Nucleation Stages Of Isothermal Transformation In Titanium And Titanium Free Micro-Alloyed Steels

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Abstract - **This work is focused on nucleation stages during isothermal austenite transformation in two types of Vanadium micro-alloyed steels. Isothermal treatment was carried out in the temperature range 350 to 600°C. Metallographic evaluation using optical and scanning electron microscopy (SEM) enabled determination of the nucleation curves of isothermally decomposed austenite. Three curves are found to be relevant to this initiation stage of transformation: first curve is related to grain boundary nucleated ferrite (GBF), second curve is related to intra-granularly nucleated ferrite (IGF) and the third to pearlite (P) curve. GBF and IGF curves are divided into two regions, which represents the high temperature and the low temperature segments as consequence of either displacive nature of transformation or diffusion transformation. Addition of Ti to V – micro-alloyed steel in this work seems to be balanced by a slightly higher C and Mn content, leading to limited effect on nucleation stage of austenite decomposition.**

Index Terms– **Micro-alloyed steel, Ferrite, Bainitic Sheaves, Acicular ferrite, Widmanstatten ferrite, Polygonal ferrite.**

I. INTRODUCTION

Ferrite formation during austenite decomposition can result in obtaining two different morphologies: (i) diffusion controlled (allotriomorphic and idiomorphic) or (ii) displacive (Widmanstätten and Intragranular plates) [1-5]. Allotriomorphic ferrite nucleates at the prior austenite grain boundaries and tends to grow along the austenite boundaries at a rate faster than in the perpendicular direction to the boundary plane. By contrast, idiomorphic ferrite nucleates at the inclusions/particles inside the austenite grains and can be identified in the microstructure by its equiaxed polygonal morphology. Therefore, the balance between the number of intra-granular nucleation sites and the number of sites at the austenite grain boundaries is a very important factor in the competitive process of allotriomorphic-idiomorphic ferrite formation.

The prior austenite grain size exerts an important influence on the decomposition of austenite [5, 6]. An increase in austenite grain size leads to a reduction in the number of nucleation sites at the austenite grain boundaries indirectly favoring the intra-granular nucleation of ferrite, i.e. the formation of idiomorphic ferrite, rather than allotriomorphic ferrite. In order to obtain bainite, the austenite grain size has to be small so that nucleation from grain boundaries dominates and subsequent growth then swamps the interior of the austenite grains. By contrast acicular ferrite is nucleated intra-granularly on inclusions within large austenite grains and then radiates in many different directions. The presence of a uniform layer of allotriomorphic ferrite along the austenite grain boundaries induces the transformation of austenite in acicular ferrite instead of bainite [1, 3-6]. The acicular ferrite is in fact intra-granularly nucleate bainite [4-6]. It is a much more disorganized microstructure with a larger ability to deflect cracks. Acicular ferrite is therefore widely recognized to be a desirable microstructure due to good mechanical properties [5]. Data related to nucleation phase of isothermal decomposition seems to be lacking; most of the published results deal with later steps (10s or longer), i.e. when the nucleation is well prolonged. Therefore, the aim of the present study is to clarify the influence of isothermal transformation temperature, time and titanium addition on the nucleation of ferrite and indirectly, on the development of the intragranular acicular ferrite in V micro-alloyed forging steels.

II. EXPERIMENTAL

Two types of commercial V micro-alloyed medium carbon forging steels with and without Ti addition have been studied. The chemical compositions of these steels are given in Table 1.

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Table 1: Chemical Composition Of The Experimental Steels By (wt%)

Steel Type		**Chemical Composition by wt%**
V-Ti	**V**	
0.309	0.256	C
0.485	0.416	Si
1.531	1.451	Mn
0.0077	0.0113	P
0.0101	0.0112	S
0.011	0.002	Ti
0.123	0.099	V
0.0221	0.0235	N

Both steels were industrially casted and hot-rolled into 22mm (V-Ti steel) and 19mm (V steel) diameter bars. Both bars were homogenized at 1250 °C for 4 hours, in argon as protective atmosphere and subsequently oil quenched. Specimens of 12mm height were cut and austenitized at 1100 °C for 10 min in an argon atmosphere. After austenitization, specimens were isothermally held at temperatures ranging from 350 °C to 600 °C for different holding times and subsequently water quenched to room temperature. The samples were prepared using standard metallographic techniques and etched in 2 % nital for their observation on optical and scanning electron microscopy (SEM).

III. RESULTS AND DISCUSSION

Figure 1 shows the nucleation curves for both steels. In both steels, the nucleation is represented by two C curves, for low and high temperatures. In V-steel Figure 1a, apparently due to overlapping effects of diffusion and displacive transformations two curves are less differentiated in comparison to V-Ti steel Figure 1b. The first phase to nucleate is the GBF at both high Figure 2a and low Figure 2b test temperatures. While the GBF at high temperature is definitely produced by diffusion, the low temperature GBF is assumed to be of Widmanstatten type [1, 3, 5]. High temperature behavior is in very good agreement with results and model related to nucleation of GBF on temperatures higher than 600°C [6, 7]. With increasing holding time, the Intra-granular Ferrite (IGF) nucleation is initiated, what is represented by the IGF nucleation curve Figure 1. High temperature intra-granular nucleation (600 – 500°C) is characterized by polygonal idiomorphic (IGF) ferrite. The amount of polygonal (IGF) ferrite increases with decreasing isothermal transformation temperature at the expense of GBF, as represented in Figure 3a. The transformation at lower temperatures (450–350°C) is characterized by the acicular (IGF) ferrite and as shown in Figure 3b. Again there are two C curves to represent IGF nucleation due to transition from high temperature diffusion mechanism to low temperature displacive mechanism [4- 6, 8 - 10] .

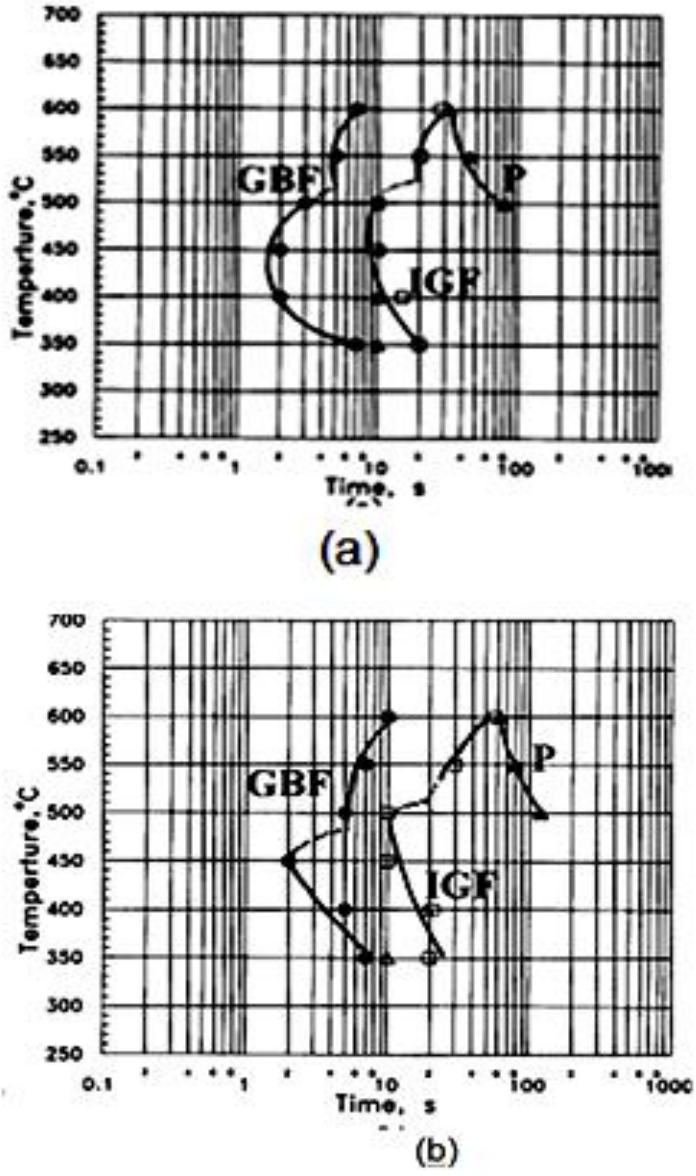

Figure 1 . Initial Stage Of TTT Diagram: (a) V- Steel (b) V – Ti Steel; Closed Circles - Grain Boundary Ferrite (GBF); Open Squares – Intra-Granular Ferrite (IGF), Open Triangles – Bainitic Sheaves (BS); Closed Triangles – Pearlite (P).

The Transition from high to low temperature takes place at about 500°C. However on increasing the isothermal time further, the nucleation of pearlite (P), as shown in figure 3a, is initiated what is represented by the P curve in Figure 1. In the low temperature region in certain localized places Bainitic Sheaves (BS) and/or Widmanstatten Ferrite (WSF) are formed on grain boundaries. The nucleation of these phases is indicated in Figure 1 by open triangles. In regard to the effect of micro-alloying elements on the kinetics of isothermal transformation it has been shown that presence of vanadium delays the nucleation of ferrite, whereas Ti speeds it up [11-13]. In the V-Ti Steel, a slightly higher carbon and manganese content which delays transformation seems to balance the influence of Ti addition. Therefore, the temperature at which the incubation time for ferrite nucleation is at minimum value (at nose of the nucleation curves) is approximately the same for both steels (approx. 450 °C). In this sense Ti addition does not exert any influence on this temperature; neither the prior austenite grain size has any clear effect on the transformation as a whole.

IV. CONCLUSIONS

The main goal of the present study was to clarify the influence of isothermal transformation temperature, time and titanium addition on the nucleation of ferrite and indirectly, on the development of the intra-granular acicular ferrite in V micro-alloyed forging steels. Metallographic studies enabled determination of the nucleation curves of isothermally transformed ferrite in two medium carbon micro-alloyed steels. Three curves are found to be relevant to nucleation stage of transformation. First, GBF curves which extends over the entire temperature range studied (350-600°C), second, IGF curve which is divided into the high temperature polygonal and the low temperature acicular ferrite curve, and the third the pearlite (P) curve. Addition of Ti to V-micro-alloyed steel in this work seems to be balanced by a slightly higher C and Mn content.

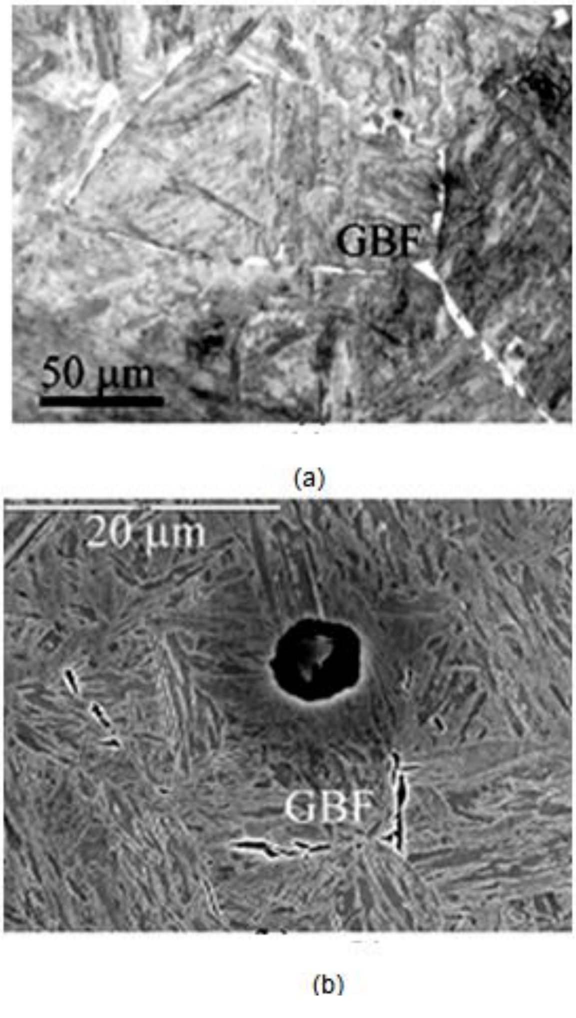

Figure 2:.Grain Boundary Ferrite (GBF): (a) 600°C / 10 s, V-Steel Optical Image, (b) 350°C/10 s, V-Ti Steel, SEM Image.

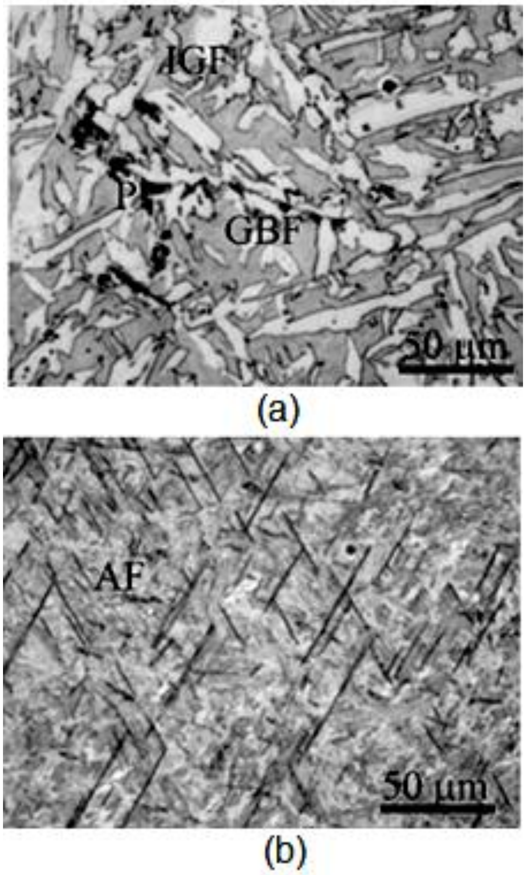

Figure 3 . Intra-Granular Ferrite (IGF): (a) 500°C/80s , V- Steel , Optical Image Of (GBF), Polygonal (IGF) And pearlite (P), (b) 350°C/20s, V-Ti Steel, Optical Image Of Acicular Ferrite (IGF).

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