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Original Article

Analysis of titanium nitrides precipitated during medium carbon steels solidification

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ABSTRACT

For certain applications, coarse titanium nitride (TiN) precipitates can be deleterious for the final properties of the material. Hence, in order to better understand the mechanisms involved in the generation of these precipitates, a characterization of the particles observed in steels with different titanium and nitrogen content was carried out. Samples from liquid steel (tundish), continuous casting billets and final product were evaluated using an Automatic Particle Analyzer (APA) coupled to a Scanning Electron Microscope (SEM). The location, frequency, size distribution and composition of the different particles observed were assessed. While only few TiN precipitates were observed in liquid steel samples, the density of this type of particles significantly increased in the continuous casting billets samples. Particles ranging from 1 to 10 μm were mainly found in the interdendritic zones of the as-cast structure. The density of TiN particles observed in these samples did not change after re-heating and rolling operations. A microsegregation model previously developed was adapted to predict TiN precipitation during solidification. A reasonable agreement was found between model results and measured data. Results of this analysis confirmed that the precipitated fraction of TiN increases as the product of steel Ti and N contents rises.

1. Introduction

Titanium is normally added to steels for several purposes [1,2]. In some cases, the addition is performed to inhibit the formation of boron nitrides that impair steel hardenability [3,4]. In others, Ti addition has the objective of limiting grain growth during heating before rolling [5], or in the Heat Affected Zone (HAZ) of welded structures [6]. Titanium also plays an important role in the mechanical properties of the final product [7]. In Interstitial Free (IF) steels, the formation of titanium carbides and nitrides improves the drawing capacity, minimizing the aging of the material [8]. It has also been suggested that Ti could help in the modification of product microstructure, because the oxides that are formed promote acicular ferrite precipitation [9]. Also, the nitrides could be active

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Table 1 – Base composition of the steel in wt%.

C	Mn	Si	Cr	Mo	Nb	Al	S	Ca
0.25	0.35	0.21	1.00	0.70	0.025	0.03	0.0015	0.0012

in microstructure modification [9]. Titanium addition in Nb alloyed steels has proven to be effective to improve ductility of continuous casting products. This is because precipitation of niobium rich fine precipitates is minimized [10,11]. Nevertheless, the effect of Ti on high temperature ductility is still under debate [12,13]. Some recent studies have shown that titanium could refine austenitic grain size in the cast structure [14,15].

In any of the aforementioned applications, Ti addition can promote titanium nitride (TiN) precipitation during steel solidification. These TiN particles formed from liquid phase have cuboidal shape and relatively big sizes (1–20 μm) [3,16–19], compared with those formed in solid state during subsequent process stages, which sizes may range between 10 and 100 nm [6,18]. While the later have specific metallurgical functions, such as control of grain growth, the former can deteriorate material toughness, by promoting cleavage crack propagation [6,16,19–21]. In certain applications, like steels for ball bearings, these coarse precipitates can also impair fatigue properties [22].

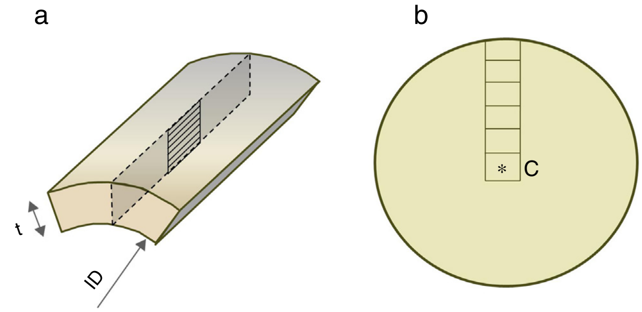
In the present paper, the characterization of the size, density and composition of precipitates found in medium carbon steels with different Ti and N contents was performed. Samples from different stages of the process (liquid steel, as-cast billets and final product) were obtained for analysis. In addition, a previously developed microsegregation model was adapted to predict the formation of these precipitates during steel solidification.

2. Materials and methods

2.1. *Analyzed samples*

Samples were obtained from seamless pipes of eight different heats of medium carbon steels, with different titanium and nitrogen contents. The base composition of steel is indicated in Table 1, while the specific titanium and nitrogen contents in each of the analyzed heats are detailed in Table 2.

These pipes were rolled from round billets produced following the route: Electric Arc Furnace – Ladle Furnace – Continuous Casting. In one of the analyzed heats (C003), samples from three different pipes were obtained to verify consistency in the obtained results. To complement the analysis, liquid steel samples from tundish and as-cast samples from the continuous casting billets were also obtained in some of the studied heats, see Table 2. In all the samples, precipitates were characterized applying the technique described in the following section.



Test pieces taken from pipe samples

Test pieces taken from as-cast material

Fig. 1 – Samples for analysis. (a) Seamless pipes, (b) continuous casting bars.

Pipe samples were sectioned longitudinally, as shown in Fig. 1(a). To assess possible differences in through thickness direction, the analyzed zone was divided into 10 smaller equal zones. Total scanned area was about 90 mm^2. In the as-cast material, 25 mm × 25 mm samples were prepared to characterize one billet radius, scanning also 90 mm^2 per sample, see Fig. 1(b). As-cast microstructure was revealed etching the samples with different reagents (Nital, Oberhoffer). In the sample taken from the center of the billet (sample C, Fig. 1 b)) additional studies were carried out to characterize central porosity. Finally, in lollypop samples taken from tundish, one of the faces was polished and an area of 90 mm^2 was also scanned to characterize the particles found.

2.2. *Characterization of the precipitates*

The obtained samples were polished and analyzed by means of a Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectroscopy (EDS). Inclusion and precipitates population was evaluated using an Automatic Particle Analyzer (APA) software incorporated to the SEM. This software is

Table 2 – Ti and N content in the analyzed cases.

Heat	Ti (%)	N (%)	Ti/N (–)	Ti*N ($10^{-4}\%^2$)	Sample
C001	0.022	0.0064	3.45	1.408	Pipe
C002	0.025	0.0081	3.09	2.025	Tundish/Billet/Pipe
C003	0.023	0.0044	5.23	1.012	Tundish/Billet/Pipe
C004	0.020	0.0063	3.16	1.264	Tundish/Billet/Pipe
C005	0.012	0.0045	2.67	0.540	Pipe
C006	0.011	0.0055	2.00	0.605	Pipe
C007	0.012	0.0046	2.61	0.552	Pipe
C008	0.019	0.0048	3.96	0.912	Pipe

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