Academy journal for Basic and Applied Sciences (AJBAS) Volume 5 # 1 **April 2023**

Austenite Grain Size Effects on Isothermal Allotriomorphic Ferrite Formation in 0.31C – 1.53Mn – 0.12V Micro alloyed Steel

Abdulnaser Hamza Fadel

University of Zawia, Faculty of Oil, Gas and Renewable Energy Engineering
Department of Materials and Metallurgical Engineering, Al Zawia Libya
Email: A.fadel@zu.edu.ly

Abstract

The rate at which austenite decomposes to form ferrite, pearlite and bainite is dependent on the composition of the steel, as well as on other factors such as the austenite grain size, and the degree of homogeneity in the distribution of the alloying elements. Allotriomorphic ferrite is the first phase to be generated at all temperatures. In the lower temperature range the Widmanstetten ferrite is formed, while on higher temperatures grain boundary allotriomorphs are produced. The present paper is concerned to the experimental study of the isothermal decomposition of austenite in allotriomorphic ferrite in a modern medium carbon vanadium–titanium micro alloyed forging steel. This paper deals with the isothermal austenite-to-allotriomorphic ferrite as a whole, considering the specific role of different features such as prior austenite grain size (PAGS) and isothermal temperature, in nucleation and growth processes independently.

Keywords: medium carbon steel, micro alloyed steel, isothermal transformation, allotriomorphic ferrite, incubation time for allotriomorphic ferrite formation.

1. Introduction

The most majority for steel production processes demands subsequently fabrication into plates, bars, rods, strips, sheets, and coils, using large scale deformation processes in which the cooling rate from austenite phase field is relatively slow. Such products are destined for use in the construction, power generation, ship building and automotive industries (amongst others), where structural materials of high strength, good toughness, low cost and weldability are required. Usually, the microstructure of these steels is a mixture of allotriomorphic ferrite and pearlite. The mechanical properties are derived from these microstructural constituents [1]. On the other hand, several authors [2-4] have reported the role of empirical to semiempirical models to predict the kinetics of ferrite transformation. Concurrently, models recently developed are becoming less empirical since they rely dependence on experimentally and phase transformation theories developed practical methodology to simulate the allotriomorphic ferrite transformation under isothermal conditions. Several previous studies [5-11] indicate the prior austenite grain size (PAGS) exerts an important influence on the decomposition of austenite, then formed microstructure and later the mechanical properties, therefore the role of PAGS on the isothermal allotriomorphic ferrite transformation is worth studying. A reduction in the austenite grain size should lead to an increase in the rate of transformation because of the greater number density of grain boundary nucleation sites. However, it is not clear if PAGS would affect the growth kinetics [5]. The present paper represents an attempt to clarify the role of austenite grain size effects on the isothermal allotriomorphic ferrite formation in 0.31C – 1.53Mn – 0.12V micro alloyed steel.

2. Materials and Experimental Procedures

The chemical composition of the steel studied is presented in Table 1. All the samples were austenitised in vacuum (1 Pa) at a constant rate of 5 C°/s. Austenitization conditions and their corresponding prior austenite grain size (PAGS) are listed in Table 2. After austenitisation, specimens were isothermally transformed at temperatures of 350 to 600 C° at different holding times and subsequently quenched to room temperature. Specimens were grounded and polished using standardised metallographic techniques. A 2% nital etching solution was used. The isothermal decomposition of austenite has been analyzed by means of optical microscope. In order to reveal the fine features in detail, etched samples were also observed by a Field Emission Gun Scanning Microscope (FEGSEM). Elemental analysis in a fine scale was carried out with an Electron Probe Micro-Analysis (EPMA). Camera SX 100 instruments were used for such purpose with an acceleration voltage of 15 kV, beam current 20 mA and with beam diameter of 1 μm.

Table 1 Chemical composition (mass%) of the steel.

C	P	Si	Mn	S	Cr	Al	Mo	Cu	Nb	Ni	Ti	V	N
0.31	0.007	0.48	1.53	0.01	0.265	0.017	0.041	0.232	0.003	0.200	0.011	0.123	0.022

3. Results and Discussion

In this study, the PAGS was estimated by means of the thermal etching method [23]. This method consists in revealing the austenite grain boundaries in a pre-polished sample by the formation of grooves in the intersections of austenite grain boundaries with the polished surface, when the steel is exposed to a high temperature in an inert atmosphere. These grooves decorate the austenite grain boundary and make it visible at room temperature in the optical microscope. Once the austenite grain boundaries are revealed, binary images of the microstructures are processed using and image analyser [1, 13] Measurements are made of at least 100 grains randomly selected from the population of grains revealed on cross sections of the steel. The PAGS results are analyzed in terms of mean values of the equivalent circle diameter $PAGS = (4A / \pi)^{1/2}$ [1,14], being A the equivalent circle area. The average PAGS result for steel present study are given in table 2, while figure 1, shows the microstructure from which the values listed in Table 2 were obtained. In regard to the solubility product of alloying elements, the distribution of vanadium and nitrogen in austenite is rationalized in terms of the temperature for complete dissolution of VN and VC, according to previous studies calculations with this steel [7,15] where by the results are 1114 °C and 1084 °C for TVN and TVC respectively, which seems to be at the austenitisation temperature range studied, TiN and VC has already dissolved.

Table 2 Austenitisation conditions, Prior Austenite Grain Size (PAGS).

Austenitisation temperature, Tγ/ C°	Austenitisation time, tγ /s	Prior austenite grain size, PAGS/μm	Austenite grain surface per unit volume, $s_V^\gamma/\mu m^{-1}$
1150	600	63 ± 5	0.029 ± 0.005
1250	600	80 ± 10	0.037 ± 0.005

Moreover, the variation in volume fraction of TiN between the two austenitisation temperatures tested is very small according to calculations, which allows us to assume no significant changes in volume fraction of these particles for the different studied transformation temperature. Concurrently the grain boundary surface area per unit volume s_V^γ was measured on the same micrographs used to determine the PAGS, by using the stereological relationship $S_V = 2P_L$, where P_L is the density of the intersection points of austenite grain boundaries with a circular test grid [1,20] Table 2 also shows the s_V^γ results for the tested steel. In respect to allotriomorphic ferrite, according to the procedure reported by S. S.

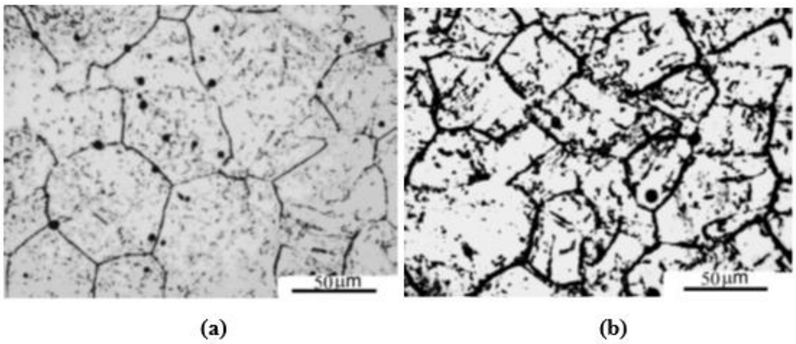

Figure 1. L. M micrograph showing austenite grain structure revelaed by means of thermal etching after austenitisation at (a) 1250 C° (b) 1150 C°

Table3. Nucleation onset time for Allotriomorphic ferrite formation

Isothermal Transformation Temperature C*	Imcubation time by second
450	2
500	5
550	5
600	10

Babu et al. [1,21,22] The allotriomorphs are considered as cylinders having their faces parallel to the austenite grain boundary plane. The cylinders are assumed to grow towards the centre of the grain with their length, L, varying parabolically with time (t) through the equation (1) [1]

$$L = \alpha(t - \tau)^{1/2} \tag{1}$$

where τ is the incubation time for allotriomorphic ferrite formation (Table 3), i.e. the minimum time at which some allotriomorphs are formed, and α is the parabolic growth rate constant. So allotriomorphic ferrite is the first phase to be nucleated during isothermal treatment in temperature range 500-600° C. Allotriomorphic ferrite nucleates on the austenite grain boundaries as shown in Fig. 4 & 5 and 6. After the first grains are produced, allotriomorphs continue to decorate austenite grains.

4. Conclusions

Grain boundary ferrite is the first phase to be generated at all temperatures. In the lower temperature range the widmanstetten ferrite is formed, while on higher temperatures grain boundary allotriomorphs are produced. This difference is attributed to displacive nature of transformation at lower and diffusional transformation at higher

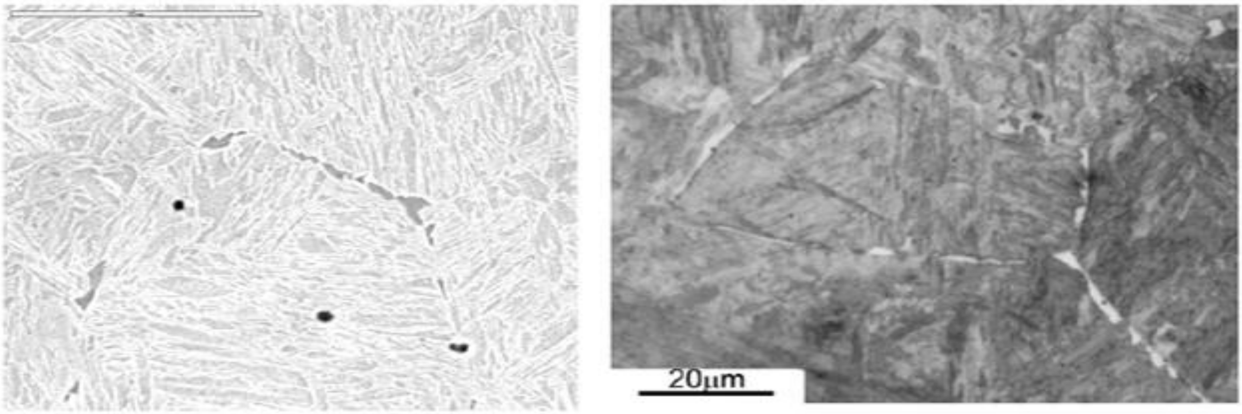

Figure 4. SEM image (left) / O.M (right) showing onset of Grain Boundary Ferrite at 600 C°- after10s.

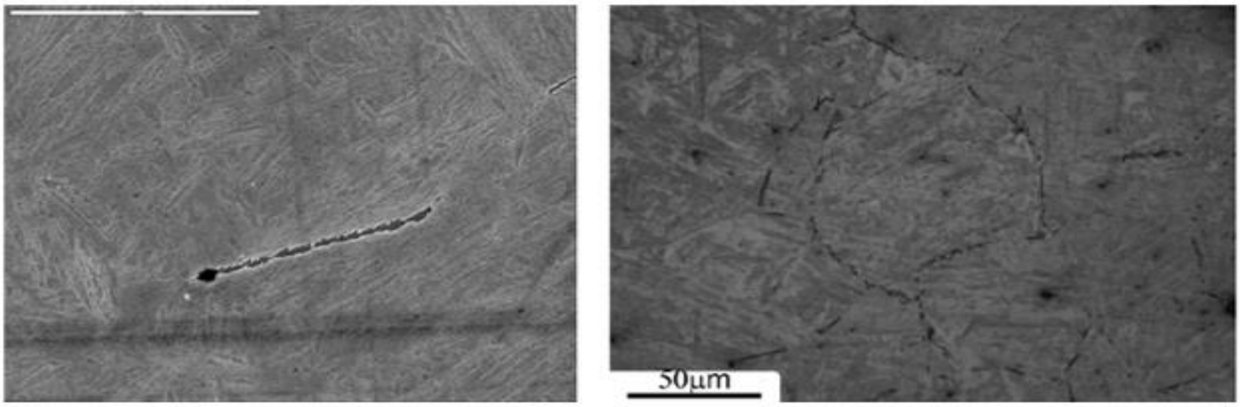

Figure 5. SEM (left) / O.M (right) showing onset of GBF at 550 C°- after 5 and 10s respectively.

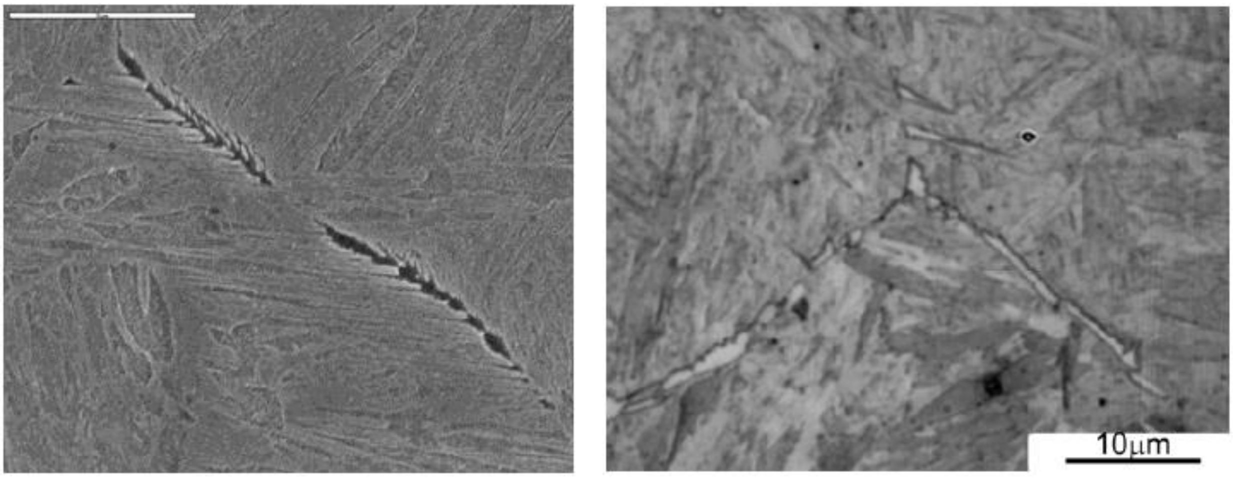

Figure 6. SEM (left) / O.M (right) showing onset of GBF at 500 C°- after 3 and 5s respectively.

References

[1] C. Capdevila, F. G. Caballero and C. de Andres, Mat. Transactions, Vol. 44, 6 (2003), 1087-1095.

[2] C. Capdevila, F.G. Caballero and C. Garcia de Andre´s, Scripta mater. 44 (2001) 593–600

[3] R. C. Sharma and G. Purdy: Metall. Trans. 5 (1974) 939–945.

[4] Božo Smoljan, Dario Iljki´c, Sunˇcana Smokvina Hanza and Krunoslav Hajdek, Metals (2021), 11, 1292.

[5] C. Capdevila, Francisca G. Caballero and Carlos Garca de Andre´s, Materials Transactions, Vol. 44, No. 6 (2003) pp. 1087 – 1095.

[6] C. de andre, S. C. Capdevila, D. San martin, F. G. Caballero, J. of Mat. Sci. 20, (2001), 1135.

[7] Fadel, A. Austenite Decomposition in Medium Carbon Microalloyed Steels: Mechanism, Structure and Properties. Ph.D. Thesis, University of Belgrade, Belgrade, Serbia, 2013.

[8] A. Fadel, D. Glišić, N. Radović, Dj. Drobnjak, J. Min. Metall. Sect. B-Metall. 49 (3) B (2013) 237

[9] Dragomir Glišić, Nenad Radović, Djordje Drobnjak, Abdunnaser Fadel, Procedia Materials Science 3 (2014) 1226 – 1231

[10] A. H. Fadel, Dragomir Glišić, Nenad Radović, Djordje Drobnjak, The International Journal of Engineering and Information Technology (IJEIT), VOL. 2, NO. 1, 2015 73

[11] M.A. Linaza, J.L. Romero, J.M. Rodrıguez-Ibabe, J.J.Urcola, Scripta Met. Mater., 32 (3) (1995) 395–400.

[12] A. Echeverria, J.M. Rodrıguez-Ibabe, Scripta Mater.,41 (2) (1999) 131–136.

[13] Annual Book of ASTM Standards, Standard Test Methods for Determining Average Grain Size Using Semiautomatic and Automatic Image Analysis, Designation: E 1382-91.

[14] L. Ciupinski, B. Ralph and K. J. Kurzydlowski: Mater. Charact. 38 (1997) 177–185.

[15] D. Glišic, N. Radovic, A. Koprivica, A. Fadel and Dj. Drobnjak, ISIJ International, Vol. 50 (2010), No. 4, 601–606

[16] N. Radovic, A. Koprivica, D. Glišic, A. Fadel and Dj. Drobnjak, Materials Science Forum Vols.638-642 (2010) 3459-3464.

[17] A. Fadel, D. Glišic, N. Radovic, Dj. Drobnjak, Journal of Materials Science & Technology 28 (2012) 1053-1058.

[18] S. Dikic, D. Glišic, A. Fadel, G. Jovanovic and N. Radovic, Metals 2021, 11, 1011.

[19] S. Dikić, D. Glišić, A. Fadel, G. Jovanović and N. Radović, Hem. Ind. 76(4) 227-236 (2022)

[20] E. E. Underwood: Quantitative Stereology, (Addison-Wesley Reading, MA, USA, 1970) 101.

[21] S. S. Babu, H. K. D. H. Bhadeshia and L. E. Svensson: J. Mater. Sci. Lett. 10 (1991) 142–144.

[22] D. Glišić, A. Fadel, N. Radović, Dj. Drobnjak, M.Zrilić, Hemijska Industrija, 67 (6) (2013) 981.

[23] A. Fadel, The Int. J. of Eng. and Information Tech. (IJEIT), VOL. 2, NO. 1, (2016) 53 – 56.

[24] N. Radovic, A. Koprivica, D. Glišic**,** A. Fadel and Dj. Drobnjak, MJOM 16 (2010) 1-9.