THE EFFECT OF ALLOYING ELEMENTS ON THE TEMPERATURE RANGE OF PEARLITE TO AUSTENITE TRANSFORMATION IN LOW ALLOY HYPOEUTECTOID STEELS

PAWŁOWSKI Bogdan[1], BAŁA Piotr[1,2], DZIURKA Rafał[1]

[1]AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Cracow, Poland, EU

[2]AGH University of Science and Technology, Academic Centre of Materials and Nanotechnology, Cracow, Poland, EU

Abstract

The formation of austenite above A_1 temperature plays very important role in the heat treatment of hypo-eutectoid steels, especially automotive DP steels. It is widely accepted that the formation of austenite during intercritical annealing takes place in three stages: 1 - very rapid pearlite to austenite transformation, 2 - slower growth of austenite into ferrite, 3 - slow final equilibrium of ferrite and austenite. According to the literature data, important factors that influence the phase transformation kinetics are the cementite morphology, the grain size and the heating rate.

In this work, experimental results of dilatometric examinations of low alloy normalized hypo-eutectoid steels show that during heating at the same rate, temperature range of pearlite to austenite transformation strongly depends on the amount of alloying elements and whether they are ferrite or austenite stabilizers. ThermoCalc and DICTRA computational tools were also used to calculate the eutectoid regions of the equilibrium phase diagrams for some low alloy steels.

Keywords: Hypo-eutectoid steels, phase transformation, pearlite, austenite, critical temperatures

1. INTRODUCTION

The austenite formation in hypo-eutectoid steels during continuous heating consists of two phenomena: pearlite dissolution and pro-eutectoid ferrite to austenite transformation The pearlite to austenite transformation (pearlite dissolution) start temperature during heating is described as Ac_{1s} (Ar_{1s} during cooling) and pearlite to austenite transformation finish temperature is described as Ac_{1f} (Ar_{1f} during cooling) [1-5]. Such split of the A_1 transformation temperature during heating (and cooling) of steels (hypo-eutectoid, eutectoid and hypereutectoid) is because in steels, contrary to the iron-carbon binary system, eutectoid transformation does not take place at constant temperature (according to the Gibbs' phase rule for binary system the number of degrees of freedom for eutectoid transformation is equal zero) but at certain temperature range. For equilibrium phase diagrams (for iron-carbon-alloying element system) A_1 transformation line splits into two lines labeled $A_{1(L)}$ (L - lower) and $A_{1(U)}$ (U - upper) as it is shown in **Fig. 1**, where X represents a steel alloying element which causes the A_3 and A_{cm} lines to shift and the A_1 line to split into A_1(L) and A_1(U) [6].

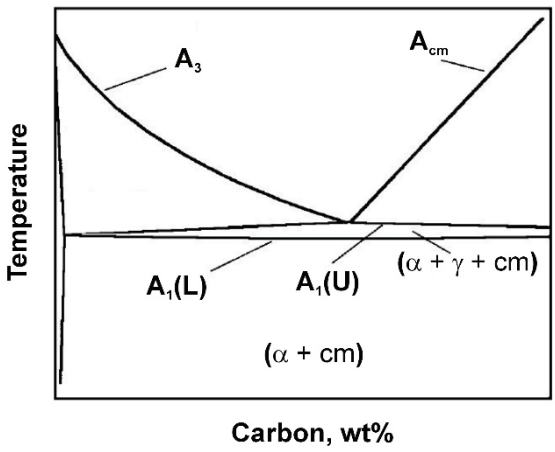


Fig. 1 Ternary Fe-C-*X* phase diagram [6]

To simplify things, the split of the A_1 is often ignored, and the shift of the lines is characterized by determining how the added elements shift the temperature of the A_1 and the composition of the pearlite point [6]. However, the Ac_{1f} temperature determines the start of the coexistence range of ferrite and austenite during heating (as

well Ar_{1f} the temperature determines the finish of this range during cooling) in hypo-eutectoid steels. The accurate determination of this coexistence range of ferrite and austenite (i.e. determination of temperatures Ac_{1f} and Ac_3, so-called - among others - critical points or critical temperatures) is of great importance in the industrial heat treatment of newer types of sheet steels, such as DP (Dual Phase) and TRIP (Transformation Induced Plasticity) steels, which were designed to pass through phase field (intercritical annealing region), with the austenite transforming to martensite on subsequent cooling to room temperature [7-9].

As phase transformations occurring in steels are accompanied by expansion or shrinkage, the most accurate means whereby the characteristic temperatures of austenite formation during continuous heating can be determined by dilatometry, however in some cases the use of dilatometer firmware may lead to improper interpretation of dilatometric data for cooling transformation in steels, as it is described in Ref. [10].

In this work, experimental results of dilatometric examinations of low alloy normalized hypo-eutectoid steels (during continuous heating) show that during heating at the same rate, temperature range of pearlite to austenite transformation strongly depends on the amount of alloying elements and whether they are ferrite or austenite stabilizers. ThermoCalc and DICTRA computational tools were also used to calculate the eutectoid regions of the equilibrium phase diagrams for some low alloy hypo-eutectoid steels.

2. EXPERIMENTAL

To estimate the influence of chemical composition of hypo-eutectoid steel on the temperature range of pearlite to austenite transformation, results of dilatometric investigations of 88 different hypo-eutectoid steel grades (performed by use of Adamel Lhomargy DT1000 and Linseis RITA L78 dilatometers in the Faculty of Metals Engineering and Industrial Computer Science, AGH University of Science and Technology, Cracow) were collected (chemical composition, Ac_{1s} and Ac_{1f} temperature). In any case the heating rate was 0.05 deg/s and before test samples were normalized according to the rules for individual grades. The ranges of the mass concentrations of elements for investigated steels are included in **Table 1**. The typical heating dilatogram (red) for structural C35 steel is presented in **Fig. 2** with the calculated differential curve (green).

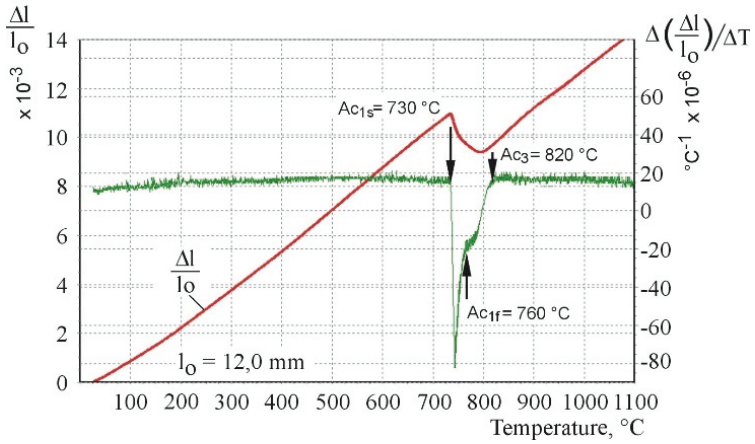


Fig. 2 Critical temperatures marked on the heating dilatogram of C35 steel, DT 1000 dilatometer

Table 1 Ranges of mass concentrations of the elements for the 88 analysed hypo-eutectoid steel

	Mass concentration of the element (%)						
Range	C	Mn	Si	Cr	Ni	Mo	V
Min.	0.06	0.12	0.01	0.01	0.00	0.00	0.00
Max.	0.62	2.94	1.21	2.04	1.05	0.68	0.77

Developed in this way data set was analysed using statistics and analytics software package Statistica 10 developed by StatSoft [11]. Additionally, ThermoCalc 4.1 and DICTRA computational tools were also used to calculate the eutectoid regions of the sample ternary Fe-C-X equilibrium phase diagrams, where X was manganese as γ stabilizer and chromium as α stabilizer in next case. In order to better analysis the effect of manganese and chromium content, their maximum mass concentration used in calculations was increased to 4 wt. % while their concentration in dilatometrically investigated steels did not exceed 2.94 % for manganese and 2.04 % for chromium, as it is shown in **Table 1**.

3. RESULTS AND DISSCUSION

Based on the collected experimental data (chemical composition, Ac_{1s} and Ac_{1f} temperature) the effect of the austenite stabilizers (carbon, manganese and nickel) on the temperature range of pearlite to austenite transformation is shown in **Fig. 3a**. Similarly, the effect of the ferrite stabilizers (silicon, chromium, molybdenum and vanadium) is shown in **Fig. 3b**.

a) b)

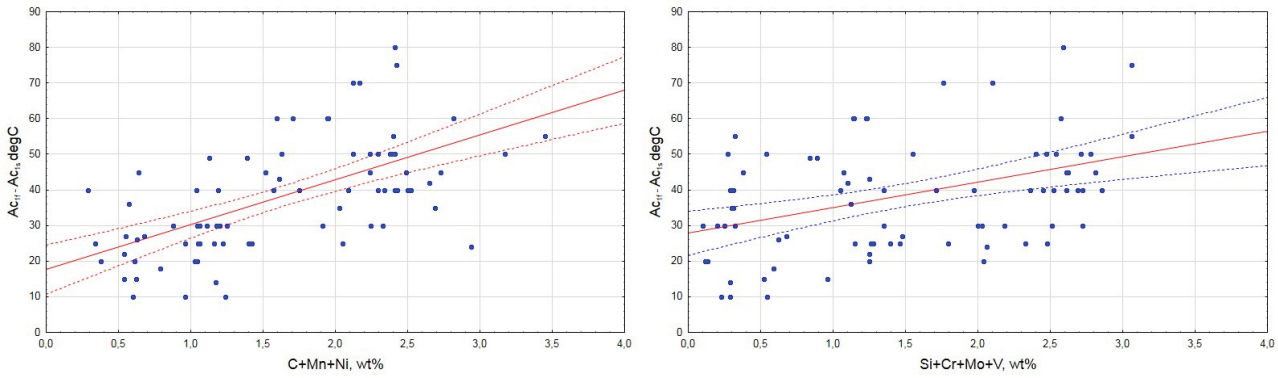
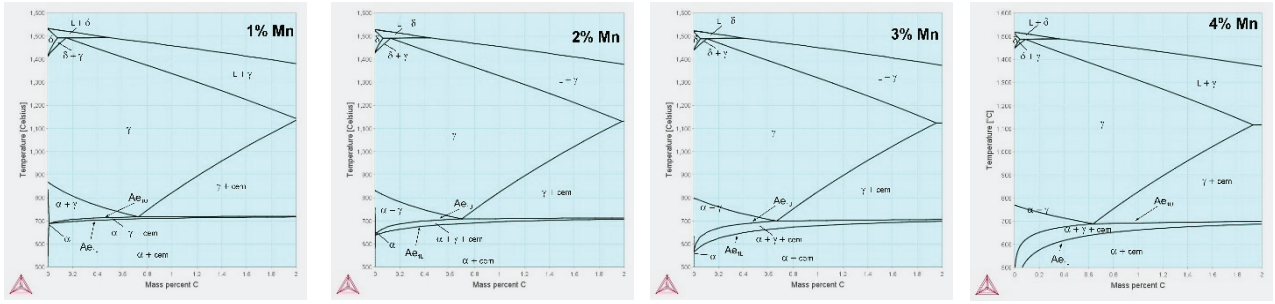


Fig. 3 The effect of the austenite (a) and ferrite (b) stabilizers on the temperature range of pearlite to austenite transformation (solid lines - regression lines, dotted lines - lower and upper confidence limit 95%)

As it can be seen in **Fig. 3**, the austenite stabilizers broaden the temperature range of pearlite to austenite transformation more strongly than ferrite stabilizers. This observation is confirmed by sample calculations made by use of ThermoCalc 4.1 software, presented in **Figs. 4-5**.

a) b) c) d)



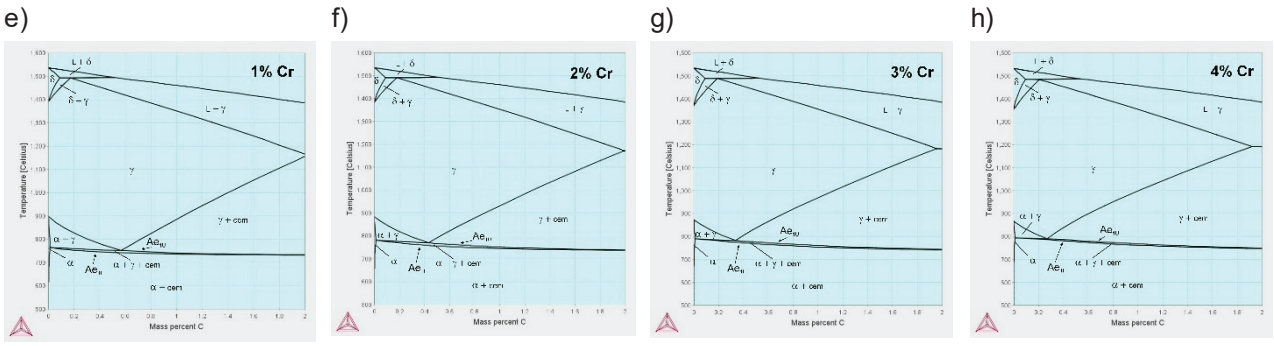


Fig. 4 Sample ternary Fe-C-X equilibrium phase diagrams: a-d) Fe-C-Mn, e-h) Fe-C-Cr (ThermoCalc)

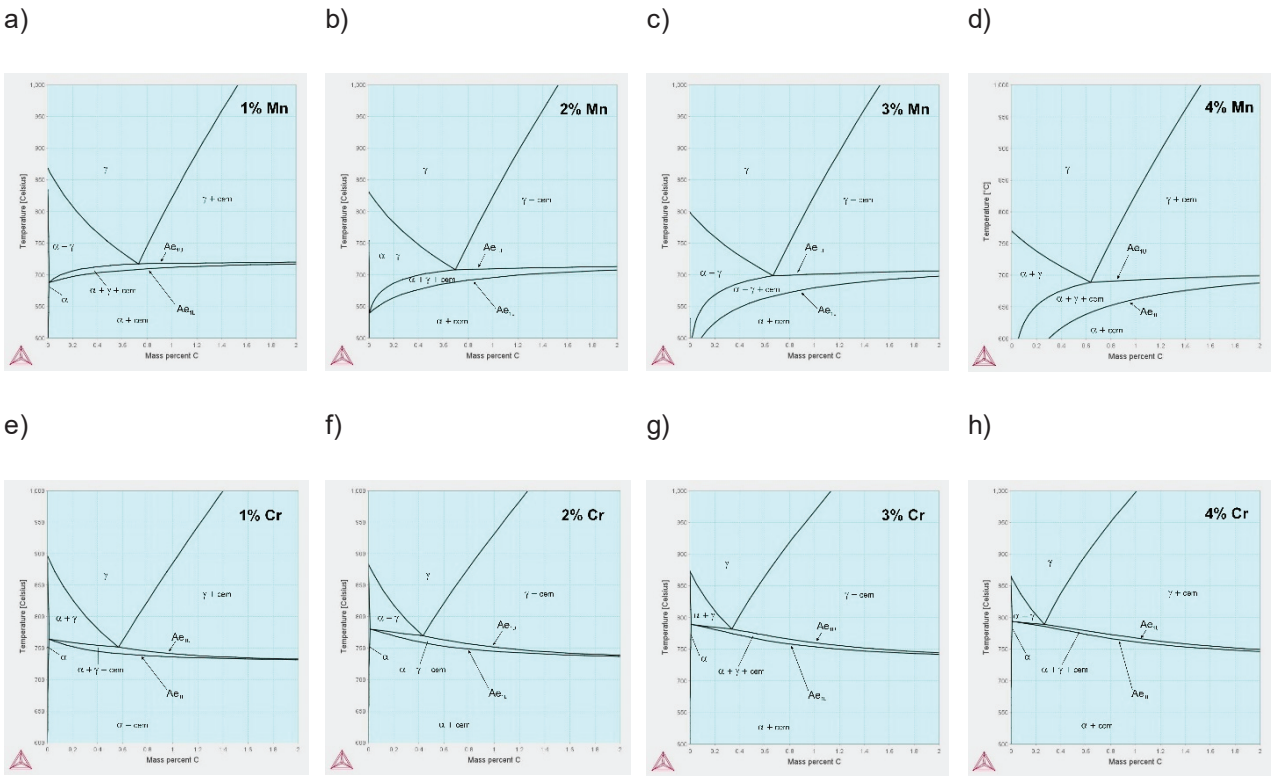


Fig. 5 Eutectoid region of Fe-C-X equilibrium phase diagrams: a-d) Fe-C-Mn, e-h) Fe-C-Cr (ThermoCalc)

4. CONCLUSIONS

The results presented in this work proved that temperature range of pearlite to austenite transformation strongly depends on the amount of alloying elements in steels. For elements which are austenite stabilizers (carbon, manganese, nickel - the contents of these elements were analysed in this work) broadening the temperature range between Ac_{1s} and Ac_{1f} (results from dilatometric investigations) is greater than for the ferrite stabilizing elements (silicon, chromium, molybdenum, vanadium) during heating at the same rate. Such conclusion was confirmed by performed calculations of the eutectoid regions of the sample ternary Fe-C-X equilibrium phase diagrams (by use of ThermoCalc 4.1 software), where X was manganese as austenite stabilizer and chromium as ferrite stabilizer in next case. The reason of such effect of alloying elements on the temperature range of pearlite to austenite transformation is slower (compared to carbon) diffusion of alloying

elements in steels. In steels, contrary to the iron-carbon binary system, eutectoid transformation requires also a redistribution of alloying elements atoms.

ACKNOWLEDGEMENTS

Financial support of the Ministry of Science and Higher Education is gratefully acknowledged (AGH University of Science and Technology statutory research project no. 11.11.110.299).

REFERENCES

[1] PAWŁOWSKI B. Determination of critical points of hypo-eutectoid steel. Archives of Metallurgy and Materials, Vol. 57, No. 4, 2012, pp.957-962.

[2] SURM H., KESSLER O.,HOFFMANN, ZOCH H.-W. Modelling of austenitising with no-constant heating rate in hypereutectoid steels. International Journal of Microstructure and Material Properties, Vol. 3, No. 1, 2008, pp.35-48.

[3] YAN F., SHI H., JIN B., FAN J., XU Z. Microstructure evaluation during hot rolling and heat treatment of the spray formed Vanadis 4 cold work steel. Materials Characterization, Vol. 59, 2008, pp.1007-1014.

[4] SURM H., KESSLER O., HUNKEL M., HOFFMANN F., MAYR P. Modelling of the ferrite/carbide → austenite transformation of hypoeutectoid and hypereutectoid steels. Journal de Physique, Vol. 120, 2004, pp.111-119.

[5] ZHANG J.G., SUN D.S., SHI H.S., XU H.B., WU J.S., WU X.F. Microstructure and continuous cooling transformation thermograms of spray formed GCr15 steel. Materials Science and Engineering, Vol. A236, 2002, pp.20-25.

[6] VERHOEVEN J.D. Steel Metallurgy for the Non-Metallurgist. ASM International, 2007, p.59.

[7] KRAUSS G. Steels: Processing, structure and performance. ASM International, 2005, p.221.

[8] GAJDA B., LIS A.K. The Characteristics of Microstructures and Properties of CMnAlSi TRIP Steel After Austenitization at (γ) AND (α+γ) Temperature Ranges. In METAL 2006: 15th International Metallurgical & Material Conference, Ostrava, TANGER, 2006, pp. 125-131.

[9] CALCAGNOTTO M., PONGE D., RAABE D. On the Effect of Manganese on Grain Size Stability and Hardenability in Ultrafine-Grained Ferrite/Martensite Dual-Phase Steels. Metallurgical and Materials Transactions, Vol. 43A, No. 1, 2012, pp.37-46.

[10] PAWŁOWSKI B., BAŁA P., DZIURKA R. Improper interpretation of dilatometric data for cooling transformation in steels. Archives of Metallurgy and Materials, Vol. 59, No.3, 2014, pp.1159-1161.

[11] www.statsoft.pl