

## Investigation of Continuous Cooling Transformations and Microstructures in a Low Carbon Ti-Nb Bearing Microalloyed Steel by Means of Dilatometry and Metallography

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### 1- Introduction

Hot rolled high strength microalloyed steels have been improved by addition of strong carbo-nitride alloying elements of Nb, Ti, and V in relation with thermo-mechanical control processing in recent years. As a result, the low carbon content of these microalloyed steels can be associated to the development of multiphase microstructures and complex phase transformations on continuous cooling heat treatments. In contrast to the ferrite-pearlite microstructures of conventional hot rolled plain carbon steels, the structures formed by continuous decomposition of austenite in such low carbon thermo-mechanical control processed steels often assume non-classical morphologies.

The purpose of this work is to investigate in detail the characterization of continuous cooling transformations and microstructures in a low carbon microalloyed steel.

### 2- Materials and Experimental Procedure

The steel used in the present study was a low carbon microalloyed steel with the chemical composition given in Table 1. The thickness of the plate was 10mm and the microstructure was a mixture of bainite and tempered martensite. To study the continuous cooling transformations and microstructures, a series of samples were cooled to room temperature at various cooling rates using a high-speed Theta dilatometer. Hollow cylindrical specimens (L = 13mm, O.D. = 4.9mm, I.D. = 3mm) were cut transversely from the as received steel plate. The samples were austenitized at 1000°C for 5min in a vacuum of about  $10^{-4}$  torr and subsequently continuously cooled at various cooling rates from 0.1-400°C/s to room temperature. Multiphase microstructural characterization was carried out after polishing and color etching specimens using 2% nital and LePera etching reagents. Hardness measurements were made with a 10kg load and are reported as Vickers hardness numbers (VHNs). In order to

confirm the results of color metallography, the microhardness measurements of various microphases were carried out using a Vickers testing machine model FUTHER-TECH FM700 with a load of 10g. The metallographic observations were carried out using a OLYMPUS PMG3 light microscope and scanning electron microscopy (SEM) model TESCAN-VEGA-III.

**Table 1 Chemical composition (in wt.%) of the investigated low carbon microalloyed steel**

C	Si	Mn	S	P	Cr
0.2	0.1	1.5	0.003	0.012	1.98
Ni	Cu	Nb	Ti	Al	Fe
0.25	0.34	0.017	0.013	0.02	Bal.

### 3- Results and Discussion

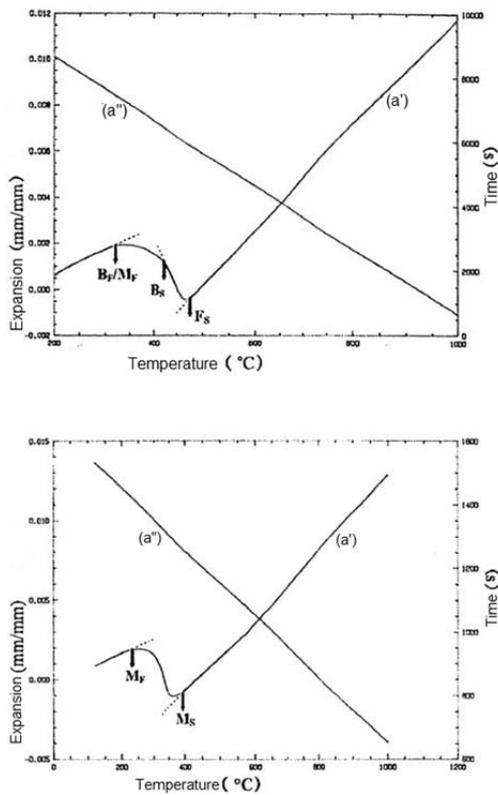
In order to determine various continuous cooling phase transformations and microstructures of the investigated low alloy microalloyed steel, the cooling rates of dilatometry samples were varied from 0.1 to 400°C/s. Fig. 1 shows typical temperature-expansion (a') and temperature-time (a'') curves of continuous cooled samples from 1000°C to room temperature. When the cooling rate was slower than 0.2°C/s, the temperature-expansion curve exhibited a two-stage expansional change as shown in Fig. 1((a), (a')). For example, the specimens were cooled at a rate of 0.1°C/s, before interrupted quenching at various temperatures during the transformation. Based on the microstructural observations, polygonal and/or quasi-polygonal ferrite was found to form firstly at about 493°C ( $F_s$ ) which is consistent with the temperature of the first-stage expansional change. The formation of bainitic products started at about 430°C ( $B_s$ ) and a mixture of bainite and martensitic microstructures formed at about 292°C ( $B_f/M_f$ ), respectively. Fig. 2 shows the continuous cooling transformation (CCT) diagram for the investigated low carbon microalloyed steel.

Fig. 3 shows examples of typical color etching and the associated scanning electron micrographs taken from 0.1 continuous cooling heat treated samples. The microstructure is characterized by a mixture of ferrite, bainite and martensite microphases. It can be observed that a good contrasting resolution can be observed between ferrite, bainite and martensite as brilliant white, brown and blue regions in the colored etching light micrograph of Fig. 3a, respectively.

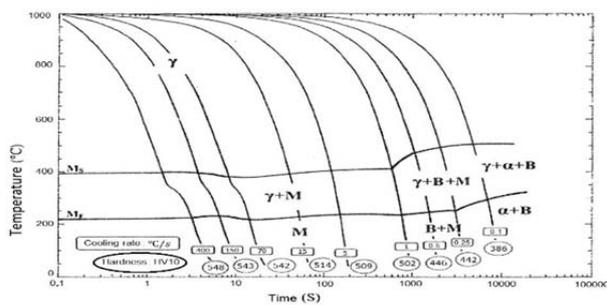
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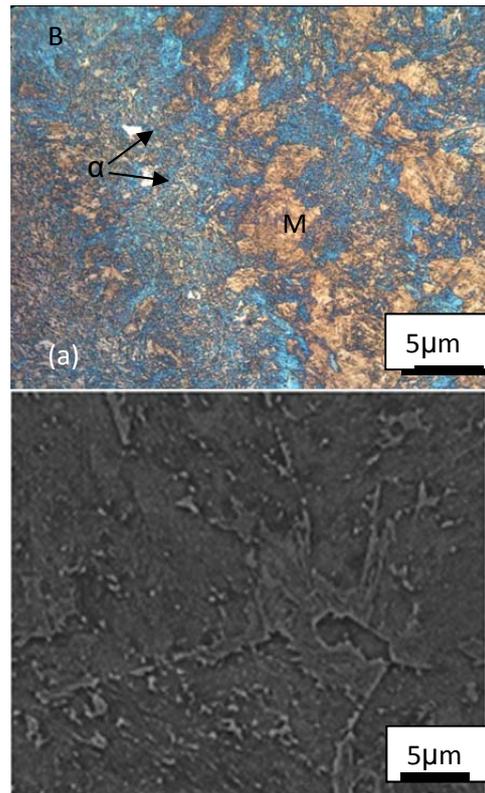
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**Fig. 1** Types of temperature-expansion (a') and temperature-time (a'') curves obtained at various continuous cooling rates: (a) 0.1°C/s; (b) 1°C/s.  $F_s$ : ferrite start temperature;  $B_s$ : bainite start temperature;  $B_f$ : bainite finish temperature;  $M_s$ : martensite start temperature;  $M_f$ : martensite finish temperature



**Fig. 2** Continuous cooling transformation diagram for the low carbon microalloyed steel.  $\gamma$ : austenite;  $\alpha$ : ferrite; B: bainite; M: martensite



**Fig. 3** a) light; and b) electron micrographs taken from 0.1°C/s continuous cooled heat treated samples.  $\alpha$ : Ferrite; B: Bainite; M: martensite

#### 4- Conclusions

The continuous cooling transformation (CCT) diagram for the low carbon microalloyed steel was constructed by a combination of dilatometry and metallographic methods. The CCT diagram exhibited a significant region for low temperature transformation products which involved curves for the evolution of bainite and martensite. Full martensitic microstructures were formed at continuous cooling rate greater than 0.8°C/s, while a mixture of bainite and martensite microstructure was developed at moderate cooling rates of 0.2-0.8°C/s. The multiphase microstructures involving ferrite, bainite and martensite were formed during slow cooling rate of 0.1°C/s. The microstructural components including ferrite, bainite and martensite were distinguishable colorful from each other as brilliant white, brown and blue colors by double etching technique based on the 2% nital and LePera reagents.