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R. DZIURKA*, J. PACYNA*

INFLUENCE OF THE CARBON CONTENT ON THE KINETICS OF PHASE TRANSFORMATIONS DURING CONTINUOUS HEATING FROM AS-QUENCHED STATE IN A Cr-Mn-Mo MODEL ALLOYS

WPŁYW ZAWARTOŚCI WĘGLA NA KINETYKĘ PRZEMIAN FAZOWYCH PODCZAS NAGRZEWANIA ZE STANU ZAHARTOWANEGO W STOPACH MODELOWYCH Cr-Mn-Mo

The presented work concerns the research on the kinetics of phase transformations during continuous heating from as-quenched state of three Cr-Mn-Mo model alloys with a different carbon content. The kinetics of phase transformations during continuous heating of investigated alloys was presented on the CHT (Continuous, Heating, Transformation) diagrams.

The CHT diagrams were made on the grounds of dilatograms recorded for quenched samples, heated with various rates. Also the methodology of the dilatometric samples preparation and the method of the characteristic points determination was described.

The investigated alloys are the model alloys. Taking into account their chemical compositions the possibility of improving their properties by means of the heat treatment can be expected. The investigations of the carbon influence on microstructures of model alloys with Cr-Mn-Mo were carried out. Broadening the knowledge on the carbon influence on the kinetics of phase transformations during continuous heating from as-quenched state, will help in designing new alloys with a better properties.

Keywords: kinetic phase transformations during continuous heating from as-quenched state, ε-carbides, cementite, retained austenite, CHT diagrams, model alloys

Niniejsza praca zawiera badania kinetyki przemian fazowych przy nagrzewaniu ze stanu zahartowanego trzech modelowych stopów Cr-Mn-Mo o różnej zawartości węgla. Kinetyka przemian fazowych przy nagrzewaniu badanych stopów jest przedstawiona za pomocą wykresów CTP_c^O.

Wykresy CTP_c^O zostały wykonane na podstawie dylatogramów nagrzewania z różnymi szybkościami uprzednio zahartowanych próbek. Ponadto w pracy zamieszczono metodologię przygotowania próbek do badań dylatometrycznych i przykłady wyznaczania punktów charakterystycznych.

Badane stopy są stopami modelowymi. Biorąc pod uwagę ich składy chemiczne istnieje możliwość poprawy ich właściwości za pomocą obróbki cieplnej. W pracy została podjęta próba zbadania wpływu węgla na mikrostrukturę stopów Cr-Mn-Mo po odpuszczaniu. Niniejsze badania poszerzą wiedzę na temat wpływu węgla na kinetykę przemian fazowych przy nagrzewaniu ze stanu zahartowanego, co pomoże w projektowaniu nowych stopów o lepszych własnościach.

1. Introduction

A properly designed chemical composition and heat treatment conditions ensure that steels attain the required combination of properties, such as: high hardness and fracture toughness, high strength at elevated temperatures, structural stability, and resistance to formation of heat cracks [1÷8]. Carbon is not an alloying element. However, by a definition, it is present in steels. Along with a carbon content increase a strength and hardness are increasing, while a ductility and weldability of steel decreasing. A strength and hardness of martensite in steels depends mainly on a carbon content. Carbon also causes an increase of the steel hardening capacity. Steels of a higher carbon content in the tempered and as-quenched state have a high strength and crack resistance.

The results of investigations concerning the carbon influence on the steel microstructure and mechanical properties originate from fifties and sixties of the last century. Due to this over the past years, an extensive qualitative and quantitative research of the effects of various alloying elements on the microstructure and properties of ferrous alloys have been carried out at the Department of Physical and Powder Metallurgy, AGH [7,9,10]. This research was carried out with the use of model al-

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE, 30-059 KRAKÓW, 30 MICKIEWICZA AV., POLAND

loys, it means alloys in which the concentration of only one element was variable.

Time Temperature – Transformation (TTT) diagrams are the best tools, which allow to perform the analysis of phase transformations of undercooled austenite. From the practical point of view more important are the CCT diagrams (Continuous Cooling Transformation). In addition, in order to investigate precisely the kinetics of phase transformations during heating from as-quenched state the CHT (Continuous Heating (from as-quenched state) –Transformation) and IHT (Isothermal Heating Transformation) diagrams were created. With these diagrams the different changes occurring during tempering can be easily tracked. There are several publications in which the important information from these diagrams [1, 2 8-19] are presented.

The aim of the present work is to describe the kinetics of phase transformation, during continuous heating from as-quenched state of three Cr-Mn-Mo model alloys with a different carbon content, in the form of the CHT diagram.

2. Experimental procedure

The three steels used in this work are Cr-Mn-Mo model alloys with a different carbon content whose chemical composition was designed in the Department of Physical and Powder Metallurgy, AGH University of Science and Technology. These steels, melted and cast in the Institute of Ferrous Metallurgy in Gliwice then reforged in the INTECH-MET Company in Gliwice and supplied as bars of a rectangular cross-section of dimensions: 35x20 mm, constituted the material for investigations. Chemical compositions of these steels are given in Table 1.

The photographs of microstructures of investigated steels in a as-delivered condition (soft annealing after forging at 650°C for 10 hours) are presented in Fig. 1.

As it is seen, W I (Fig. 1 a) alloy in as-delivered condition had the structure consisting mainly of ferrite and very small areas of bainite. Whereas W II steel (Fig. 1b) was characterized by a microstructure consisting of bainite and pearlite, which carbides were partially coagulated. A microstructure of W III steel (Fig. 1c) was characteristic for the hypereutectoid steel, in addition to which carbides – both in pearlite and hypereutectoid ones (forming network) were partially coagulated.

Before the beginning of examinations it is necessary to apply an adequate heat treatment to have the material in a state near the equilibrium one. Therefore the first melt was undergoing the normalizing annealing, for the second melt the full annealing was proposed, and for the last one – W III – the technology of soft annealing was applied.

The austenitising temperature was assumed, in a standard way on the bases of data from [20], which means higher by 50°C than Ac_3 temperature for W I and W II steel and 50°C higher than Ac_{1f} temperature for W III steel. Also the cooling rates for hardenig the steels were chosen based on the above mentioned studies.

TABLE 1

The chemical composition (wt. %) of the investigated alloys

	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Fe
W I	**0,05**	1,58	0,13	0,009	0,009	1,90	0,01	0,28	0,17	0,022	bal.
W II	**0,30**	1,43	0,14	0,014	0,007	1,78	0,02	0,25	0,19	0,021	bal.
W III	**0,99**	1,51	0,13	0,009	0,012	1,88	0,01	0,27	0,17	0,021	bal.

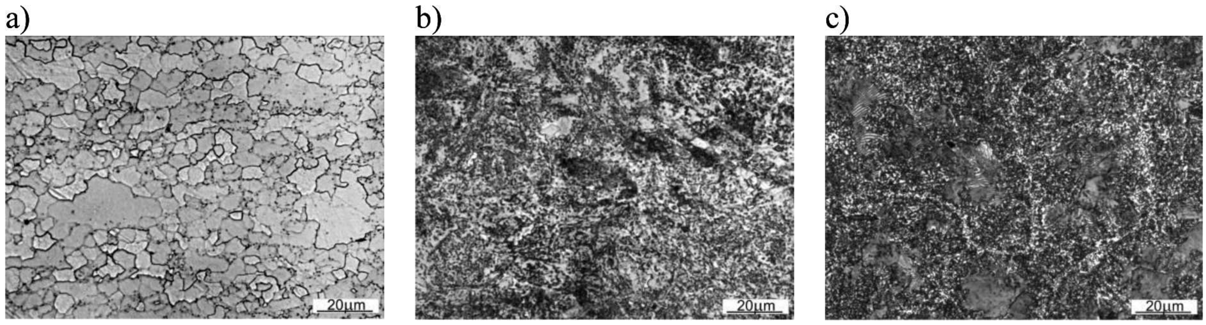

Fig. 1. Microstructure of the investigated steels: a) W I, b) W II, c) W III in as-delivered condition. Etched by 2% nital

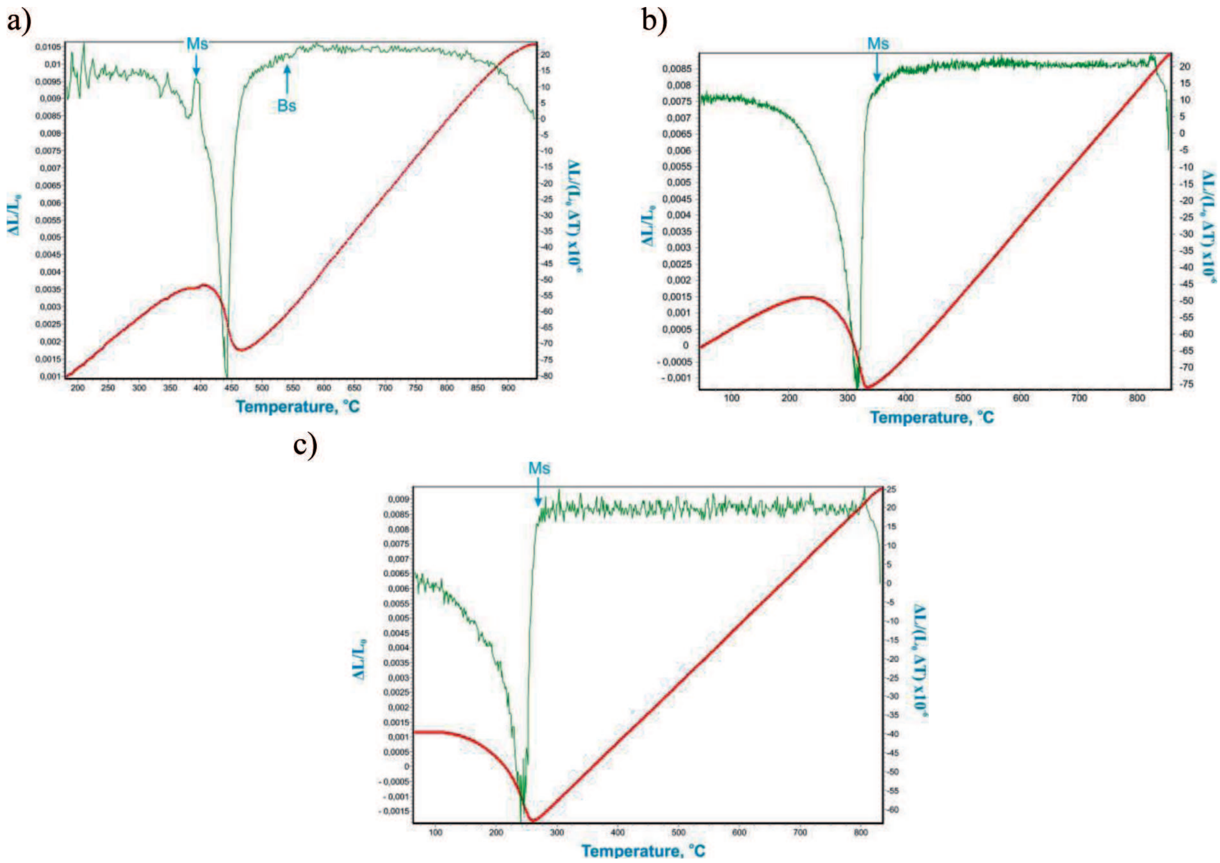

Fig. 2. Dilatometric curve of cooling the sample from : a) W I, b) W II, c) W III steel with differential curve

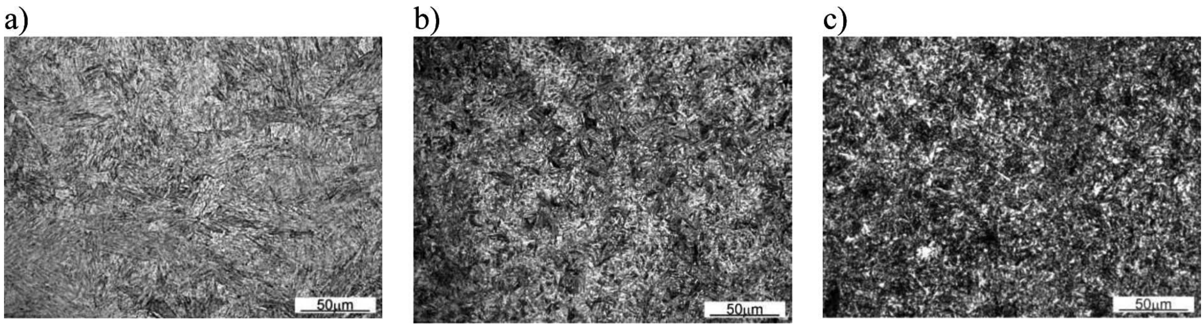

Fig. 3. Microstructure of the investigated steels: a) W I, b) W II, c) W III – after quenching. Etched by 2% nital

The microstructure of the steels in as-quenched condition is shown in Fig. 3. It is the output microstructure for researches of the kinetics of phase transformations during continuous heating from as-quenched state.

Dilatometric experiments were performed by means of the DT 1000 dilatometer made by Adamel, the French Company. Tests were made on samples of a size: ∅2×12 mm and the CHT diagrams (of the kinetics of phase transformation at continuous heating from as-quenched state) were determined.

The microstructure of the steels was observed by means of the light microscope *Zeiss Axiovert 200 MAT*. The metallographic specimens were prepared in four steps, i.e. pre-grinding on a magnetic grinder, grinding on abrasive papers, polishing with diamond pastes and fine-polishing by means of Al_2O_3 suspension. After etching in 2% nital, their microstructure was observed.

3. Results and discussion

In order to make the CHT diagram, the previously quenched samples for each steel were heated with the following rates: 0.05; 0.1; 0.5; 1; 5; 10; 15; 35°C/s to a temperature of 700°C, while changes in the samples elongation in dependence of the temperature were recorded. In this case, numerically recorded dilatograms were also differentiated for a more precise reading of characteristic temperatures. Figure 4 presents examples of the chosen dilatometric curves together with the corresponding differential curve, recorded at 0.5 and 35°C/s heating rates for the investigated steels with the marked start and finish temperatures of phase transformations.

The results of testing W II and W III steels shows, in the first stage of the tempering process a certain shrinkage, related – the most probably to the carbide ε precipitation. Only for W III steel the temperature of the beginning of the ε_s carbide precipitations was possible to be determined. For both steels the finish temperature of the ε_f carbide precipitations was determined. Very small contraction effect in the first stage of the tempering process for steel W I – visible only on the differential curve – can be associated with the rearrangement of carbon atoms or clusters. But this effect for steel W I is very small, and cannot be taken into account.

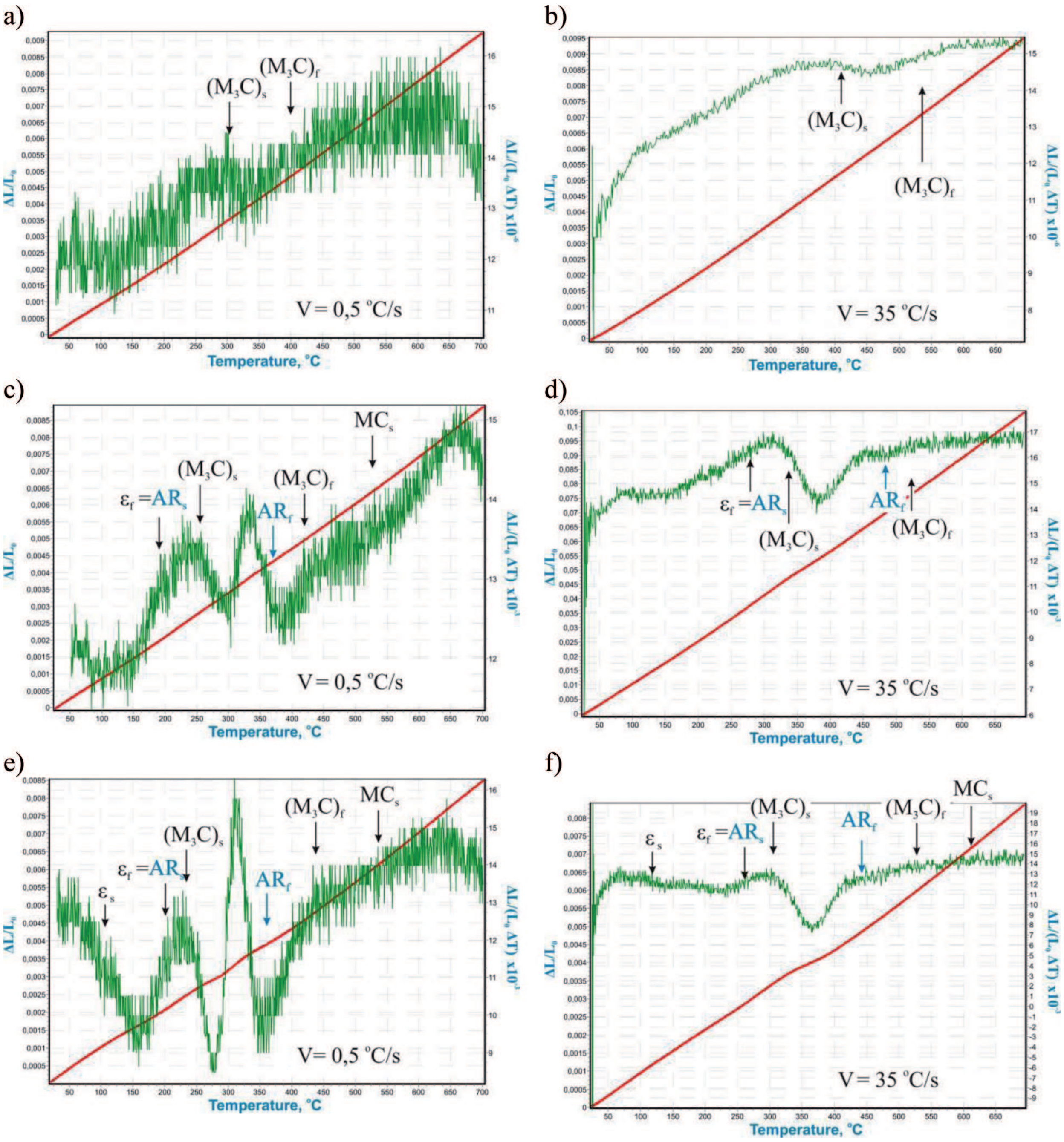

Fig. 4. Dilatometric curves recorded for the a, b) W I, c, d) W II, e, f) W III steel at 0.5 and 35°C/s heating rates

Similarly as in the case of epsilon carbide, positive effects associated with the transformation of the retained austenite (after quenching) occurred only during tempering for steels W II and W III. Analysis of all dilatograms of tempering performed with various heating rates: 0.05÷ 35°C/s – indicates the presence of the retained austenite transformation in the temperature range RA_S÷RA_f for both, W II and W III, steels.

The shrinkage, starting at a temperature $(M_3C)_s$, related to the cementite precipitation, occurred in the case of each tempered steel. But only for W II and W III this effect superimposes on the positive dilatation effect caused by the transformation of the residual austenite. The cementite precipitation ends at a temperature $(M_3C)_f$.

The last positive effect, which was observed for steels W II and W III during high tempering is related, the most probably, to the independent MC carbide precipitation. For W III steel this precipitation occurred at all performed heating rates: 0.05÷35°C/s and for W II steel its ends during heating with 5°C/s heating rate.

A higher carbon content significantly affected the clarity of the effects of expansion of the obtained dilatometric curves. Along with a carbon content increase from 0.30 up to 0.99% the intensity of a precipitation during the first stage of tempering increases. Starting from 0.30%C the intensity of a cementite precipitation also increases. The shrinkage related to its precipitation is the highest in the case of W III steel (0.99%C). In this alloy the significant role also plays a high share of the retained austenite, the transformation of which manifests itself with a strong positive dilatation effect.

The CHT diagram for W I steel is presented in Fig. 5. The CHT diagrams for W II and W III steels are presented in Figs 6 and 7 respectively.

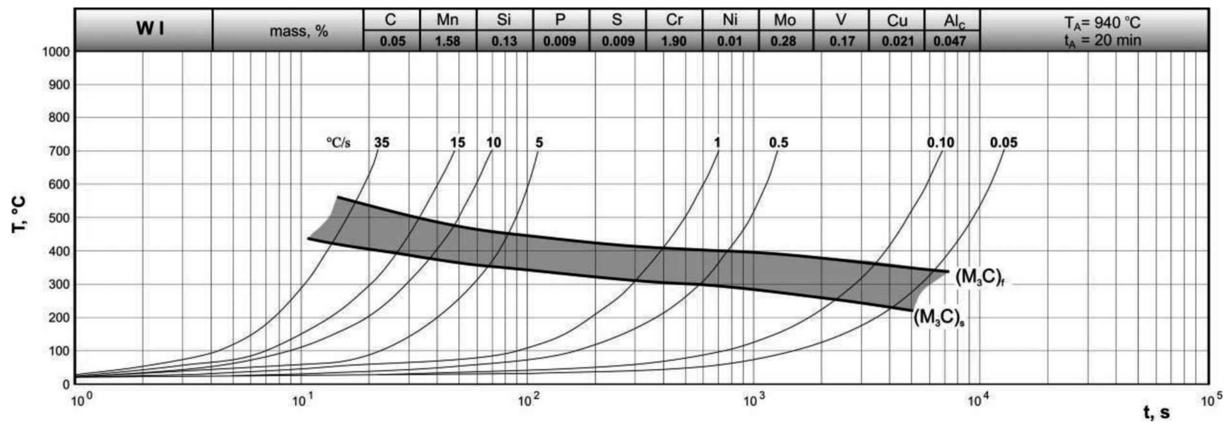

Fig. 5. The CHT diagram of W I steel

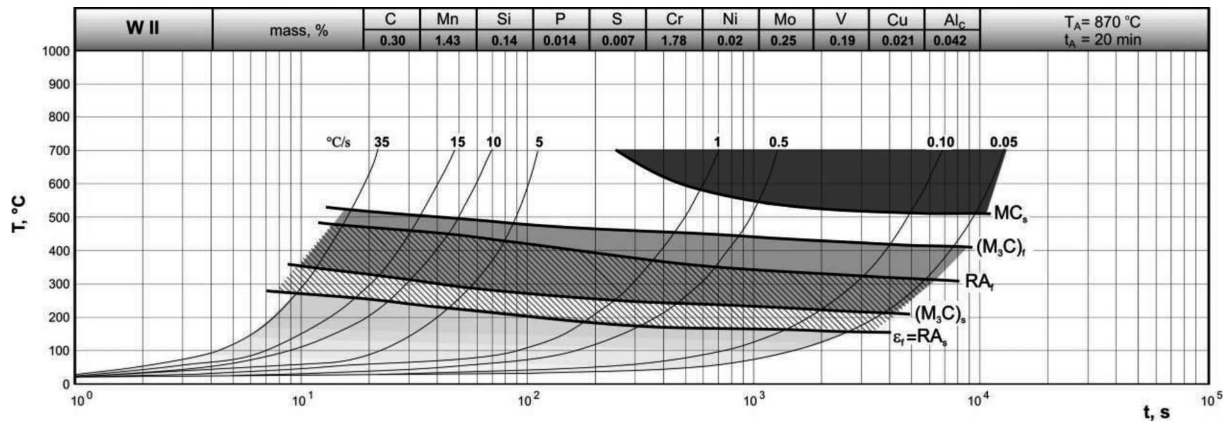

Fig. 6. The CHT diagram of W II steel

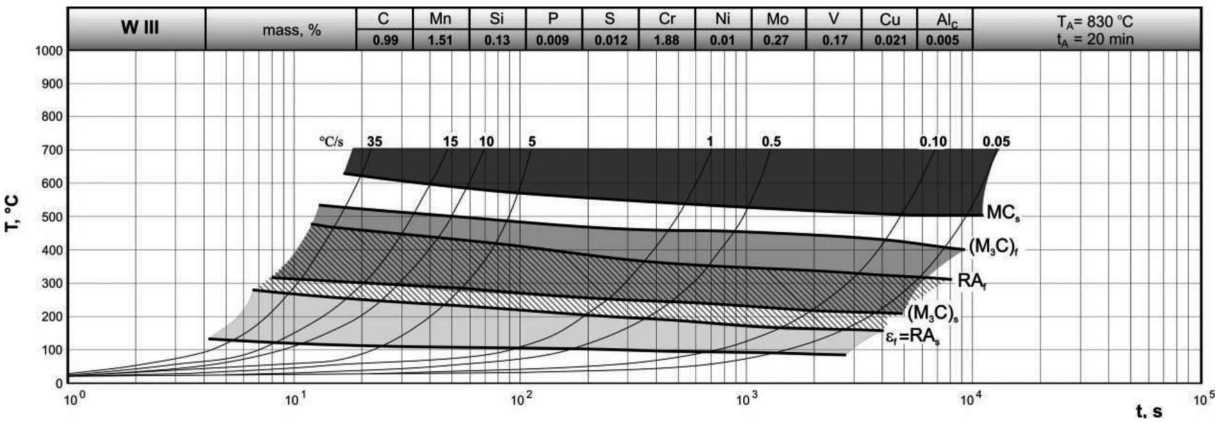

Fig. 7. The CHT diagram of W III steel

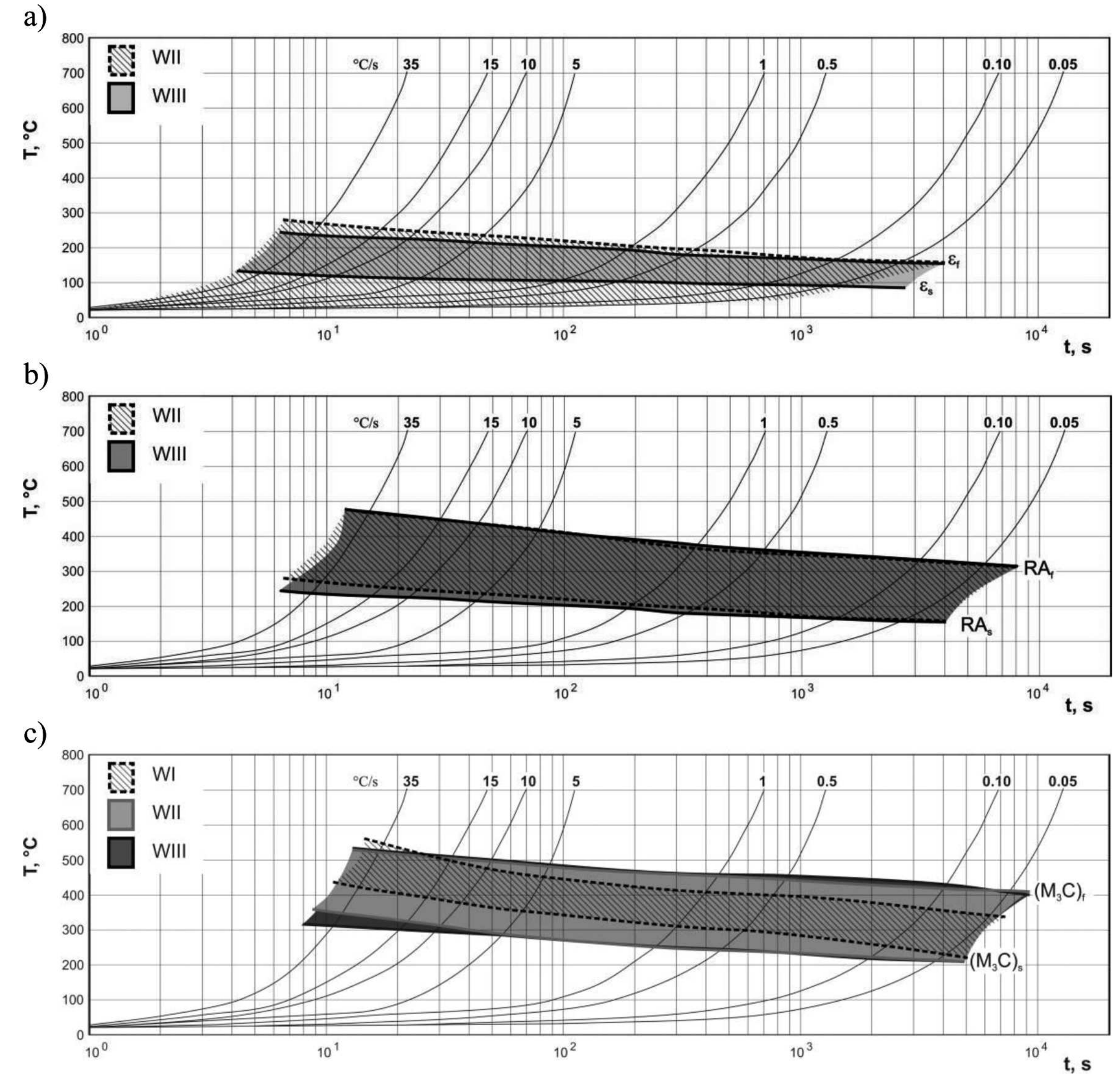

Fig. 8. Combination of each phase transformation: a) Carbide ε precipitation, b) Retained austenite transformation, c) Cementite precipitation, d) Independent MC carbide precipitation (for each steel)

Ranges of the carbide ε precipitation as well as ranges of the retained austenite transformation, cementite precipitation and also the independent MC carbide precipitation are marked in the CHT diagrams of the investigated steels (Fig. 5÷7). As can be noticed, temperatures of starting and ending of individual transformations increase with the heating rate increase from 0.05 to 35°C/s. To investigate precisely the effect of the carbon content on the kinetics of various phase transformations the respective combinations of phase transformations for each steel are shown in Fig. 8.

As it is shown, in the presented statement of the influence of the carbon content on the kinetics of various phase transformations, carbon has little effect on the temperature range of the these transformations. Although one can also see a small influence on the ranges of the various phase transformations, but only at higher heating rates. It can be noted that carbon shows higher effect on the ranges of the carbide (ε carbide, cementite, independent MC carbide) transformations. The carbon content has little effect on the range of the retained austenite transformation, only it has an impact on its quantity.

4. Conclusions

The results that are contained in the present paper and their discussion allow for the formulation of the following conclusions:

1. The testing of W II and W III steels shows, in the first stage of the tempering process a certain shrinkage, related – the most probably to the carbide ε precipitation. Only for W III steel the temperature of the beginning of the ε carbide precipitations was possible to be determined. For both steels the finish temperature of the ε carbide precipitations was determined.
2. Positive effects associated with the transformation of the retained austenite occurred only during tempering steels W II and W III.
3. The shrinkage, starting at a temperature $(M_3C)_s$, related to the cementite precipitation, occurred in the case of each tempered steels. The cementite precipitation ends at a temperature $(MC)_f$.
4. The last positive effect which was observed for steel W II and W III during high tempering is related, the most probably, to the independent MC carbide precipitation.
5. Along with the increase of the carbon content from 0.30 up to 0.99% the intensity of the precipitation during the first stage of tempering increases. Starting from 0.30% C the intensity of the cementite precipitation also increases.
6. The shrinkage related to the precipitation is the highest in the case of W III steel (0.99%C). In this alloy the significant role plays also a high content of the retained austenite, the transformation of which into martensite manifests itself with a strong positive dilatation effect, above 500°C, which can be associated with the absence of brittle martensite in the steel.
7. As it is shown, the carbon content has little effect on the kinetics of various phase transformations in their temperature ranges.
8. It can be noted that carbon has higher effect on the ranges of the carbide (ε carbide, cementite, independent MC carbide) transformations.
9. The carbon content has little effect on the range of the retained austenite transformation, only it has an impact on its quantity.

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