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The kinetics of phase transformations of undercooled austenite of the Mn-Ni iron based model alloy

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Materials

ABSTRACT

Purpose: Present work corresponds to the research on the kinetics of phase transformations of undercooled austenite of Mn-Ni iron based model alloy. The kinetics of phase transformations of undercooled 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 Ac_3 temperature for model alloy. A technique of full annealing was proposed for the model alloy. The CCT diagrams were made on the basis of dilatograms recorded for samples cooled at various rates. The microstructure of each dilatometric sample was photographed after its cooling to the room temperature and the hardness of the samples was measured.

Findings: The test material was a Mn-Ni hypoeutectoid iron based alloy. The microstructure of test Mn-Ni alloy on CCT diagram changes depending on the cooling rate. At the cooling rates of 10°C/s and 5°C/s there is ferrite in Widmannstätten structure present in the structure of tested alloy.

Research limitations/implications: The new Mn-Ni iron based model alloy and a 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 38MnNi6-4.

Originality/value: The new Mn-Ni iron based model alloy.

Keywords: Iron based alloy; Kinetics of phase transformations of undercooled austenite; CCT diagram; Model alloy

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1. Introduction

Good mechanical properties of steels are achieved by their chemical composition and the microstructure obtained by appropriately designed heat treatment [1-8]. Therefore, these steels should have a suitably complex chemical composition, carbon content from 0.35% to 0.40% and the specific kinetics of phase transformation of supercooled austenite [9-16]. These alloys represent large groups of alloy steels designated for quenching and tempering, which are subjected to high requirements regarding Re/Rm ratio as well as ductility and toughness.

The analysis of microgradients of chemical compositions seems to be important for these alloys. 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. This mutual interaction of various elements on the effects of the others, may be the basis for among others assessment of the impact magnitude of each of them on e.g. hardenability of steel in the conditions of the presence of even one or several other elements in the above mentioned alloys with iron matrix. Until now, the impact of each element was considered separately, only sometimes, pointing to a group of alloys, in which this interaction was evaluated [17-20].

Therefore, this work concerns the kinetics of phase transformations of undercooled austenite in manganese – nickel iron based model alloy. The tests are aimed at a preliminary analysis of the effect of two elements such as manganese and nickel on the microstructure of the tested alloy.

2. Experimental procedure

The chemical composition of the model alloy 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 using the light microscope Axiovert 200 MAT

The hardness measurements were performed with the Vickers HPO250 apparatus.

The dilatometric measurements were performed with the L78R.I.T.A. dilatometer.

3. Material for investigations

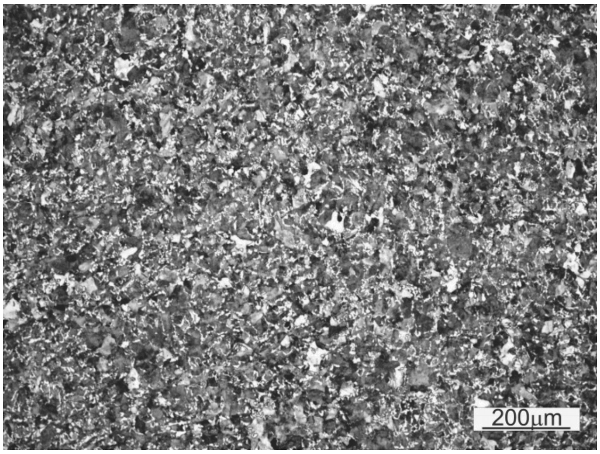
This iron based model alloy was melted and cast in the Faculty of Foundry Engineering of AGH University of Science and Technology in Cracow then reforged in INTECH-MET in Gliwice. According to PN-EN 10027 standard this steel should have a symbol 38MnNi6-4. Chemical compositions of this steel is given in Table 1.

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

C	Mn	Ni	Si	P	S	Cu	Al
0.38	1.49	1.01	0.022	<0.0010	0.0076	0.042	0.014

The microstructure of tested Mn-Ni alloy with iron matrix after forging is shown in Figure 1. It is clear that the microstructure of the tested alloy after forging consists of ferrite and pearlite, where ferrite is arranged on the former austenite grain boundaries. The hardness of the tested alloy after forging is 248 HV30.

a)



b)

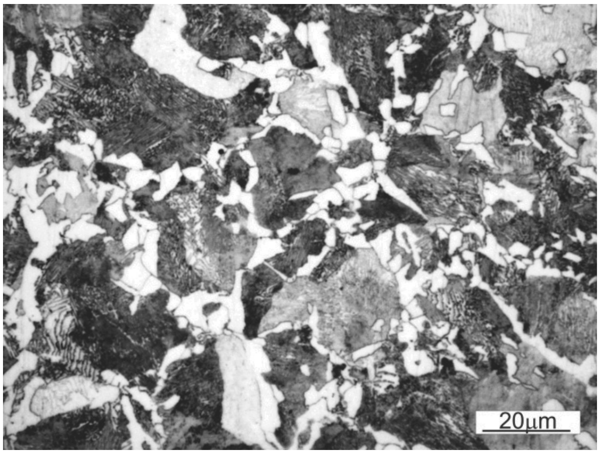


Fig. 1. Microstructure of Mn-Ni iron based model alloy after reforging. Etched with 2% nital

In order to determine the correct critical temperatures (break points) for the investigated Mn-Ni alloy 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 temperatures of the alloy were as following: Ac_{1s} = 680°C, Ac_{1f} = 705°C, Ac_3 = 820°C.

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 870°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 Mn-Ni model alloy after such annealing is shown in Figure 2. It is clear that the microstructure is ferro-pearlitic while tested alloy hardness after full annealing is 203 HV30.

Again, a set of break points for the investigated Mn-Ni alloy with iron matrix after such annealing was determined, which is respectively: Ac_{1s} = 690°C, Ac_{1f} = 705°C, Ac_3 = 790°C. Figure 3 presents the heating curve and the corresponding differential curve of the tested alloy after full annealing with marked critical temperatures.

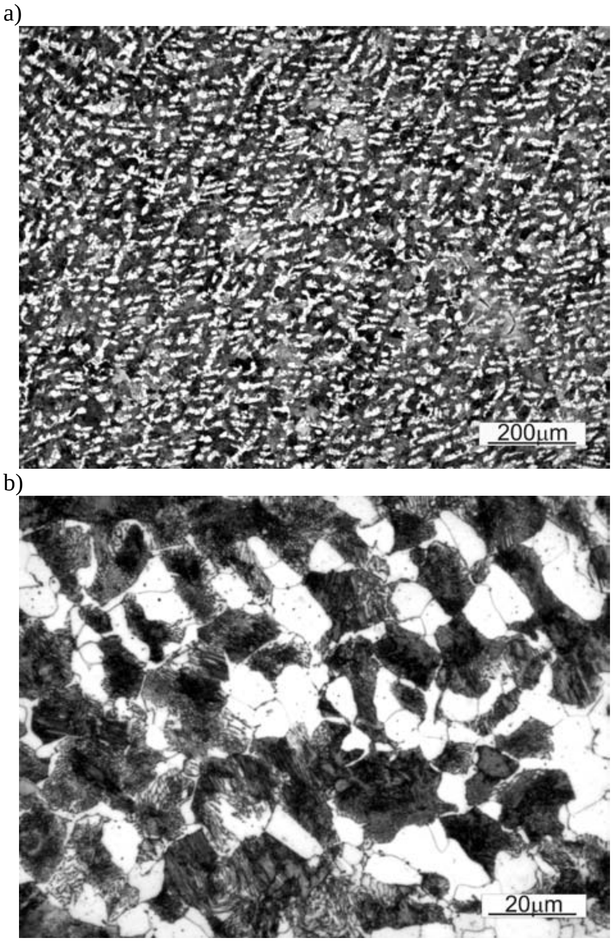


Fig. 2. Microstructure of Mn-Ni iron based model alloy after full annealing. Etched with 2% nital

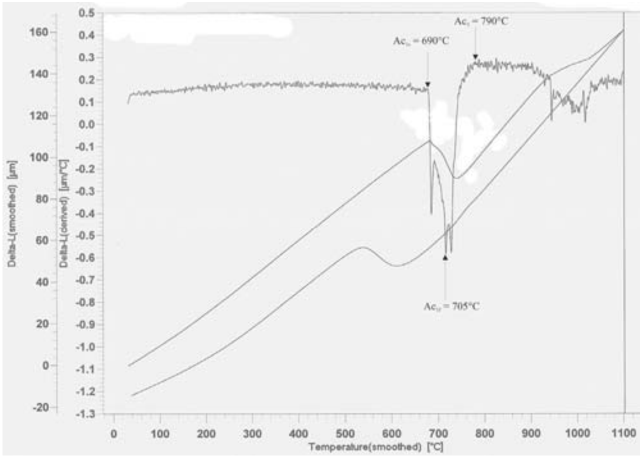


Fig. 3. Heating curve of Mn-Ni alloy after full annealing to temperature of 1100 °C and corresponding differential curve with marked break points

The next step of research was to determine the kinetics of phase transformations of supercooled austenite in model alloy 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 = 820°C, which is 30°C higher than the Ac_3 temperature for the test Mn-Ni alloy with the iron matrix.

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 = 820°C, annealed for 20 min and then cooled at different rates (ranging from 94°C/s to 0.17°C/s).

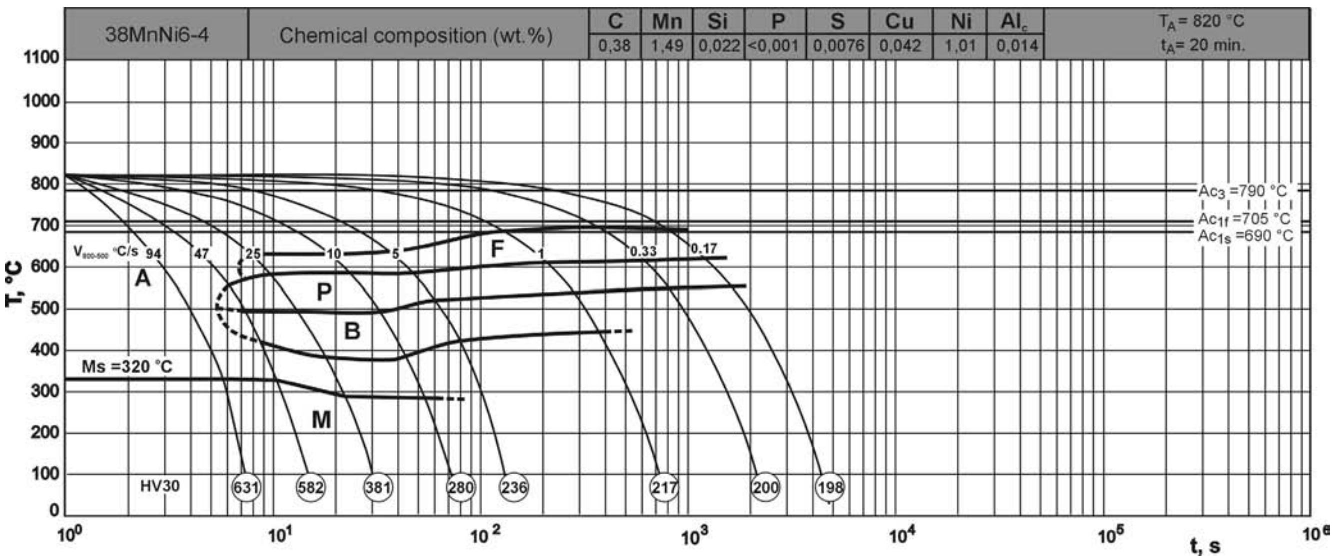
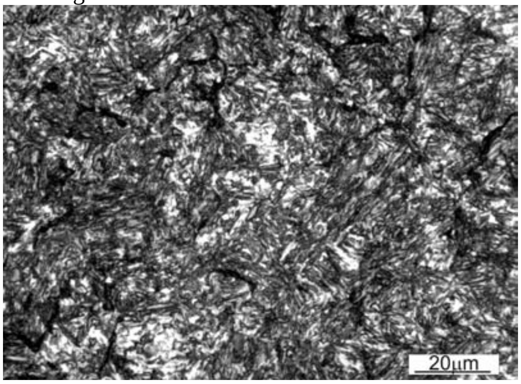
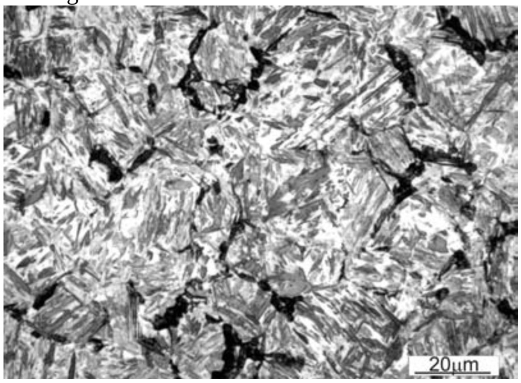


Fig. 4. The CCT diagram of Mn-Ni iron based model alloy

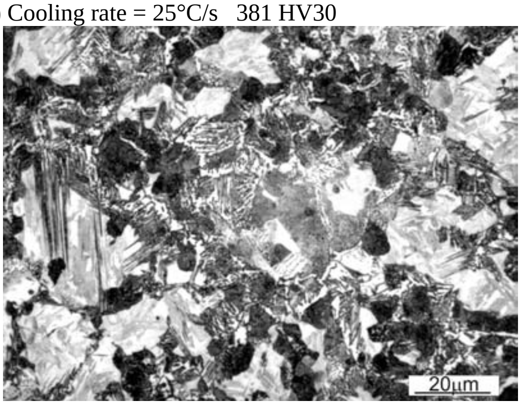
a) Cooling rate = 94°C/s   631 HV30



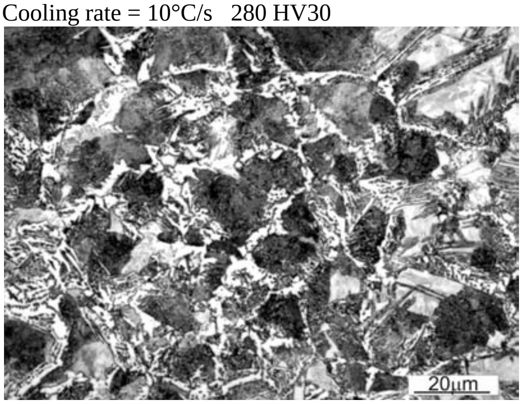
b) Cooling rate = 47°C/s   582 HV30



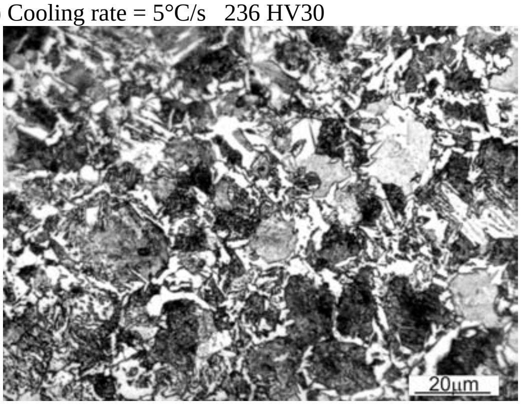
c) Cooling rate = 25°C/s   381 HV30



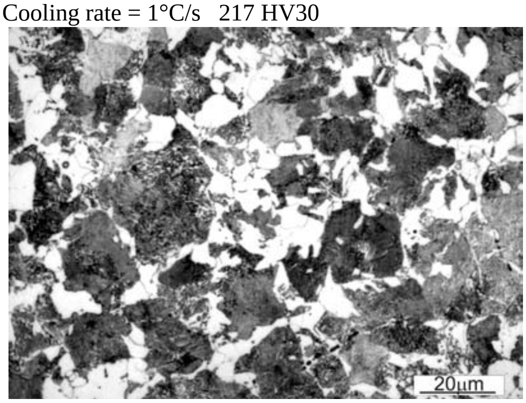
d) Cooling rate = 10°C/s   280 HV30



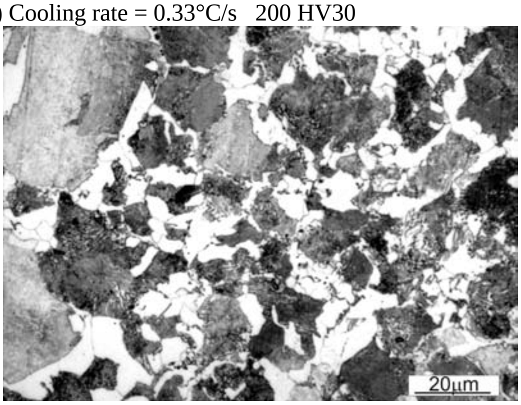
e) Cooling rate = 5°C/s   236 HV30



f) Cooling rate = 1°C/s   217 HV30



g) Cooling rate = 0.33°C/s   200 HV30



h) Cooling rate = 0.17°C/s   198 HV30

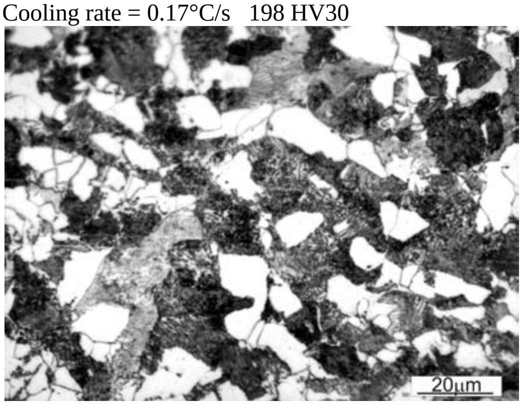


Fig. 5. Microstructures of the investigated alloy after dilatometric test. Samples cooled at various rates. Etched with 2% nital

4. Research results and discussion

Figure 4 contains a CCT diagram of tested Mn-Ni model alloy with the iron matrix after austenitizing at temperatures T_A = 820°C. It is a type II diagram (according to Wever, Rose [16]). That is the curves representing the beginning of transformation have the shape of the letter C, while at the ends of the curves the extended times of their end are indicated. For the austenitizing temperature of T_A = 820°C, the beginning of the transition of ferrite was observed on 25°C/s cooling curve. However the beginning of the pearlitic transformation (pearlite precipitation), as well as bainitic one was observed on cooling curve equal to 47°C/s. Beginning of the martensitic transformation for the investigated alloy is Ms = 320°C and decreases with decreasing cooling rate. It may be noticed that the diffusion transformations are shifted towards longer times, due to the large amounts of manganese and nickel – austenite-generating elements. This also results in "pushing" the diffusion transformations to lower temperatures.

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

As one can see, there is martensite present in the microstructure of the tested alloy samples cooled at the highest applied rate (i.e. 94°C/s). After applying the cooling rate of about 47°C/s there is, along with martensite, bainite and pearlite in small amounts appearing in the microstructure. However, after applying cooling rates ranging from 25°C/s-1°C/s the microstructure of the tested alloy consists of pearlite, ferrite and bainite in decreasing content. After applying the cooling rate of 10°C/s and 5°C/s the ferrite is present as Widmannstätten structure. At the slowest cooling rates (i.e. 0.33°C/s and 0.17°C/s) the microstructure of the investigated alloy is ferro-pearlitic.

5. Conclusions

Within the frames of the studies carried out on Mn-Ni model alloy with iron matrix the evaluation of the kinetics of phase transformation of supercooled austenite was performed. A CCT diagram of tested alloy was developed for austenitizing temperature equal to T_A = 820°C.

Studies performed and results obtained revealed that use of austenitizing temperature T_A = 820°C (30°C above the Ac_3 temperature) extended the times of transformation start of both diffusion (ferritic and pearlitic) and bainitic transformations. The interaction of two austenite-generating elements (Mn and Ni) also lowers the temperature of ferritic transformation.

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