



BAINITE MORPHOLOGY IN EXPERIMENTAL Fe-Mo-Cr-V-Ti-C STEEL

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Abstract

The development of bainitic transformation was studied using TEM, dilatometry and thermodynamic calculations, both from a fully austenitic microstructure ($T_A=1200^\circ\text{C}$) and from a microstructure containing a mixture of austenite and undissolved carbides ($T_A=1000^\circ\text{C}$). The amount, distribution and morphology of retained austenite, bainitic ferrite and precipitation of carbides strongly depends on both; prior austenitization and isothermal transformation temperatures within the bainitic range.

Keywords: *bainite morphology, bainitic transformation, low alloy steel*

1. Introduction

The present paper attempts to investigate the morphology of bainite formation in laboratory prepared low alloy Cr-Mo-V-Ti (signed as 15HM2VT steel). Vanadium and titanium are present to refine the austenite grain size, resulting in a fine grained ferritic structure. Low carbon content promotes good toughness and weldability by elimination the volume fraction of carbide containing microconstituents (e.g. pearlite). In Fe-C-X steels, when X is a strong carbide forming alloying element, interphase boundary carbides and fibrous carbides were present after isothermal reaction at temperatures above the bay temperature [1,2,7,8]. This type of high strength low alloy (HSLA) steels are supposed to have the requisite good combination of strength, toughness and weldability for many industrial applications.

The main aim of the present investigation was to investigate the influence of austenitizing temperature (changing the volume of dissolved carbides and from this the chemical composition of austenite) and temperature of isothermal transformation on bainite transformation.

2. Material and experimental procedure

The composition of the alloy investigated is given in Tab. 1. The specimens were austenitized for 20 minutes at 1000 and 1200°C. A coating layers were used to protect the specimens against decarburization. After isothermal transformation, the specimens were water quenched.

Tab. 1. Chemical compositions of the investigated steel (Wt Pct)

Steel	C	Si	Cr	Mn	Mo	V	Ti	P	S	Al
15HM2VT	0.15	0.24	0.84	0.92	2.6	0.24	0.12	0.022	0.019	0.06

Dilatometric analysis was carried out on a Leitz-Wetzlar vacuum dilatometer using a 20 mm by 3.5 mm dia. specimens to establish the A_1 and A_3 temperatures (Tab. 2). A high-speed LK-02 Adamel Lhomargy dilatometer was used to establish the M_S temperature (Tab. 2). In order to ensure rapid quenching (300 K s^{-1}) the specimens were 12mm in length and 1.0mm in diameter. The specimens were austenitized for 10 min. at 1000°C in dilatometry furnace and subsequently gas quenched to the isothermal transformation temperature by an automatically controlled high-pressure helium jet.

Tab. 2. A_1 , A_3 , B_S and M_S temperatures

Steel	Temperature, $^\circ\text{C}$				Experimentally determined		Thermodynamically calculated	
	A_{c1}	A_{c3}	A_{r1}	A_{r2}	M_S	B_S	M_S^*	B_S^*
15HM2VT	807	969	730	896	453	-	423	555

*Assuming full austenitization (1200°C) ensuring complete dissolving of carbides in austenite

The specimens for transmission electron microscopy (TEM) were machined to 3mm dia. rod, carefully avoiding any heating. The rods were sliced into 0.35mm thick discs while being kerosene cooled. The discs were subsequently ground down to a thickness of 40-50 μm on 500 grid paper. These foils were finally electropolished in a twin-jet at room temperature and at 55-60V using a 25-pct glycerol, 5 pct perchloric acid and 70 pct ethanol mixture. Thin foils were stored in ethanol and subsequently examined in a Tesla BS-540 electron microscope at an operating voltage of 120 kV. Optical microscopy was used to examine etched structures. Specimens were etched in 2% nital solution.

3. Results and discussion

To plan the heat treatments a time-temperature-transformation (TTT) diagrams (Fig. 1) were calculated for the composition given in Tab. 1. The calculation was done using a method developed by Bhadeshia [3,4].

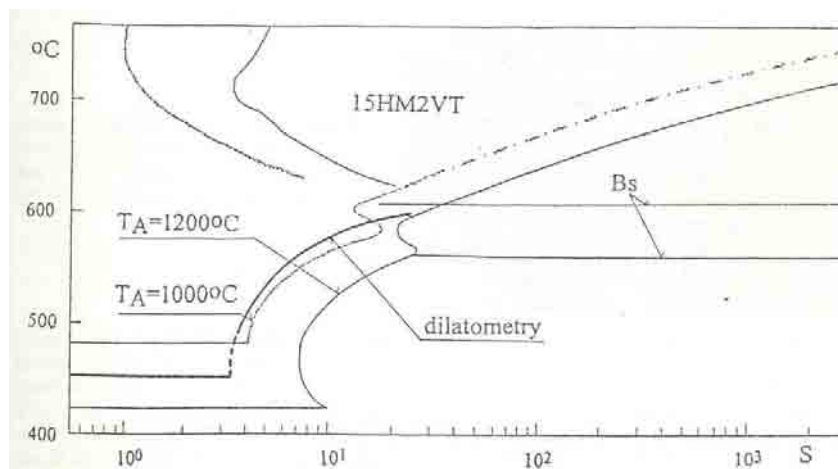


Fig. 1. Time-temperature-transformation (TTT) diagram of investigated 15HM2VT steel [10]

In that method the TTT diagram has been treated as being composed of two separate C curves, one of which represents diffusional transformations and the other, displacive reactions (Widmanstätten ferrite and bainite). The technique is capable of correctly generating the bay region of time-temperature-transformation diagrams, while at the same time allowing relative shifts in the shear and diffusional C curves, as a function of alloying element content. The bainitic ferrite B_S and martensitic M_S start temperatures were also calculated using the same method. The bainite start temperature B_S is the temperature corresponding to the upper part of the shear transformation C curve and it strictly refers to the point at which the nucleation of ferrite that grows displacively first becomes possible [3,5]. The transformation temperature data are given in Tab. 2.

Based on the dilatometry data and the data from the calculated TTT diagram heat treatment of 15HM2VT steel was planned as follows: two austenitizing temperatures 1000 and 1200°C/20minutes, and two utmost temperatures of bainite range, e.g. 575 – 500°C and 550 – 450°C respectively. Austenitizing temperature 1200°C was required for complete dissolution of VC carbides [2]. Isothermal reaction temperatures were chosen to lie above the M_S temperature to avoid formation of martensite during the isothermal heat treatment, and below the bay temperature of investigated steel.

Optical microscopy was carried out in order to observe any variations in the gross features of microstructure, e.g. prior austenite grain size, bainitic packet size and distribution of blocky austenite with heat treatment. The microstructural dimensions are given in Tab. 3.

Tab. 3. Microstructural parameters of 15HM2VT steel

Microstructural parameters	Austenitization temperature:			
	1200°C		1000°C	
	Transformation temperature, °C		Transformation temperature, °C	
	550	450	575	500
Average austenite grain size, μm	50	50	17	17
Volume of bainite in the form of packets, %	45	50	40	45
Packet length, μm	40	40	-	-
Packet width, μm	30	36	-	-
Width of bainite lath, μm	0.5	0.4	0.6	0.5
Morphology of retained austenite	thin films, also irregular islands	mainly thin films	irregular islands and thin films	irregular islands and thin films
Volume fraction of retained austenite, % *	5.0	8.6	-	-

* Volume fraction of retained austenite were determined by xrd diffractometer on samples quenched to ambient temperature after isothermal transformation for 6h at temperature 550°C and for 3h at temperature 450°C

Optical micrographs of the partially reacted specimens of the 15HM2VT steel are shown in figures 2 and 3. Only large individual carbides TiC, regardless of austenitization temperature, can be detected in micrograph of the 15HM2VT steel (TiC carbides are arrowed). In observed microstructures the bainite reaction has not proceeded to completion, and large pools of residual austenite have subsequently transformed to martensite on water quenching.

There is a general tendency for structural refinement with decreasing austenitizing temperature.

The packet size after austenitization at 1200°C is coarser than that of 1100°C, which can be related to the larger austenite grain size (Tab. 3).

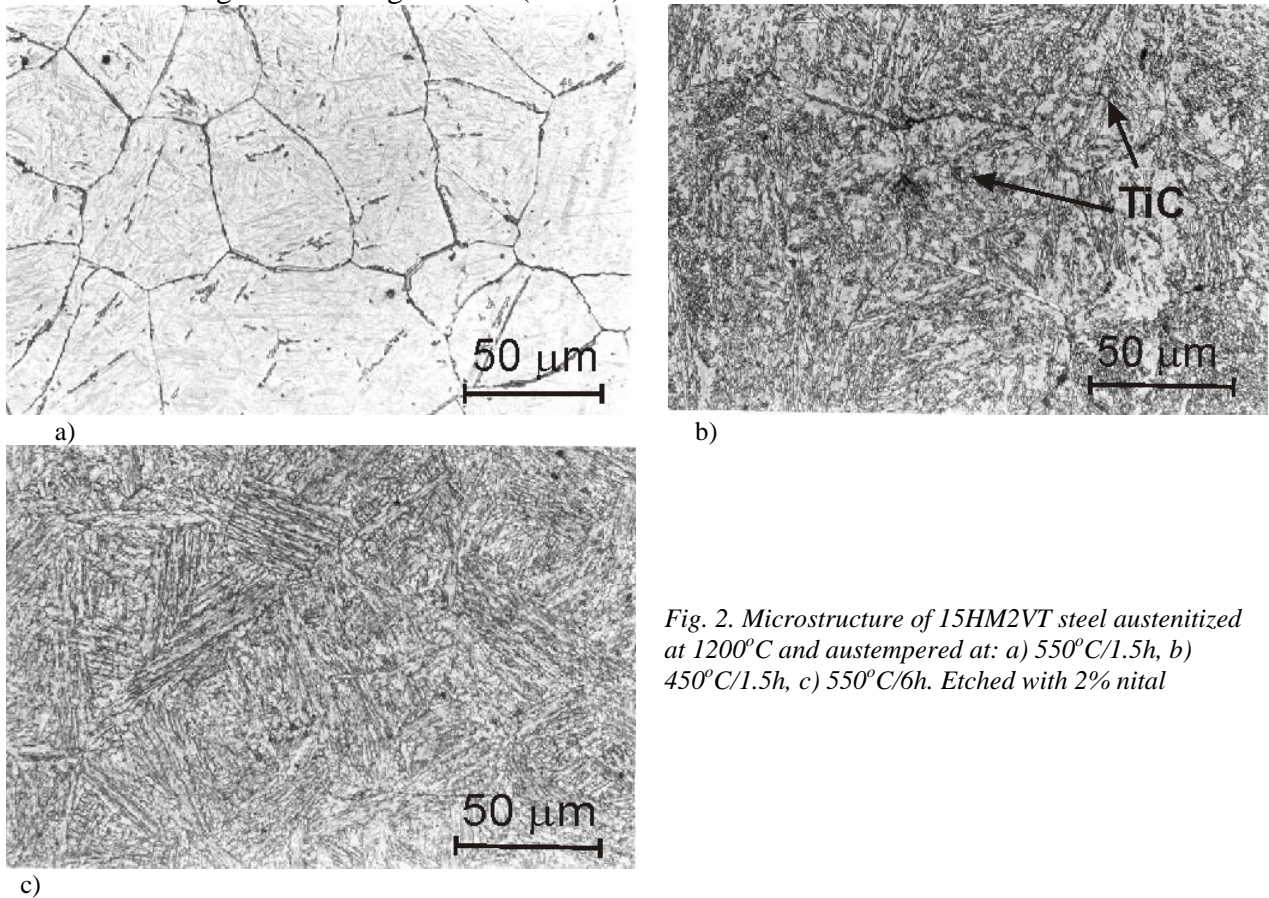


Fig. 2. Microstructure of 15HM2VT steel austenitized at 1200°C and austempered at: a) 550°C/1.5h, b) 450°C/1.5h, c) 550°C/6h. Etched with 2% nital

After transformation to bainite at higher temperature retained austenite exhibited a blocky, triangular shape. It was found that for 15HM2VT steel the volume fraction of retained austenite increased with decreasing of the isothermal transformation temperature (Tab. 3). The volume fraction of retained austenite after austenitization at 1000°C was beneath the level of resolution of applied X-ray diffractometer. When temperature of isothermal transformation was decreased the blocky morphology of retained austenite was replaced by films of retained austenite separated by platelets of bainitic ferrite. This film austenite, since it is trapped in the immediate vicinity of bainite laths is known to contain a higher carbon content than blocky austenite has and it is difficult to transform to martensite [6,8]. Therefore an increase in the volume fraction of retained austenite with an decrease in isothermal transformation temperature results as a higher amount of residual austenite with a higher carbon content.

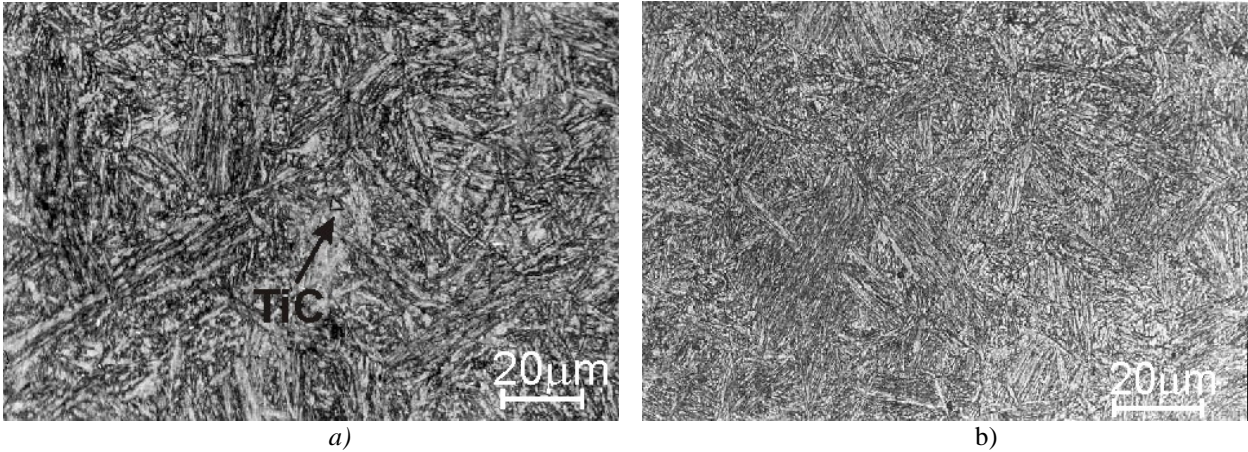


Fig. 3. Microstructure of 15HM2VT steel austenitized at 1000°C and austempered at: a) 575°C/1.5h, b) 500°C/1.5h. Etched with 2% nital

The fine details of the microstructure were examined by TEM. Fig. 4 shows a morphology of blocky austenite in 15HM2VT steel after heat treatment at 1000°C following isothermal transformation at 500°C for 120s. Beside blocky austenite, interlath films of retained austenite in the bainitic regions were also observed after this treatment. In 15HM2VT steel after austenitization at higher temperature (1200°C), retained austenite occurs mainly as interlath films (Fig. 5). As the austenitization temperature increases from 1000 to 1200°C the structure changes from upper (granular) bainite to upper lath bainite. It is assumed that upper bainite in these steel is a structure composed of carbide free bainitic ferrite laths with interlath retained austenite films replacing the interlath cementite of the classical upper bainitic microstructure. The interlath retained austenite films are stable and there is no apparent decomposition to martensite.

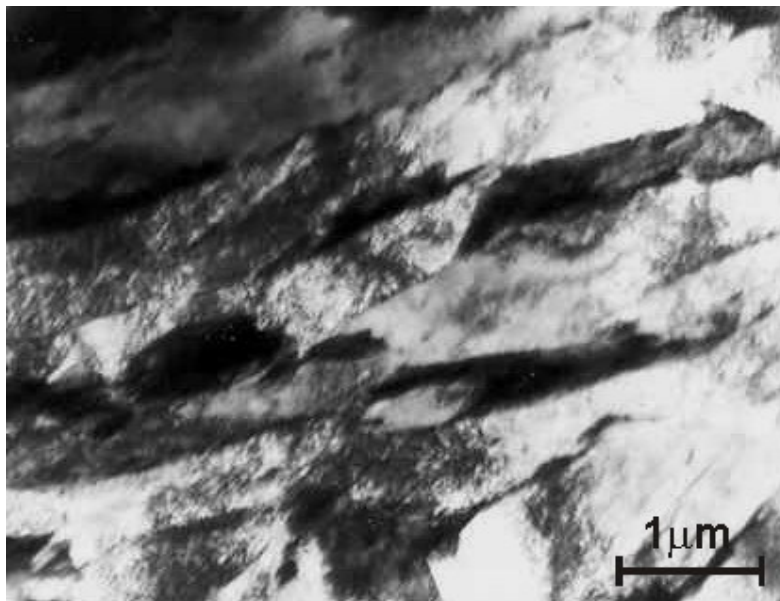


Fig. 4. Microstructure of 15HM2VT steel after austenitization at 1000°C following isothermal transformation at 500°C for 120s. Thin foil

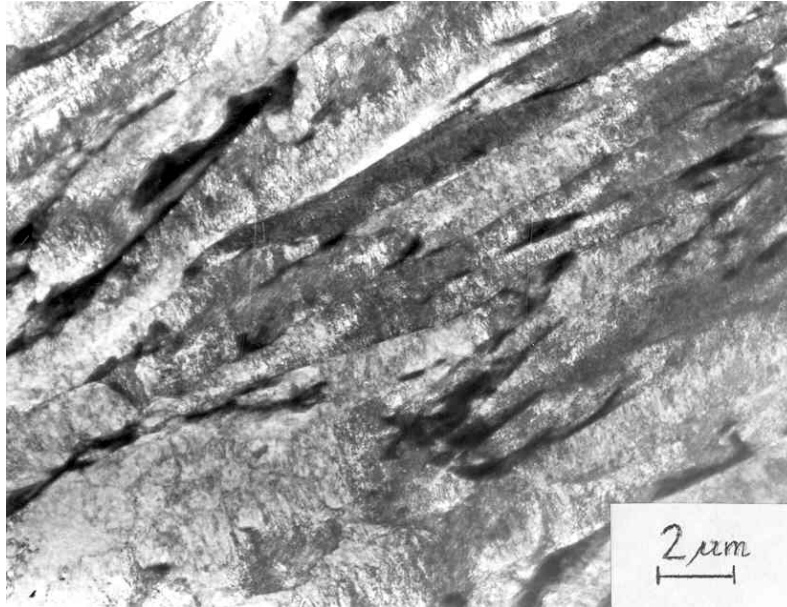


Fig. 5. Microstructure of 15HM2VT steel after austenitization at 1200°C following isothermal transformation at 550°C for 3600s. Thin foil

Fig. 6 shows the general morphology of the microstructure in 15HM2VT steel after austenitization at 1200°C and isothermal transformation at 550°C for 7200s. The morphology of the bainite is similar to low carbon lath martensite, where dislocated laths are separated by films of retained austenite. No blocky austenite was observed in this structure. Careful examination of this microstructure shows no evidence of carbides precipitation. No significant changes in morphology with increasing reaction time were observed after isothermal transformation at 550°C. This structure, therefore, belongs to upper bainite assuming that upper bainite in this steel is a structure composed of carbide free bainitic laths with interlath retained austenite films [5,12].

After austenitization at 1200°C and at lower transformation temperature (450°C), bainite changes into a morphology with carbides within the laths (Fig. 7). It is also seen that carbide particles within ferrite laths and the long axis of the laths are at angles of 55 to 60 deg, as observed in lower bainite [13]. On the presently widely accepted view [5,11,13], in lower bainite carbides precipitate from highly supersaturated ferrite laths. During a progress of bainitic reaction the excess of carbon in bainitic ferrite may partition eventually into the residual austenite or precipitate from the ferrite in the form of carbides. If the latter process is dominant, then lower bainite is obtained [13].

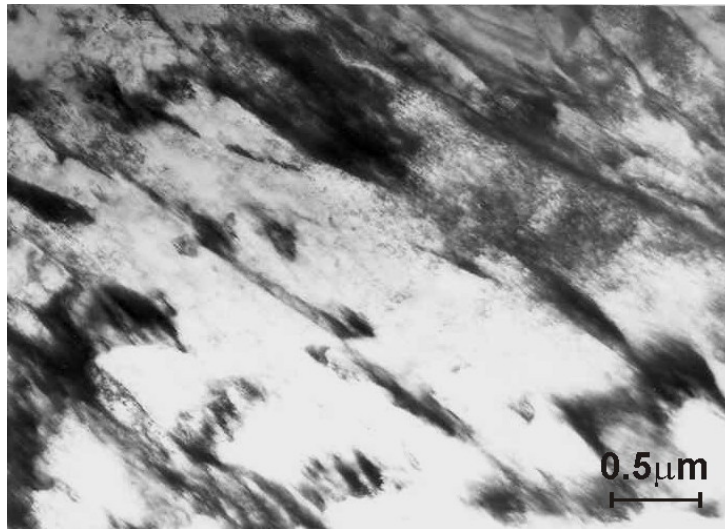


Fig. 6. Microstructure of 15HM2VT steel after austenitization at 1200°C and isothermal transformation at 550°C for 7200s. Thin foil

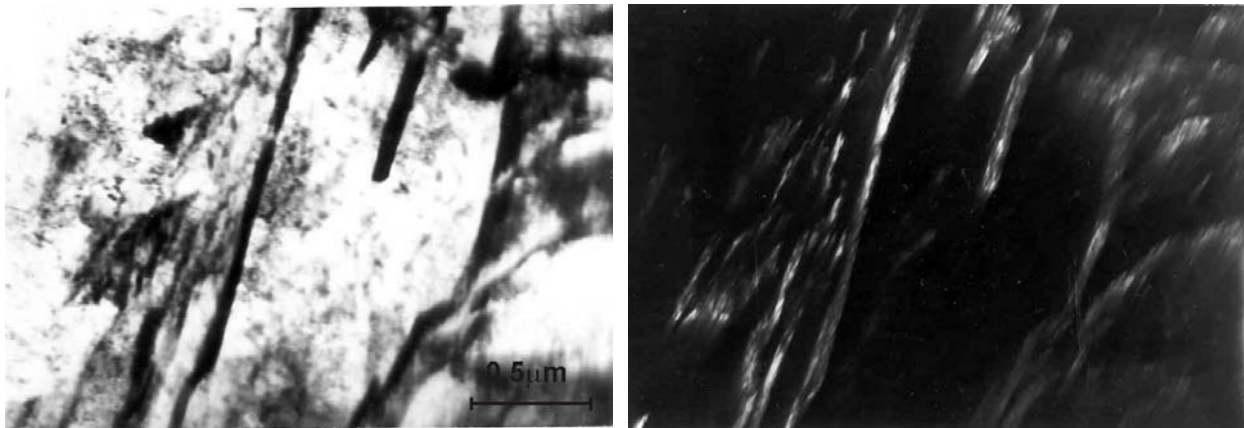


Fig. 7. Microstructure of 15HM2VT steel after austenitization at 1200°C and isothermal transformation at 450°C for 7200s. Bright and dark field from residual austenite. Thin foil

Thus the amount, distribution and morphology of retained austenite and occurrence of carbides vary with the austenitizing and transformation temperatures. The dispersed and ductile austenite films between the ferrite platelets (Fig. 7) can be expected to have a crack blunting effect. But the blocks of austenite tend to transform to high carbon untempered martensite under the influence of small stresses and consequently have an embrittling effect. Also other intrinsic components of the microstructure, such as particles of cementite laying especially in the interlath regions can be responsible for damage initiation.

4. Conclusions

The development of bainitic transformation was studied using TEM, dilatometry and thermodynamic calculations, both from a fully austenitic microstructure ($T_A=1200^\circ\text{C}$) and from a microstructure containing a mixture of austenite and undissolved carbides ($T_A=1000^\circ\text{C}$).

Transmission electron microscopy revealed that after isothermal transformation the microstructure within the prior austenite grains consists of a mixture of ferritic bainite, residual austenite and/or carbides. After austenitization at 1200°C followed by bainitic reaction, the bainite was in the form of classical sheaves. The amount, distribution and morphology of retained

austenite, bainitic ferrite and precipitation of carbides strongly depends on both; prior austenitization and isothermal transformation temperatures within the bainitic range.

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