NIOBIUM EFFECT ON BASE METAL AND HEAT AFFECTED ZONE MICROSTRUCTURE OF GIRTH WELDED JOINTS

Andrea Di Schino$^{1)}$*, Paolo Emilio Di Nunzio*$^{2)}$
$^{1)}$*Dipartimento di Ingegneria, Università di Perugia, 01625 Perugia, Italy*
$^{2)}$*Centro Sviluppo Materiali SpA, Via di Castel Romano 100, 00128 Roma, Italy*

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*Corresponding author: *email: andrea.dischino@unipg.it, Tel.+39 0744 492953, Dipartimento di Ingegneria, Università di Perugia, Via G. Duranti, 01625 Perugia, Italy*

Abstract

The development of steels for line pipes during the last decades has been driven by the need to obtain improved combinations of high strength, toughness, weldability on industrial scale at affordable prices. The effect of niobium content on the heat affected zone (HAZ) microstructure is reported in this paper. Niobium, for its specific thermodynamic and kinetic attitude to form carbide and nitride precipitates, played a key role in the development of modern HSLA steels Results show that niobium addition is able to refine both the bainitic packet and cells size in the heat affected zone during welding. This implies that niobium addition leads to an improvement of both toughness and hardness of welded joints manufactured by Nb micro-alloyed steels.

Keyword: welded joints, microstructure, precipitation

1 Introduction

The development of steels for line pipes during the last decades has been driven by the need to obtain improved combinations of high strength, toughness, weldability on industrial scale at affordable prices. A similar situation occurred in other fields of application of structural steels like offshore steel structures or ships, with broadly similar objectives, even though the balance of requirements could vary depending on the specific design or operational needs. Niobium, for its specific thermodynamic and kinetic attitude to form carbide and nitride precipitates, played a key role in the development of modern HSLA steels [1-8]. These steels have certainly made possible the efficient and cost-effective design and the development of construction technologies in a variety of applications. In the field of transportation pipelines, for example, the increase in the available strength level of linepipe that have taken place during the last forty years has produced cumulative benefits valued in the billion-dollar range. The effect of niobium on the microstructure and the properties of the heat affected zone (HAZ) of a girth weld is a very complex issue because of a number of different interrelated mechanisms depending on the chemical composition of the steel and on the welding parameters.

In particular it is known that:

- undissolved precipitates (typically complex (Ti,Nb)(C,N)) have a significant effect on austenite grain size [9-12]. On the other hand, it is well known that austenite grain size affects the hardenability of the steel and has consequently an influence on the toughness through the packet size of the final microstructure [13-16];
- Nb in solid solution has a direct impact on the hardenability by reducing the transformation temperature of the austenite [17-18];

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- Nb carbonitrides may precipitate in ferrite with a consequent impact on strength and toughness.

Despite the importance of Nb in the development of high strength pipelines with good toughness, possible detrimental effects in the properties of HAZ of welded joints are reported in the literature [19-20]. For this reason, in the past decades niobium content has been often limited up to about 0.05 percent. However, in the last years a new generation of higher (up to about 0.1%) niobium pipeline steels have been developed and produced in for high pressure long distance gas transportation, and such linepipes passed the qualification process, indicating the suitability of the high niobium concept.

Aim of this paper is to investigate the effect of Nb addition up to 0.10% on HAZ microstructure of X80 large diameter linepipes.

2 Materials and experimental details

X80 pipes manufactured from the steels reported in **Table 1** were considered.

Table 1 Steel chemical composition of the considered steels (mass, %)

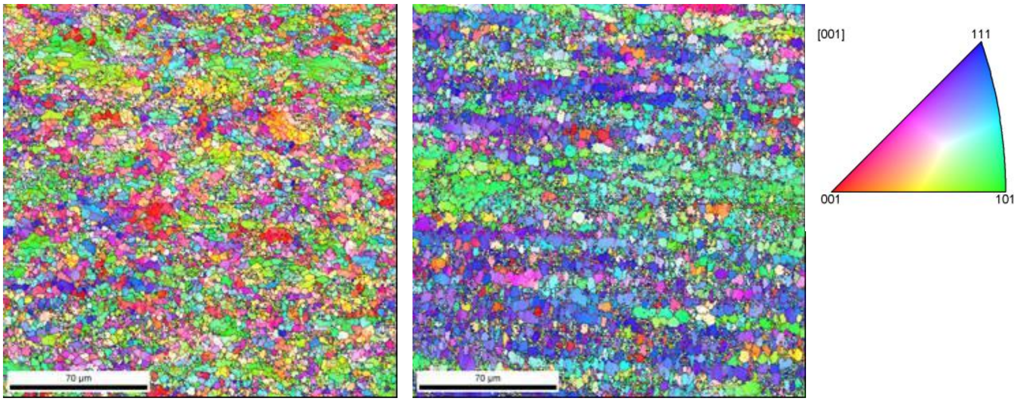
	C, %	Mn, %	Ni, %	Cr, %	Mo, %	Nb, %	Ti, %
Pipe A	0.04	1.83	0.25	0.26	0.10	0.07	0.013
Pipe B	0.04	1.75	0.26	0.23	0.25	0.10	0.018

Steels have similar chemical composition, apart for Nb content, ranging 0.07%-0.10%. Microstructure was observed by means of Light Microscopy (LM) on polished sections after 2%-nital etching. Packet size was determined by Image Orientation Microscopy (OIM). Precipitation state was examined by TEM extraction replicas and transmission extraction in a JEOL JEM 3200FS-HR scanning transmission electron microscope.

3 Results

3.1 Microstructure and precipitation of the base materials

The microstructure of the base material of both pipes A and B is reported in **Fig. 1**.

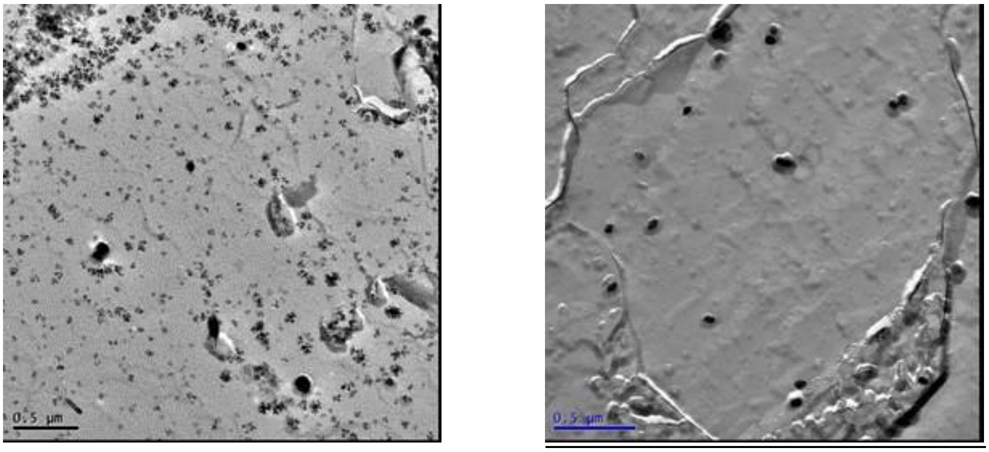


Pipe A Pipe B

Fig. 1 General view of microstructure of pipes A and B by EBSD

Both pipes are characterized by an acicular ferrite microstructure; pipe A shows a coarser microstructure (larger packet size) with a visible pancaking feature typical of plate rolling. Precipitates are mainly Nb/Ti carbides in both materials.

Precipitation state analysis revealed by the observation of carbon replicas by TEM, shows that both in Steel A and B a population of coarse particles with size greater than 100 nm is present (**Fig. 2**). A more abundant precipitation is found in pipe A with respect to pipe B.

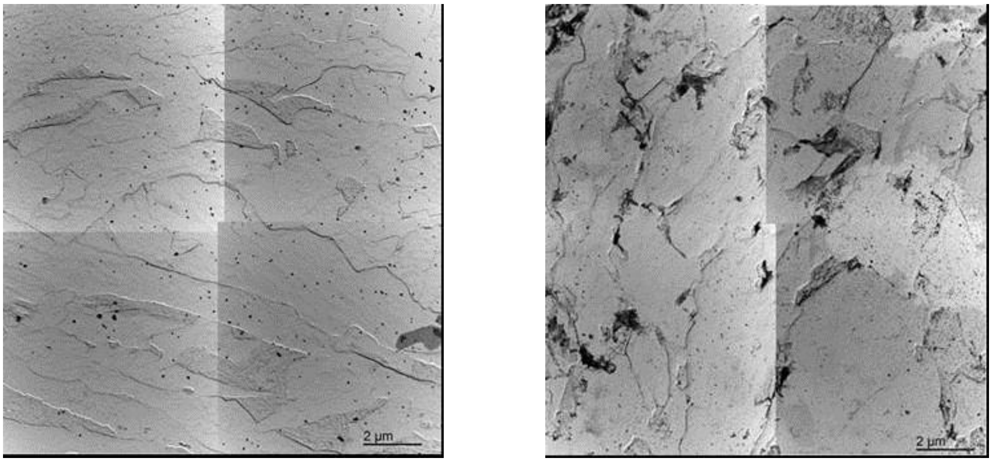


Pipe A Pipe B

Fig. 2 General view of precipitation state in the base metal of pipes A and B, by TEM extraction replica

This result is also confirmed by TEM analysis by transmission extraction technique (**Fig. 3**). The use of this method has been chosen as a comparison in order to put in evidence if any small precipitates were lost in the standard extraction replica method.

Precipitates are mainly Nb/Ti carbides in all the materials (**Fig. 4**). Generally speaking, in micro-alloyed steels with both Ti and Nb, it is expected that smaller particles are richer in Nb and the larger in Ti, according to the precipitation sequence as a function of temperature. This feature is present in the plot of precipitate composition of steels A and B.



Pipe A Pipe B

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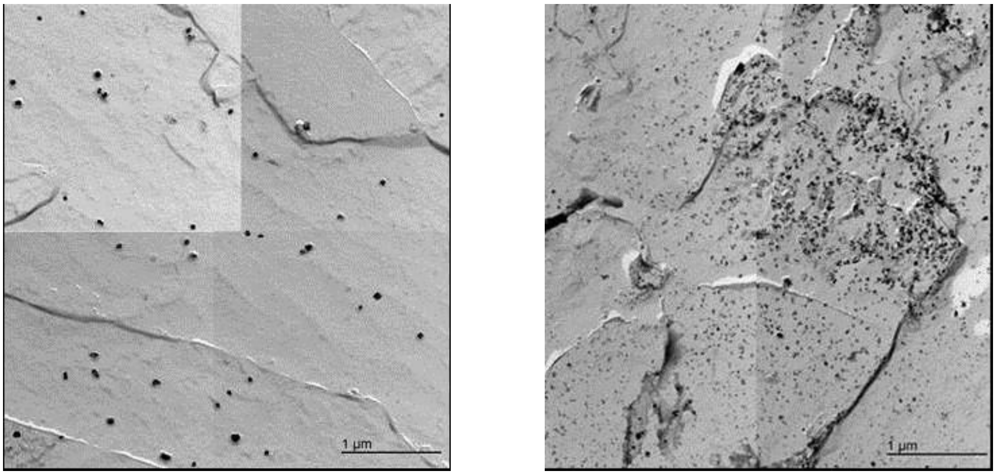
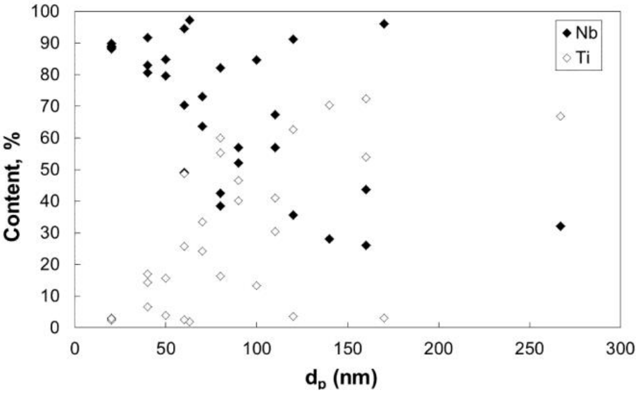
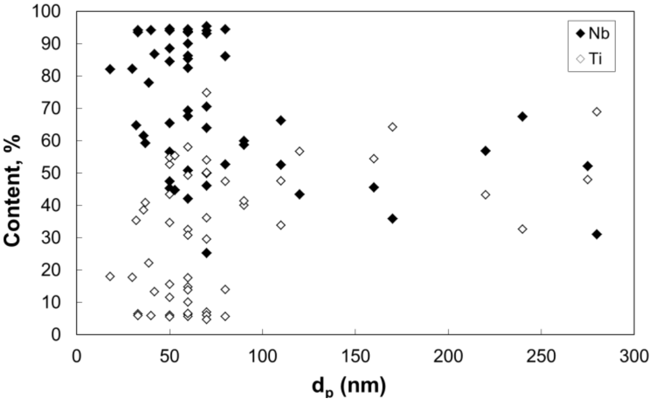


Pipe A Pipe B

Fig. 3 General view of precipitation state in the base metal of pipes A and B by TEM (transmission extraction method)



Pipe A



Pipe B

Fig. 4 Content of Nb and Ti in carbonitrides (expressed as atomic percent in the metallic sublattice) as a function of the precipitate size

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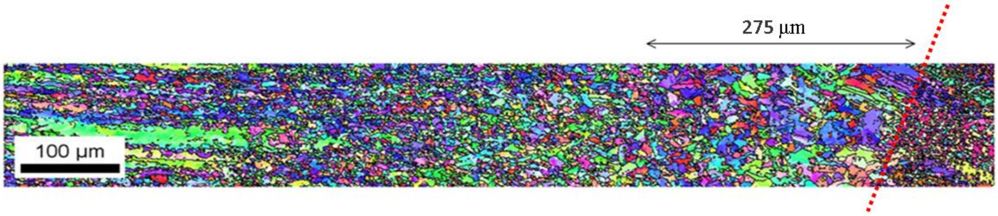
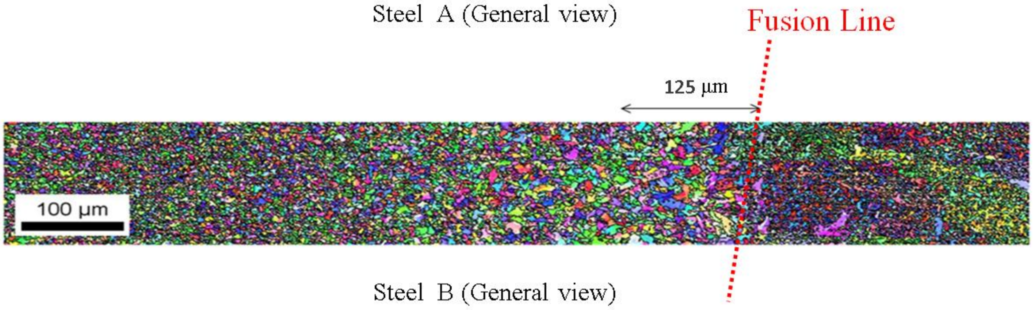
3.2 Microstructure in HAZ

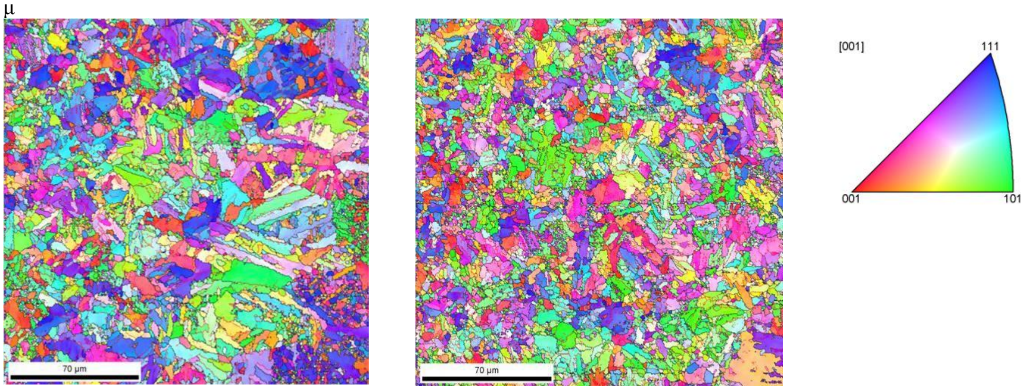
The general aspect of the microstructure of welded joints is reported in **Fig. 5**.



Steel A (General view)



Steel B (General view)



Steel A (CGHAZ) Steel B (CGHAZ)

Fig. 5 Microstructure of the welded joint by EBSD

EBSD images show the microstructure variation from weld metal to base material in steels A and B. Microstructure appears to be constituted by acicular ferrite. Results show that the increase of Nb content from 0.07% to 0.10% reduces of the CGHAZ extension (from 275 µm down to 125 µm). Moreover, a finer microstructure (finer packet size) is found in Steel B (higher Nb content) with respect to Steel A in the CGHAZ region.

The finer microstructure in the steel with higher Nb content might be explained by the following mechanism. At first, the austenite grain size in the HAZ is not affected by the Nb content because the fraction of coarse particles, present in both steels, do not dissolve completely during the reheating stage of welding and limits the growth of austenite grains by exerting an effective pinning on their boundaries. In the mean time, a certain fraction of carbides, especially those with a smaller size, is completely dissolved. The amount of Nb which goes into solution is greater for steel B. This implies that also the amount that can be precipitated at lower temperature, as well as the driving force for this process to occur, are higher for this material. Although no direct observation of the precipitation state in the HAZ is available, it is expected that, during the cooling stage of welding, also in this region the higher amount of Nb could produce an abundant precipitation of small and Nb-rich particles, similarly to what is found in the base metal.

4 Conclusions

The effect of Nb content in the range 0.07%-0.10% on the HAZ microstructure of X80 large diameter pipes is reported in this paper. As far as base materials are concerned, both pipes are characterized by an acicular ferrite microstructure; the pipe with 0.07% Nb shows a coarser microstructure (larger packet size). Precipitates are mainly Nb/Ti carbides in both materials. Moreover, in the case of a higher Nb content, they are richer in Nb, and present in higher volume fraction. Concerning the welded joint, results show that, although the small difference in Nb content is able to influence the size of the bainitic packet and of cells in heat affected zone.

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