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The kinetics of phase transformations of undercooled austenite of the 38MnCrNi6-4-4 hypoeutectoid steel

E. Rożniata*, R. Dziurka, R. Dąbrowski
Faculty of Metals Engineering and Industrial Computer Science,
AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Kraków, Poland
* Corresponding e-mail address: edyta.rozniata@agh.edu.pl

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Materials

ABSTRACT

Purpose: Present work corresponds to the research on the kinetic of phase transformation of undercooled austenite of 38MnCrNi6-4-4 hypoeutctoid steel. The kinetic of phase transformation of under cooled austenite of investigated alloy was presented on CCT diagram (continuous cooling transformation). Also the methodology of a dilatometric samples preparation and the method of the critical points determination were described.
Design/methodology/approach: The austenitising temperature was defined in a standard way i.e. 30-50°C higher than Ac3 temperature for hypoeutectoid steels. The technology of full annealing was proposed for the iron based alloy. The CCT diagram was made on the grounds of dilatograms recorded for samples cooled with various rates. The microstructure of each dilatometric sample was photographed after its cooling to the room temperature and the sample hardness was measured.
Findings: The test material has been hypoeutectoid steel. These steels represent a groups of alloy steels for quenching and tempering. The microstructure of test 38MnCrNi6-4-4 hypoeutectoid steel on CCT diagram changes depending on the cooling rate.
Research limitations/implications: The new hypoeutectoid steel and new CCT diagram.
Practical implications: The paper contains a description of one from a group of iron based model alloys with 0.35-0.40% carbon content. According to PN-EN 10027 standard this steel should have a symbol 38MnCrNi6-4-4.
Originality/value: The new hypoeutectoid steel (Mn-Cr-Ni iron based model alloy).
Keywords: I base alloy; Kinetic phase transformations of undercooled austenite; CCT diagram; Hypoeutectoid steel

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1. Introduction

The aim of this study was to determine the appropriate austenitizing temperature T_A of 38MnCrNi6-4-4 hypoeutectoid steel and the kinetic of phase transformation of undercooled austenite of tested steel [1-10]. These steels represent a groups of alloy steels for quenching and tempering [11-14]. The hypoeutectoid steels belong to elementary materials used for production of construction for metal forming. The basic requirements for these steels are: sufficient hardenability, wear resistance as high as possible strength and fracture toughness.

The analysis of microgradients of chemical compositions seems to be important for these steels. It should be noted that the interaction of two or more alloying elements is significantly different from the sum of effects of these elements added separately. The most important may be the common effect of molybdenum and chromium, molybdenum and nickel, chromium and nickel, manganese and chromium, manganese and nickel, manganese and molybdenum, manganese and cobalt. Until now, the impact of each element was considered separately, only sometimes, pointing to a group of alloys, in which this interaction was evaluated.

Therefore, this work concerns the kinetics of transformations of undercooled austenite in hypoeutectoid steels. The tests are aimed at a preliminary analysis of the impact of three elements such as manganese, chromium and nickel on the microstructure of the tested alloy.

2. Experimental procedure

The chemical composition of the hypoeutectoid steel was designed in the Laboratory of Phase Transformations, Department of Physical and Powder Metallurgy, AGH University of Science and Technology.

The microstructure of the investigated material was examined by the light microscope Axiovert 200 MAT.

The hardness measurements were performed with the Vickers HPO250 apparatus.

The research of kinetics of the phase transformations of the undercooled austenite has been performed with a dilatometric method. The Continuous- Cooling-Transformation (CCT) diagram (for steel austenitized at 830°C) was made by means of a L78R.I.T.A. optical dilatometer. The samples (Φ3x10 mm) were heated with the rate of 3°C/s to the temperature given above, held for 1200 s and next cooled down with different rates, governed bz a regulated blow of argon.

3. Material for investigations

This hypoeutectoid steel was melted and cast in the Faculty of Foundry Engineering of AGH University of Science and Technology in Cracow then reforged in INTECH-MET in Gliwice. According to PN-EN 10027 standard this steel should have a symbol 38MnCrNi6-4-4. Chemical compositions of this steel is given in Table 1.

Table 1.
The chemical composition (wt. %) of the investigated steel

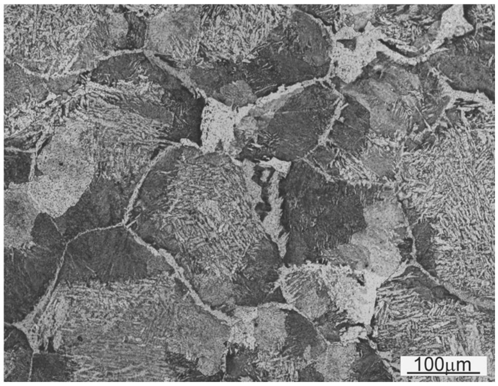
C	Mn	Cr	Ni	Si	P	S	Cu	Al
0.38	1.56	1.10	0.98	0.09	<0.001	<0.001	0.042	0.014

The microstructure of tested steel after forging is shown in Fig. 1. It is clear that the microstructure of the tested alloy after forging consists of ferrite and pearlite. Ferrite is precipitated along grain boundaries of the former austenite in Widmannstätten structure.

In hypoeutectoid steels the Widmannstätten structure, in terms of morphology, is characterized by plates (needles) of ferrite, which are arranged at angles of 60° and 120°. Hardness of the studied steel after forging is 205 HV30.

In order to determine the correct critical temperatures (break points) for the investigated 38MnCrNi6-4-4 steel after forging, the heating at the rate of 0.05°C/s to a temperature of 1100°C and then cooling at a rate of 1°C/s to a room temperature with dilatometric method was performed. The determined critical temperature A_{C3} of the steel (after forging) was as following: 780°C.

a)



b)

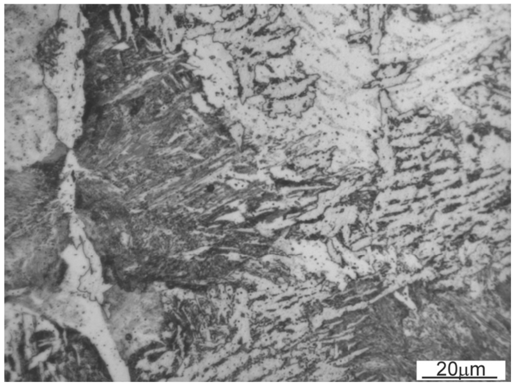


Fig. 1. Microstructure of the 38MnCrNi6-4-4 steel after reforging. Hardness 205 HV30. Etched by 3% nital

The next step of research was to make a full annealing, which was performed in a laboratory oven Carbolite RHF16/19. A sample of the tested alloy was heated to a temperature of 820°C, hold 2 hours, and then cooled at a rate of 3°C/min to 500°C and further cooled at a rate of 30°C/min to a room temperature.

Microstructure of 38MnCrNi6-4-4 after such annealing is shown in Fig. 2. It is clear that the microstructure is ferro-pearlitic. Ferrite is precipitated in Widmannstätten structure, similarly as in case of steel after forging. Hardness of the studied steel is 199HV30.

Again, a set of break points for the investigated 38MnCrNi6-4-4 hypoeutectoid steel after such annealing was determined, which is respectively: Ac_{1s} = 720°C, Ac_{1f} = 750°C, Ac_3 = 780°C.

Fig. 3 presents the heating curve and the corresponding differential curve of the tested alloy after full annealing with marked critical temperatures.

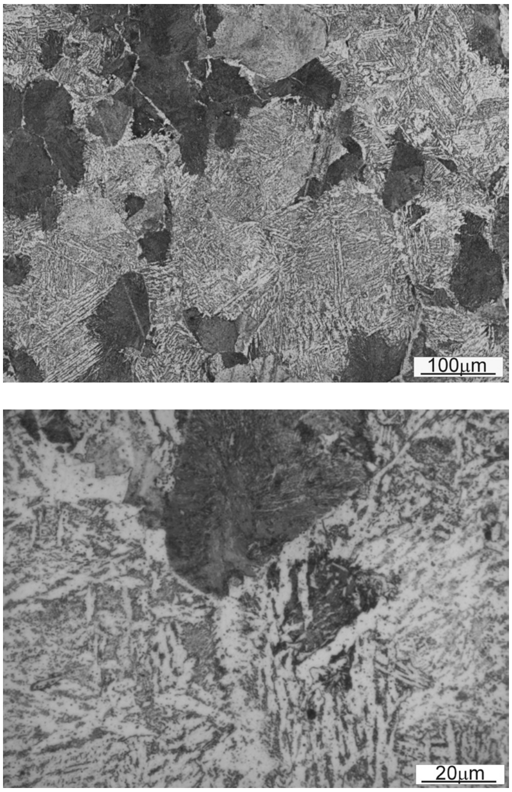


Fig. 2. Microstructure of 38MnCrNi6-4-4 after full annealing. Etched with 3% nital

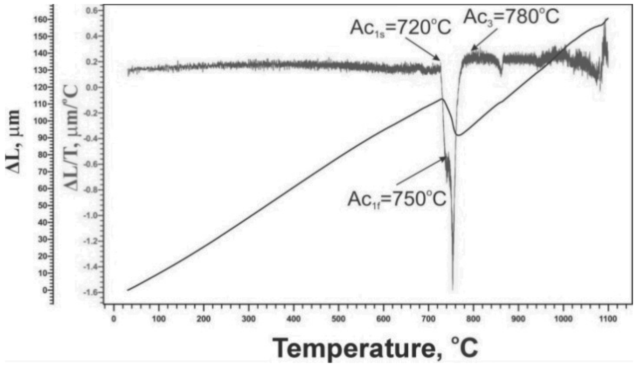


Fig. 3. Heating curve of 38MnCrNi6-4-4 after full annealing to temperature of 1100°C and corresponding differential curve with marked break points

The next step of research was to determine the kinetics of phase transformations of undercooled austenite in tested steel with dilatometric method. Individual cooling curves were differentiated, what allowed to define precisely the temperatures of the beginning and the end of transformations. Austenitizing temperature was assumed to be T_A = 830°C, which is 50°C higher than the Ac_3 temperature for the hypoeutectoid steel.

To draw a CCT diagram the samples with dimensions Φ3 x 10 mm in annealed condition were used. Samples were heated at a rate of 5°C/s to austenitizing temperature T_A = 830°C, annealed for 20 min and then cooled at different rates (ranging from 25°C/s to 0.33°C/s).

4. Research results and discussion

Fig. 4 contains a CCT diagram of 38MnCrNi6-4-4 steel after austenitizing at temperatures T_A = 830°C.

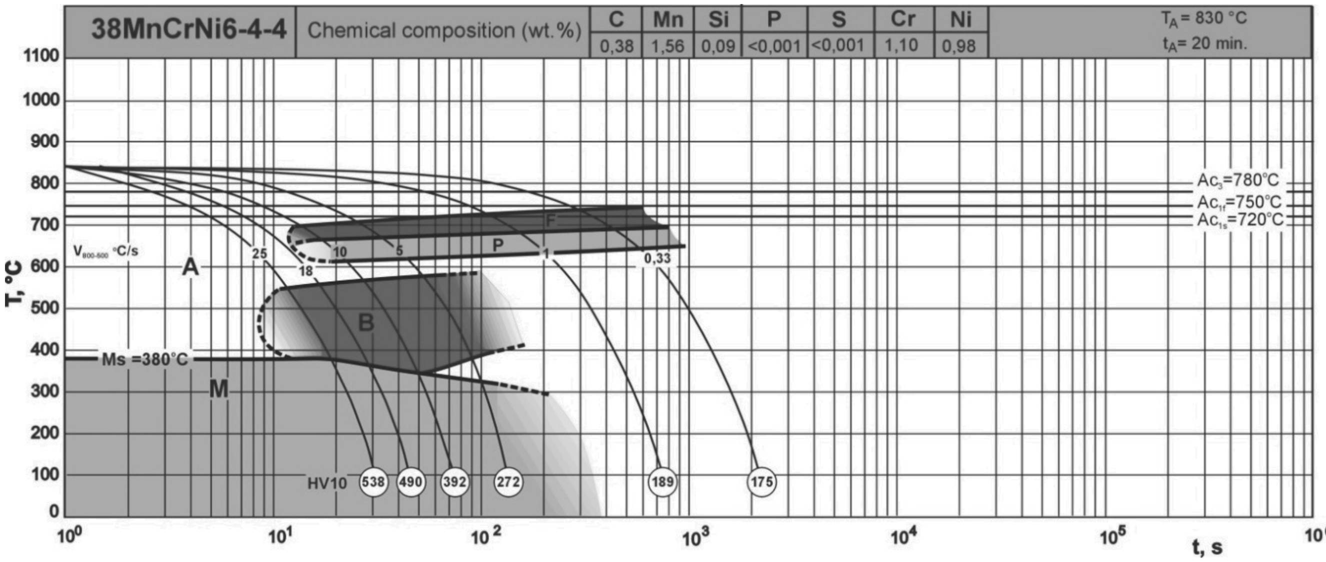
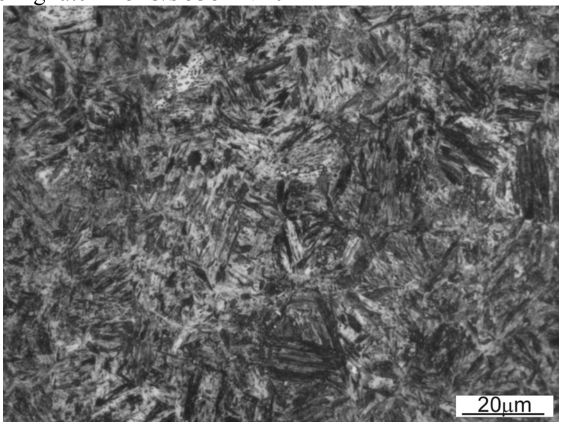
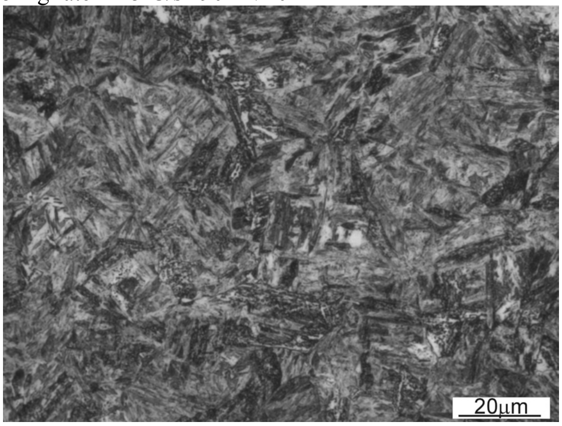


Fig. 4. The CCT diagram of 38MnCrNi6-4-4 steel

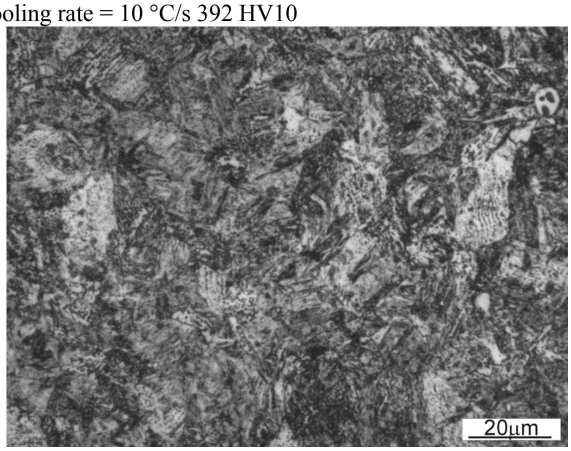
a) Cooling rate = 25°C/s 538 HV10



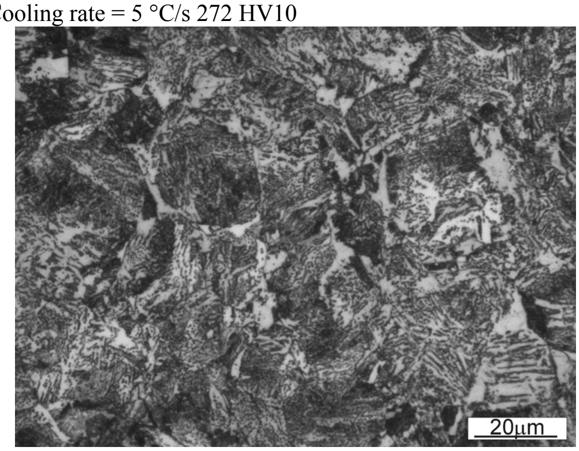
b) Cooling rate = 18°C/s 490 HV10



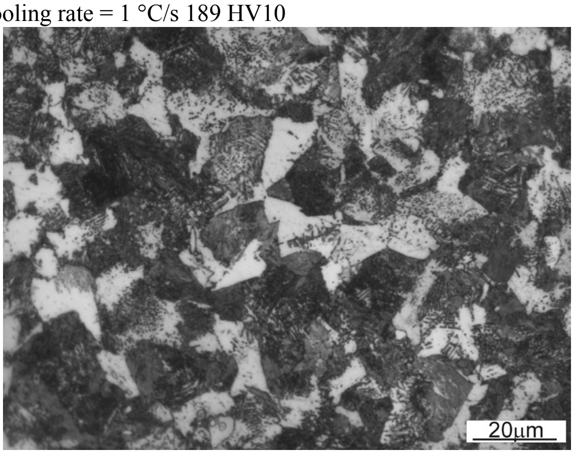
c) Cooling rate = 10 °C/s 392 HV10



d) Cooling rate = 5 °C/s 272 HV10



e) Cooling rate = 1 °C/s 189 HV10



f) Cooling rate = 0.33 °C/s 175 HV10

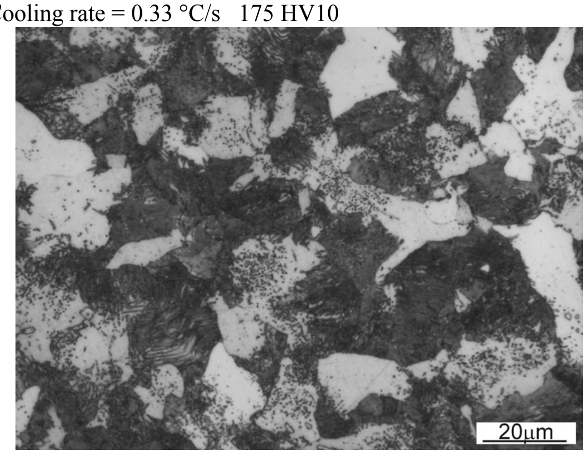


Fig. 5. Microstructures of the 38MnCrNi6-4-4 hypoeutectoid steel after dilatometric test. Etched with 3% nital

As one can see the curves of transitions beginning are continuous, i.e. the maxima of diffusion transition rate (i.e. pearlitic and ferritic) converge. On the curve of diffusion transitions end there is visible a distinct time elongation of these transitions. Bainitic transformation begins earlier and is separated from the diffusion transformations by austenite range. At the end of the transition curve marked by a prolonged diffusion time of transition.

For the austenitizing temperature $T_A = 830°C$ the beginning of ferrite and pearlite precipitation (diffusion transitions) was observed on cooling curve 10°C/s, while a „nose" of bainitic transition is observed at the cooling rate of 25°C/s. The beginning of the martensitic transition of 38MnCrNi6-4-4 test steel is $M_s = 320°C$.

It should be noted that manganese and nickel, are the elements that increase A_4 and decrease A_3 temperatures and with iron form diagrams with an open field of austenite, therefore they are called austenite-generating elements. Different (opposite) role is played by above mentioned elements in terms of transition kinetics of undercooled austenite and hardenability of steel. That is, all elements (among others Mn, Ni, Cr) apart from Co only, increase the incubation period of austenite decomposition, and thus shift the curves of transitions beginning to the right (towards extended times). Since the critical cooling rate V_{kr} is associated with austenite stability, therefore it can be concluded that all the elements (including Mn) increases the hardenability of steel. Only cobalt in some cases decreases the hardenability of steel.

Manganese, chromium and nickel result in shift of curves of transitions beginning of undercooled austenite to the right on CCT diagrams (compare with Fig. 4), but don't change its characteristics (i.e. they still have the shape of letter C).

The CCT diagram (Fig. 4) is supported by detailed metallographic documentation, which is given in Fig. 5.

5. Summary and conclusions

Within the frames of research performed on hypoeutectoid steel also the evaluation of transition kinetics of undercooled austenite was made. A CCT diagram of tested steel was prepared for the austenitizing temperature T_A=830°C, which was supported by metallographic documentation and hardness measurements.

Tests performed and the obtained results allowed to state that application of the austenitizing temperature T_A= 830°C (about 50°C above the Ac_3 temperature) for 38MnCrNi6-4-4 steel did not change the nature of the transition curves for the diffusion transitions (pearlitic and ferritic) nor the intermediate one (bainitic) - they have the shape of the letter "C". In addition, Mn and Ni as austenite-generating elements play in the transition kinetics of undercooled austenite different role. Also, Cr (as ferrite-generating element) increases the hardenability of steel.

It should be added that the bainite which is present in the microstructure of tested steel according to the 350°C temperature criterion [15] may be divided into upper and lower bainite. The before mentioned types of bainite are different from each other in terms of morphology. Upper bainite is created above 350°C and consists of ferrite grains solutioned with carbon, with carbides present between them. Upper bainite has a feather type nature and is characterized by very low cracking resistance. On the other hand the lower bainite (created below 350°C) is a strip type. It has a nature of strips of solutioned ferrite with carbides inside and is similar to martensitic structure [15].

It has been demonstrated that new steel, after applying of a proper heat treatment, poseses properties. It is anticipated to use this steel for manufacturing of case-hardened constructions.

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