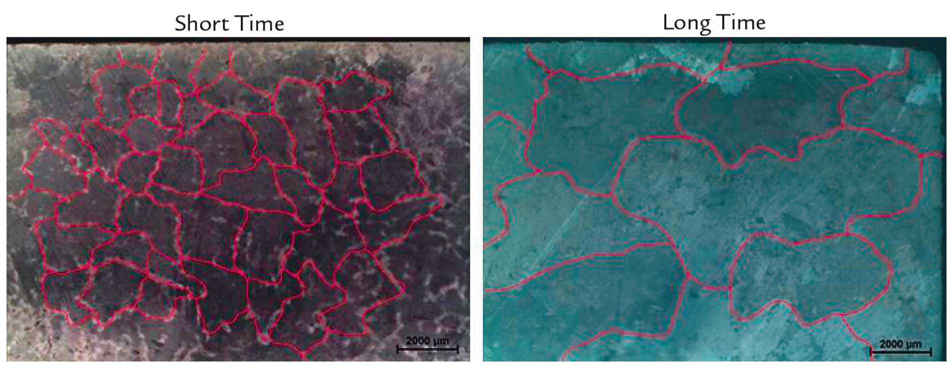

Figure 2
Austenitic grain size of samples extracted from slabs (no deformation) for two different soaking times: short (< 200min) and long (> 260min).

Figure 3 shows the results of qualitative and quantitative analysis of TiN precipitates of the samples extracted from industrial hot bands (with deformation) for the two different soaking times. Quantitative analysis showed that 75% of total Ti were precipitated as TiN. Samples submitted to the long soaking time showed larger average TiN precipitate size, ranging from 50.2 to 68.3nm, as well as a larger particle size distribution.

As previously discussed, it occurs due to the occurrence of titanium nitride (TiN) precipitates coarsening through its partial dissolution during the soaking in the reheating furnace and subsequent precipitation together with the deformation in austenite. After slab reheating, roughing brings down the slab thickness (225mm) to around 28mm, leading to a deformation induced precipitation and to smaller mean size precipitates. This behavior can be explained by the generation of crystalline defects during deformation, even in the dynamic recrystallization region, which act as a driving force to new precipitation.

These defects (dislocations or substructure boundaries) act as nucleation sites for further finer precipitates derived from the Ti and N in solid solution, coming from the dissolution of the TiN during the slab reheating process. This phenomenon was also reported by Liu, Jonas (1998) and Saikaly, et al. (2001).

Figure 4 shows the austenitic grain

size of samples extracted from hot bands. No significant variation in grain size before transformation of the austenite was observed, indicating that the variation of the size of TiN precipitates (50.2 to 68.3 nm) is not sufficient to produce substantial differences when compared with the austenitic grain size of the slab after reheating furnace simulation (figure 2).

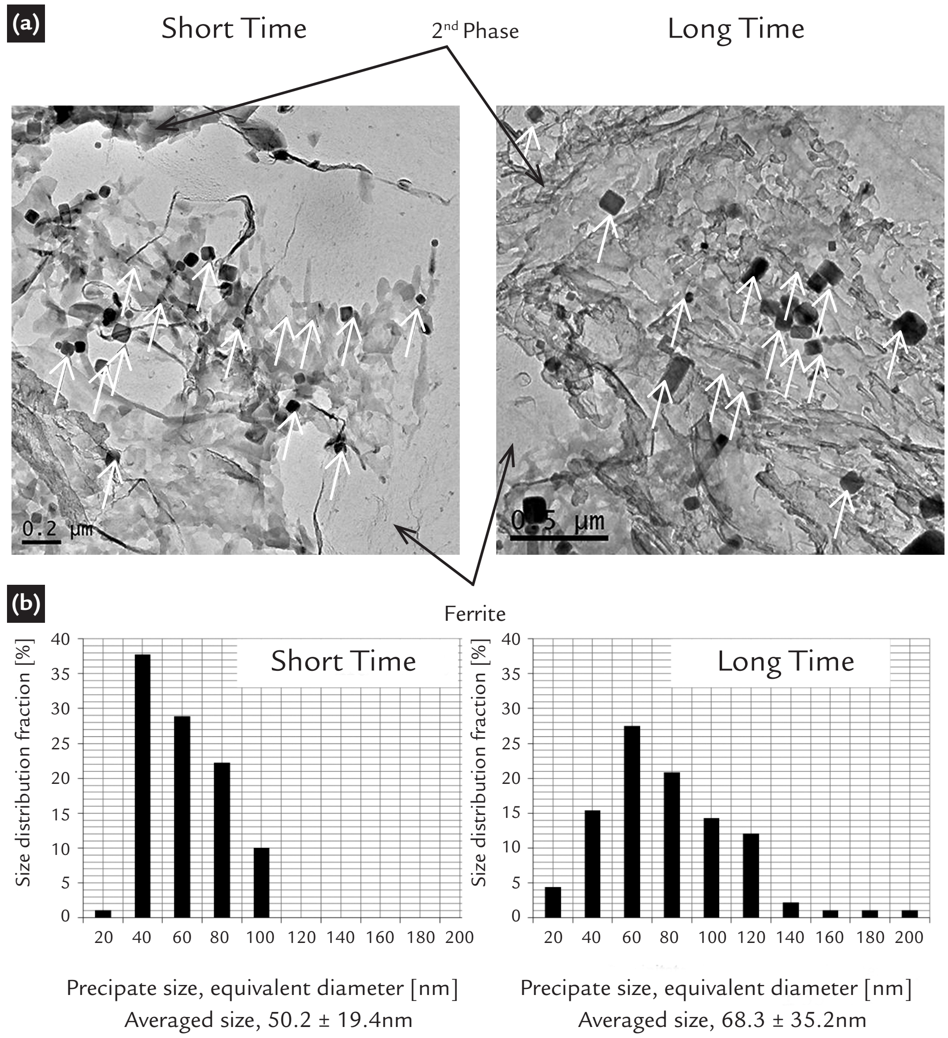

Figure 3
Carbon extraction replica characterization by TEM (a) and particle size distribution (b) of samples extracted from industrial hot bands (with deformation) for the two different soaking times: short (< 200min) and long (> 260min). The TiN precipitates are marked by white arrows.

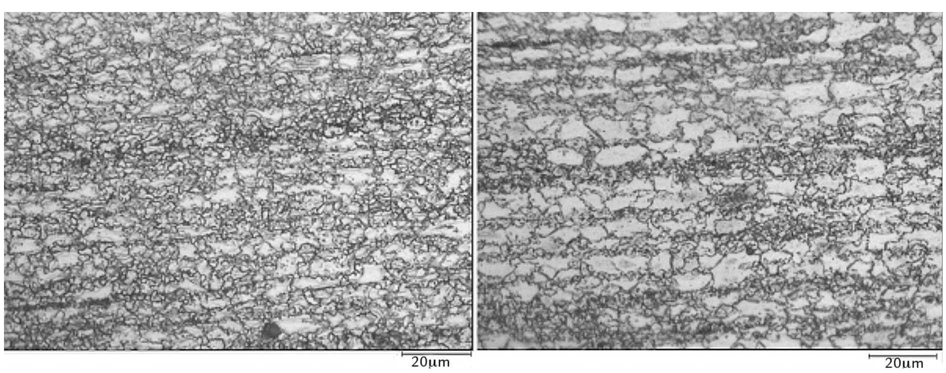

Figure 4
Austenitic grain size of samples extracted from industrial hot bands (with deformation) for the two different soaking times: short (< 200min) and long (> 260min).

4. Conclusions

The longer the slab reheating furnace soaking time, the higher the austenitic grain size even in the presence of precipitates of TiN.

For longer soaking times, TiN is larger and becomes less effective for pinning austenitic grain boundaries. However, with plastic deformation promoted by hot rolling, precipitates become smaller due to deformation induced precipitation and, consequently, provides a more effective pinning of the austenitic grain boundary. This condition was observed in the samples extracted from hot bands (with deformation) and is in agreement with literature.

5. Acknowledgments

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