



ISOTHERMAL DECOMPOSITION OF MEDIUM CARBON V MICROALLOYED AUSTENITE IN LOWER TEMPERATURE RANGE: MICROSTRUCTURE AND PROPERTIES

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Introduction

The demand for economical steels has increased over past years. Steels are expected to have as lean chemistry as possible and to be easier to fabricate. At the same time they are expected to have properties at least equal to steels which are being substituted. These demands have been, at least in part, met by V microalloyed medium carbon forging steels in order to substitute traditional quenched and tempered (Q+T) steels. In spite of some lower toughness, V microalloyed medium carbon forging steels broaden its application due to considerable energy save by eliminating the heat treatment from the production route. During continuous cooling, dominantly acicular ferrite microstructure is formed. Main characteristics of acicular ferrite are intragranular nucleation and strongly 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]. On the other hand, generally, data related to isothermal decomposition seems to be lacking. Therefore, the aim of the present study is to clarify the influence of transformation temperature and time on austenite isothermal decomposition in V-microalloyed forging steels.

Experimental

The chemical composition of tested steel is given in Table 1. Steel was industrially cast and hot-rolled into 19mm diameter bars. 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 450°C for different holding times (between 2 to 1800s) 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 microscope (SEM). After full microstructural examination, samples were cut to ø5x5mm dimension for compression testing. These tests were carried out on servo-hydraulic tensile machine INSTRON.

Table 1: Chemical composition of the experimental steels (wt%)

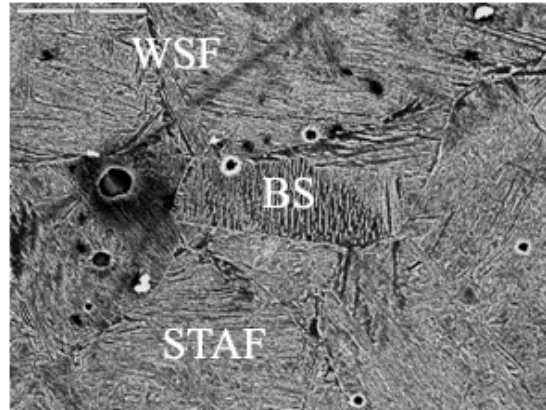
Alloying	C	Si	Mn	P	S	Ti	V	N
Wt.%	0.256	0.416	1.451	0.0113	0.0112	0.002	0.099	0.0235

Results and Discussion

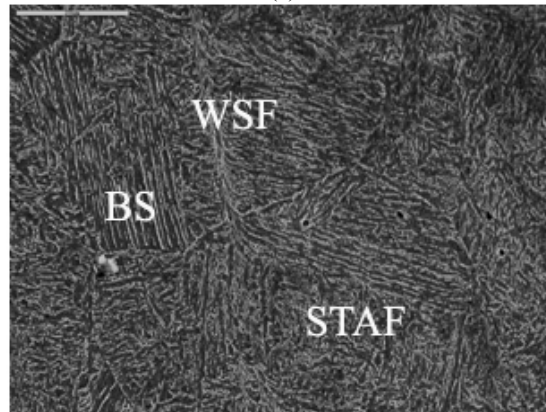
Austenite grain size after austenitization 1100°C/10min is 57 ±3µm. This austenitization is selected in order to enhance intragranular AF formation rather than bainite by increasing the ratio between intragranular and grain boundary sites [29,30] and eliminate influence of prior austenite grain size. Final microstructures obtained after holding of 30 minutes at all three temperatures are shown in Fig. 1 and summarized in Table 2.

At 350°C, first phase to be nucleated are ferrite grains along prior austenite boundaries. The incubation period was 7 seconds. Due to its characteristic grain shape and low temperatures, new phase was identified as Widmanstatten ferrite (WSF). During Widmanstatten ferrite formation carbon must partition into the austenite, providing localized areas enriched with carbon. With longer times more pronounced nucleation of WSF takes place, together with some growth into austenite grains. At 10 seconds, additional grain boundaries nucleation occurs. At segments of austenite boundaries that were not covered with WSF, bainitic sheaves (BS) were nucleated. They are characterized by packets of parallel

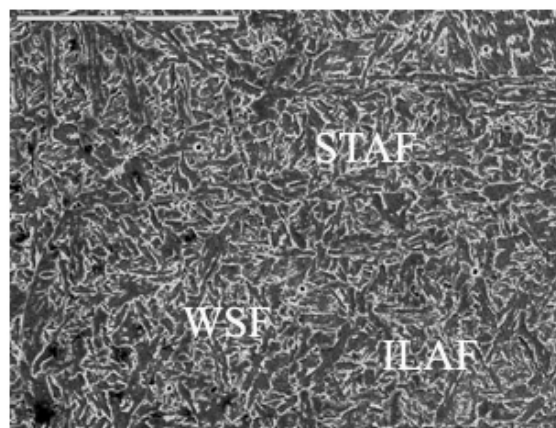
sheaves originating from grain boundaries. Bainitic sheaves are produced dominantly by shearing mechanism. Further delay up to 20 seconds leads to start of intragranular nucleation of acicular ferrite. In many cases, bainitic sheaves and acicular ferrite are differentiated only by place of origin; acicular ferrite nucleates exclusively intragranularly. Acicular ferrite formed at low temperatures follows the tendency to form sheaves composed of parallel plates. This behavior is introduced by differences in the carbon concentration profiles in the parent austenite in the front of the interface of the Widmanstatten ferrite grains. As it is suggested [22,23], at initial stages for the transformation at 350°C, the carbon concentration in austenite close to the tips of primary plates is lower than at the faces (side direction).



(a)



(b)



(c)

Figure 1. Microstructure after completed isothermal decomposition at different temperatures: (a) 350°C – bar 20 μ m; (b) 400°C – bar 20 μ m; (c) 450°C – bar 50 μ m (SEM microphotographs)



Therefore, instead of growth in side direction, nucleation on the tips of present sheaf is favoured, due to carbon enrichment on side direction. Therefore, final microstructure consists of Widmanstatten Ferrite + Bainitic Sheaves + Sheaf Type Acicular Ferrite (WSF+BS+STAF).

At 400°C, austenite decomposition follows, generally, the same pattern as at 350°C. Incubation period is shorter, i.e. Widmanstatten ferrite nucleates after 2 seconds. Bainitic sheaves are observed after 10 seconds, while acicular ferrite is observed after 15seconds. The main difference is that bainitic sheaves are observed sporadically, while sheaf type acicular ferrite is dominant microconstituent. Therefore, final microstructure consists of Widmanstatten Ferrite + Sheaf Type Acicular (+Ferrite Bainitic Sheaves) - WSF+STAF (+BS).

At 450°C, small portion of grain boundary ferrite is evaluated after 2 seconds incubation time. On the other hand, after 10 seconds, very pronounced nucleation of acicular ferrite starts. Due to increase in temperature, together with sheaf type acicular ferrite, interlocking acicular ferrite is also intragranularly nucleated.

Table 2. Microstructure and yield strength after decomposition at different temperatures

Temperature, °C	Structure	Yield stress, MPa
350	Widmanstatten Ferrite + Bainitic Sheaves + Sheaf Type Acicular Ferrite	900
400	Widmanstatten Ferrite + Sheaf Type Acicular Ferrite (+ Bainitic Sheaves)	800
450	Sheaf Type Acicular Ferrite (+ Interlocking Type Acicular Ferrite + Widmanstatten Ferrite)	680

The yield strength is the most important value for structure design because it determines the stress at which the material begins to deform plastically after dislocations start the glide. Highest value of 900MPa is determined for samples transformed at 350C. With increase of decomposition temperature, yield stress decreases to 800 and 680MPa, for 400 and 450C, respectively. Due to dominantly displacive nature of isothermal decomposition at lower temperatures, this behavior can be related to dislocation strengthening associated with the presence of hard phases such as bainite. As have been reported previously, the dislocation density of the ferrite increases with decreasing transformation temperature. This observation can be associated with a high strain-hardening rate imposed by bainite.

Summary

The aim of this work was to evaluate microstructure and mechanical properties after isothermal decomposition of austenite in V microalloyed steel. Tested steel contained 0.256%C, 0.12%V and 0.229%N. Samples were reheated at 1100C for 10 minutes and then isothermally treated in salt bath at 350, 400 and 450C. Microstructure was revealed using light and SEM microscopy. Yield stress was determined by compression testing on samples with final microstructure. Results indicate presence of three dominant morphologies, Widmanstatten ferrite (WSF), bainitic sheaves (BS) and sheaf type acicular ferrite (STAF). WSF was first nucleated at grain boundaries, at all temperatures. In some cases, bainitic sheaves are also present at prior austenite grain boundaries. This feature decreases with increase of temperature. As time elapsed, intragranular nucleation of acicular ferrite started. Acicular ferrite has typical sheaf type morphology, differing from bainitic sheaves only in nucleation place. Yield strength decreases from 1000 MPa to 800 MPa with increase of holding temperature from 350C to 450C. This behavior is attributed to decrease in dislocation density with increase of temperature in the case of displacive transformation

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