J. LIS, A. LIS, C. KOLAN

ISSN 0543-5846
METABK 50(2) 123-126 (2011)
UDC – UDK 669.14:66.066.1:669.781=111

INVESTIGATION OF BORON SEGREGATION IN LOW CARBON STEEL

Received – Prispjelo: 2010-05-26
Accepted – Prihvaćeno: 2010-10-25
Preliminary Note – Prethodno priopćenje

Traces of born in the range 0,002-0,009 % are usually added to many grades of steel. The effect of boron on phase transformations and hardenability of low carbon low alloy steels depends on the form of its behavior in solid solution either in segregations or in precipitations. Temperature and cooling rate determine the existence of boron segregations on grain boundaries. In present paper simulations of boron concentrations were calculated with computer programme DICTRA for low carbon 0,08 %C steel with 0,006 % boron. Investigations were carried out for temperature 1300 – 700 °C and cooling rates from 1 °C/s to 100 °C/s. The changes of boron concentrations in austenite and ferrite after commencement of $\gamma \rightarrow \alpha$ phase transformation were established.

Key words: Low carbon manganese steel, boron segregation, austenite grain size

Istraživanje segregacije bora kod niskougljičnih čelika. Tragovi bora u rasponu 0,002-0,009 % se obično dodaju mnogim tipovima čelika. Utjecaj bora na fazne transformacije i zakaljivost niskougljičnih niskolegiranih čelika ovisi o obliku njegovog ponašanja u čvrstoj otpini ili u segregacijama ili u precipitatima. Temperatura i brzina hlađenja određuju postojanje segregacija bora na granicama zrna. U ovom radu simulacije koncentracija bora su proračunate pomoću kompjutorskog programa DICTRA za niskougljični čelik s 0,08 % C i 0,006 % bora. Istraživanja su provedena ta temperature 1 300–700 °C i brzine hlađenja od 1°C/s do 100 °C/s. Utvrđene su promjene koncentracije bora u austenitu i feritu nakon početka $\gamma \rightarrow \alpha$ fazne transformacije.

Ključne riječi: niskougljični manganski čelik, segregacija bora, veličina austenitnog zrna

INTRODUCTION

For low carbon low alloyed steels to effectively use microadditon of boron on the improvement of mechanical properties by an increased hardenability there is necessary knowledge about form of boron occurrence either in uniform distribution in solid solution, or in segregations, or in precipitates. In the investigations of austenitic [1] and low alloyed steels [2-4] it was ascertained that boron segregations toward grain boundaries depend on temperature and rate of cooling. At temperature greater than 980 °C the existence of boron in solid solution was confirmed at water cooling rates. At air cooling rates segregation process occurred. From the above results it may be stated that boron segregation toward austenite grain boundaries will be controlled by cooling rate from temperature of austenitization. Investigations of boron existence in steel are difficult due to its small addition 0,001 – 0,009 mass % and as light element (atomic number 5) is on detection limit for electron and X-ray microanalysis [5]. Thus in present paper for low carbon steel with 0,006%B, modeling of boron segregation to austenite grain boundaries was performed with program DICTRA as a function of austenitization temperature 1300 – 700 °C and cooling rate 1 °C/s to 100 °C/s. The modeling data were taken from papers [6-8].

The effect of boron on the phase transformations is caused by its migration to austenite grain boundaries during cooling from austenitization temperature. Effect of boron on retardation of bainitic transformation was decreasing with the increase of boron segregation process along austenite grain boundaries. Segregation of boron to austenite grain boundaries most intensively influenced retardation of phase transformation $\gamma \rightarrow \alpha$ and to the lesser extent retardation of bainite transformation [3,9].

MATERIAL

Modeling of boron segregation with program DICTRA was done for low carbon steel which chemical composition is given in Table 1.

The investigation of austenite grain growth in the temperature range 800 – 1300 °C during 1,5 hour next cooled in water was done.

Appearance of the former austenite grain boundaries was done with Bechet-Beaujard method and estimation of grain size in accordance with PN-EN ISO 643. The results of the average grain diameter measured from in-

J. Lis, Department of Production Management and Logistic, Częstochowa University of Technology.
A. Lis, C. Kolan, Institute of Materials Engineering, Częstochowa University of Technology, Częstochowa, Poland.

Table 1 **Chemical composition of the investigated steel / mass %.**

C	Mn	Si	P	S	Cr
0,08	0,46	0,1	0,013	0,016	0,06
Cu	**Ni**	**Mo**	**N**	**B**	**Al**
0,22	0,11	0,02	0,009	0,006	0,003

Table 2 **Results of the austenite grain growth.**

Temperature / °C	Average grain diameter / μm	Standard deviation / μm
800	12,49	3,36
850	15,97	1,31
900	21,65	2,82
950	45,97	23,18
1000	56,97	38,39
1050	62,72	20,25
1200	110,50	20,10
1300	203,50	21,51

tersections of grain boundaries with measuring length segment are given in Table 2.

Temperature A_{c1} and A_{c3} at heating rate 20°C/s and 3 °C/min are equal to A_{c1} = 692 °C, A_{c3} = 983 °C and A_{c1} = 735 °C, A_{c3} = 873 °C.

SIMULATION OF BORON CONCENTRA - TIONS IN AUSTENITE AND FERRITE

Modeling of boron segregation was performed for the steel reheated to temperature 1300 °C at 60 s then cooled to intercritical temperatures with cooling rates V_c : 1, 10, 50 and 100 °C/s.

Concentration of boron as function of distance in the area of γ/α phases after different time steps from the beginning of simulation at cooling rate V_c = 1 °C/s is shown in Figure 1; at V_c = 10 °C/s in Figure 2, at V_c = 100 °C/s is in Figure 3. The precise boron concentrations in austenite and ferrite in the vicinity of grain boundary area γ/α at constant cooling rate are given in Figures: Figure 4 for 100 °C/s, Figure 5 for 50 °C/s, Figure 6 for 10°C/s and Figure 7 for 1°C/s.

The highest concentration of boron in ferrite 0,0245 – 0,024 % B occurred at the onset of transformation $\gamma\rightarrow\alpha$ at temperature 875 °C and decreased to 0,021 % B at temperature 730 °C for cooling rate 1°C/s – Figure 7. Distance with increased boron concentration in ferrite was 100 μm at 550 s and V_c = 1 °C/s – Figure 1.

The higher cooling rate, the shorter was distance of increased concentration of B in ferrite. In Figure 2 distance was 15 μm and in Figure 3 distance was 10 μm. At cooling rate 100 °C/s concentration of boron in austenite was changing from 0,006 % at 890 °C to 0,00525 % at 770 – 740 °C while in ferrite from 0,024%B to 0,021%B at 740 °C – Figure 4. At cooling rate 50 °C/s concentration of boron in austenite was changing from 0,006 % B at 865 °C to 0,0041 % B at 680 °C while in ferrite from 0,024 % B to 0,045 % B – Figure 5. There was no change in boron concentration in austenite at temperatures 1300

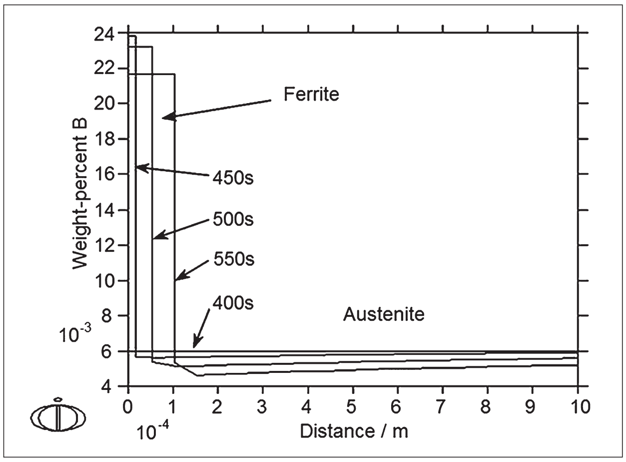

Figure 1 Concentration of boron in the function of distance in γ/α phase area after simulation time 400, 450, 500 and 550 s at cooling rate V_c = 1 °C/s

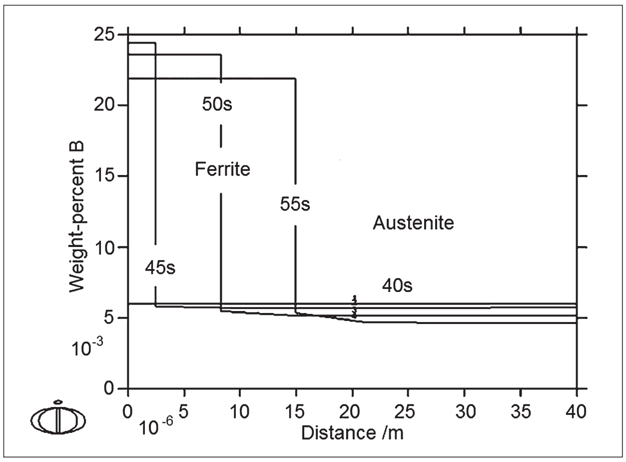

Figure 2 Concentration of boron in the function of distance in γ/α phase area after simulation time 40, 45, 50 and 55 s at cooling rate V_c = 10 °C/s

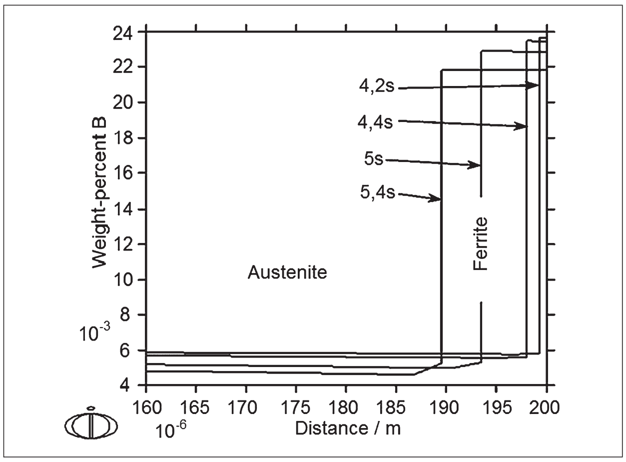

Figure 3 Concentration of boron in the function of distance in γ/α phase area after simulation time 4,2-5,4 s at cooling rate V_c = 100 °C/s

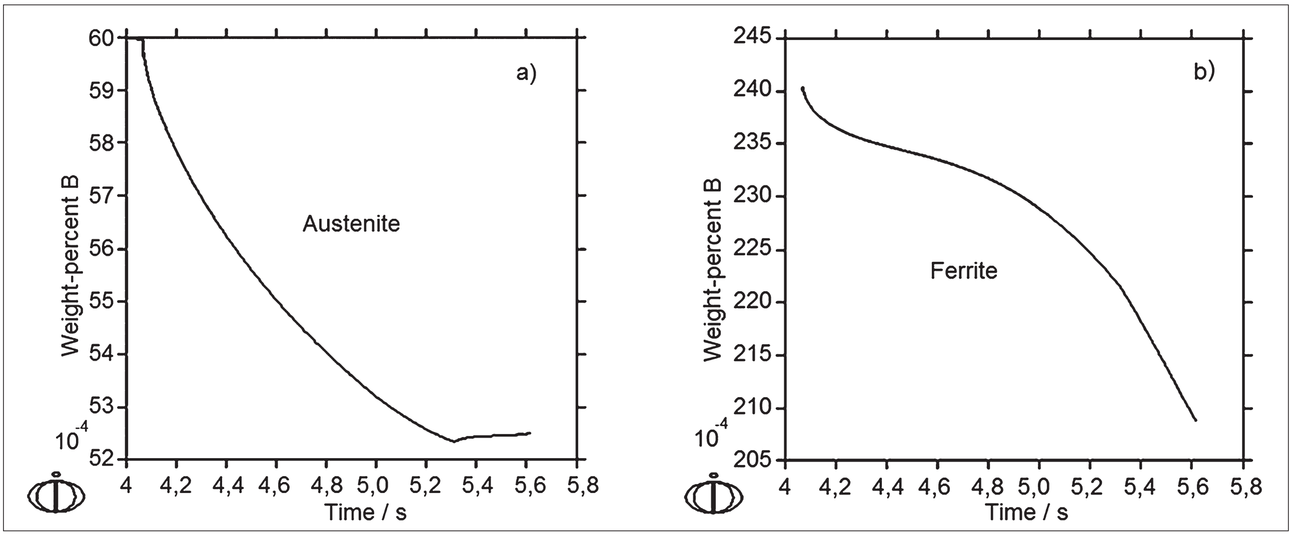

Figure 4 Concentration of B in austenite a) and ferrite b) in the grain boundary area γ/α at V_c = 100 °C/s

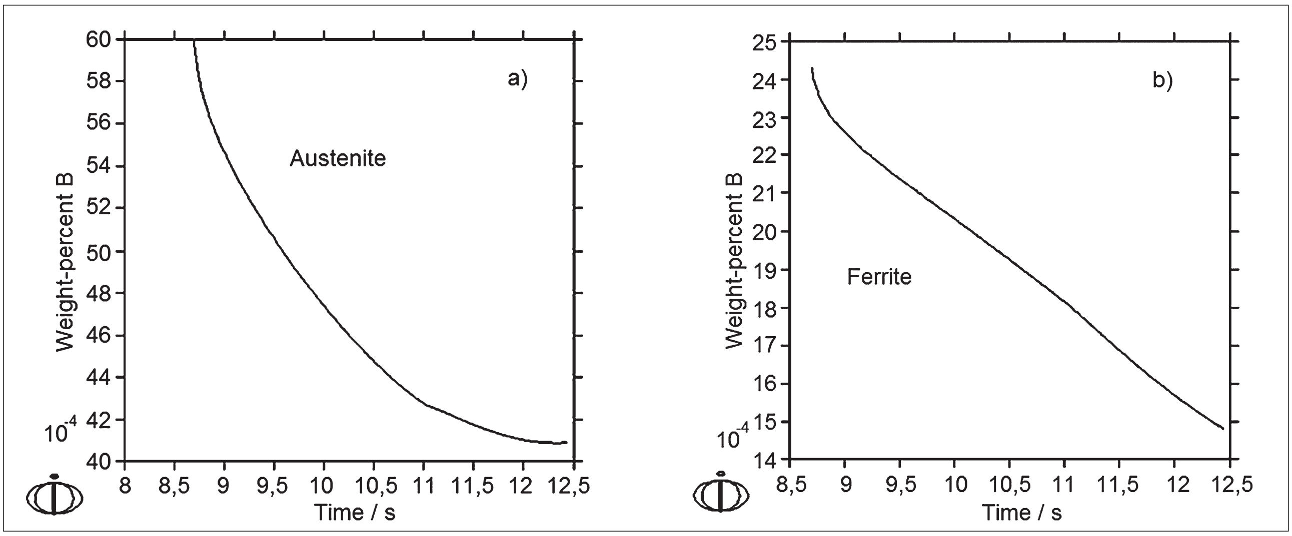

Figure 5 Concentration of B in austenite a) and ferrite b) in the grain boundary area γ/α at V_c = 50 °C/s

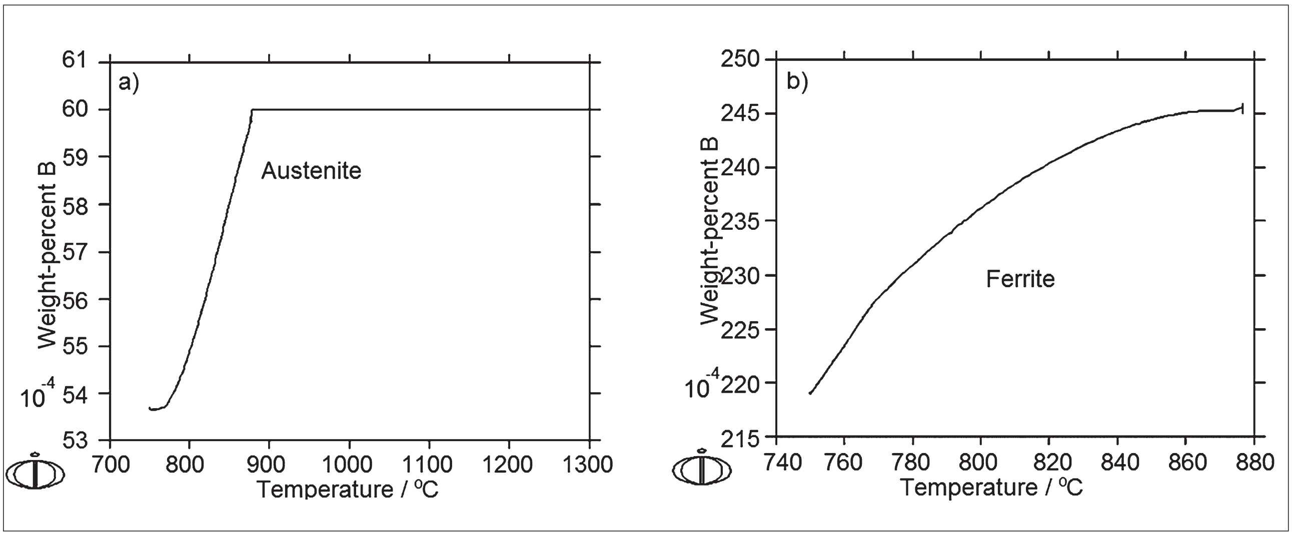

Figure 6 Concentration of B in austenite a) and ferrite b) in the grain boundary area γ/α at V_c = 10 °C/s

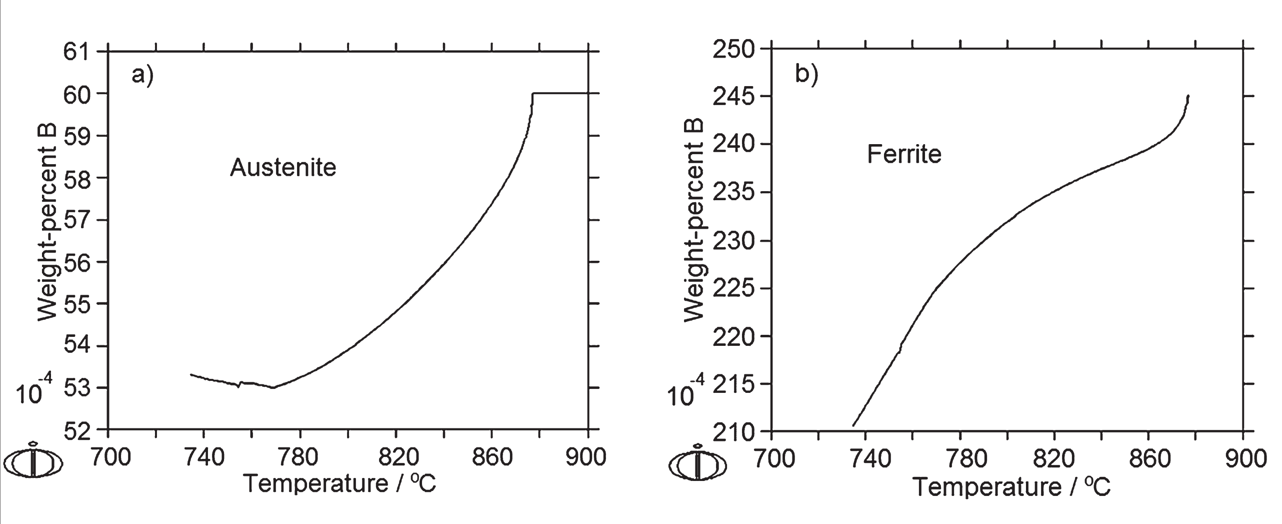

Figure 7 Concentration of B in austenite a) and ferrite b) in the grain boundary area γ/α at V_c = 1 °C/s

°C till A_{r3} = 875 °C at cooling rate 10 °C/s – Figure 6. Then it changed from 0,006 % B to 0,00535 % B at 750 °C while in ferrite from 0,0245 % B to 0,0218 % B.

CONCLUSIONS

1. Segregation of boron concentration in austenite and ferrite took place below temperature $A_{r3,}$ independently to applied cooling rate for simulation from temperature 1300 °C.
2. The concentration of boron in ferrite was four time greater than in austenite at given temperature below A_{r3}.
3. At higher cooling rate there was shorter distance of increased concentration of boron in ferrite.
4. The increase of the average grain diameter lowers free energy and retards nucleation of phases.

REFERENCES

[1] T. M. Wiliams: The segregation and effects of boron in an austenitic stainless steel; Materials Science Journal 6 (1972), 68 - 69.

[2] K. A. Taylor, S. S. Hansen: The boron hardenability effect in thermomechanically processed, direct-quenched 0,2 pct C steels; Metallurgical Transactions A 21A (1990), 1697 - 1708

[3] M. Ueno, T. Inone: Distribtion of boron at austenite grain boundaries and bainitic transformation in low carbon steels; Transformations ISIJ 13 (1973), 210 - 217.

[4] A. Lis, C. Kolan, P. Wieczorek, J. Lis: Wpływ segregacji boru na kinetykę przemian fazowych stali niskowęglowej; Hutnik-Wiadomoœci Hutnicze, (2009), 507 - 509 /in Polish/.

[5] S. R. Keown: Boron in steel; Scandinavian Journal of Metallurgy 2 (1973), 59 - 63.

[6] J. Agren: Carbon diffusion in fcc C-Fe; Scripta Met. 20 (1985), 1507 - 1510.

[7] Thermo-Calc Software: Volume data included Ion the TCFE4 database TCFE 4. (May 2006).

[8] A. Lis, J. Lis, N. Wolańska, C. Kolan, P. Wieczorek, M. Knapiński, H. Dyja: Ciągliwość na gorąco stali z borem i bez boru dla warunków ciągłego odlewania i walcowania stali; Grant Nr 3 TO8BO 19030, Politechnika Częstochowska 2009.

[9] M. X. Wang, L. X. He: Effect of boron on structure and properties of low carbon bainitic steels, ISIJ International, 42 (2002), Supplement, 38 - 46.

Note: Language consultant – Michał Szota, Czestochowa, Poland