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Effect of heating rate on the phase transformations during tempering of low carbon Cr-Mn-Mo alloy steel

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ABSTRACT

Purpose: The effect of heating rate to the tempering temperature on the microstructure and properties of lath martensite tempered at a various temperatures was studied in literature from point of the cemntite precipitations view. It has been shown that cementite dispersion is finer and more uniform in the rapidly heated and tempered than in the slowly heated and tempered specimen. Aim of this work is to investigate the effect of heating rate on the phase transformations during tempering.

Design/methodology/approach: The investigations of phase transformations during tempering of the low carbon steel were made on the grounds of dilatometric curves recorded during heating from as-quenched state. Heating to isothermal holding at 350°C was made with two different heating rates (100°C/s and 5°C/s) and was performed by use of the L78 R.I.T.A. dilatometer made by Linseis. The investigations of phase transformations during continuous heating from as-quenched state were performed by use of the DT 1000 dilatometer made by Adamel.

Findings: It is possible to reduce probability of the occurrence of some phase transformations in favor of other. The difference in advancement of the various phase transformations can effects on various mechanical properties of the steels.

Research limitations/implications: The effect of the heating rates (100°C/s and 5°C/s) during heating from as-quenched state on the phase transformations during isothermal holding at 350°C was submitted. It is expected to carry out further research on the effect of the heating rate on the phase transformations during isothermal holding at different temperatures and their effects on mechanical properties.

Practical implications: The obtained information may be used to design new technologies of steels tempering.

Originality/value: The new point of view on the tempering of the steels can be assumed.

Keywords: Metallic alloys; Tempering; Cementite; Dilatometric investigation

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MATERIALS

1. Introduction

Tempering reduces the hardness, residual stress, but increases the ductility. The structural changes that occur during tempering of steels depend on the temperature, time of the process and the carbon concentration. After tempering of the low alloy medium carbon steels above 200°C (range of low and medium tempering) transition carbide ε transforms into cementite and retained austenite into fresh martensite (lower bainite) [1,2]. Mostly in each grade of the steel during tempering above 200°C the unfavorable irreversible temper brittleness effect occurred which is very interesting problem [3-8]. This effect is often explained by the transformation of the epsilon carbides as well as formation of cementite.

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 are presented [9-21].

The effect of heating rate to the tempering temperature on the microstructure and properties of lath martensite tempered at a various temperatures was studied in literature from point of the cementite precipitations view [22]. It has been shown that cementite dispersion is finer and more uniform in the rapidly heated and tempered specimen than in the slowly heated and tempered. It was considered that increase of the heating rate to the tempering temperature leads to a higher nucleation rate and a finer dispersion of cementite [23]. The induction heating with a rapid heating rate (100-200 K/s) is more effective for the improvement of strength and toughness than the ordinary slow heating and tempering (1 K/s). It was considered that the size of cementite seems to be refined by the increase of the heating rate to tempering temperatures.

2. Tested material

The investigations were performed on the low carbon Cr-Mn-Mo model alloy steel which chemical composition is presented in Table 1. The material was supplied as bars of a rectangular cross-section of dimensions 35x20 mm after soft annealing at 650°C for 10 hours after forging. Its microstructure is presented at Fig 1a. As it is seen in as-delivered condition the steel had the structure consisting mainly of ferrite. Hardness of this steel in as-delivered condition was 139 HV30.

Before the beginning of examinations it is necessary to apply an adequate heat treatment to have the material in a normalization state. The normalizing annealing was applied, which means that the steel was austenitised for 60 minutes at Ac_3+50°C=940°C and then cooled along with the furnace. Microstructure of the steel after annealing is presented at Fig 1b.

3. Experimental procedure and heat treatment

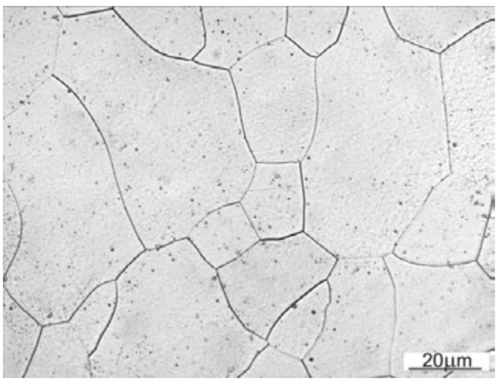
The austenitising temperature was assumed, in a standard way on the bases of data from [9,10], which means 50°C higher than Ac_3 temperature. Austenitizing temperature to the hardening for each of the samples was equally 940°C.

The microstructure of the investigated material was examined by the light microscope Axiovert 200 MAT, photos of the microstructure of the dilatometric samples after dilatometric investigation, were taken using the scanning electron microscope HITACHI SU-70 in SE and BSE contrast.

Dilatometric investigations were performed by use of the L78 R.I.T.A. (Rapid Intensive Thermal Analysis) dilatometer made by Linseis and DT1000 dilatometer made by Adamel. By the use of the DT1000 dilatometer the investigations of phase transformations during continuous heating from as-quenched state were performed. The samples for this test (Ø2x12 mm), were quenched outside the dilatometer in the water. By the use of R.I.T.A. dilatometer the isothermal tempering test, at 350°C was performed also hardening of the sample (Ø3x10 mm) was performed by the use of the same dilatometer (Fig 2).

The microstructure of the samples from the investigated steel after water quenching is shown in Fig 3a and after quenching in the dilatometer (blowing with the inert gas helium) in Fig 3b. It is the output microstructure for researches of the kinetics of phase transformations during tempering.

a)



b)

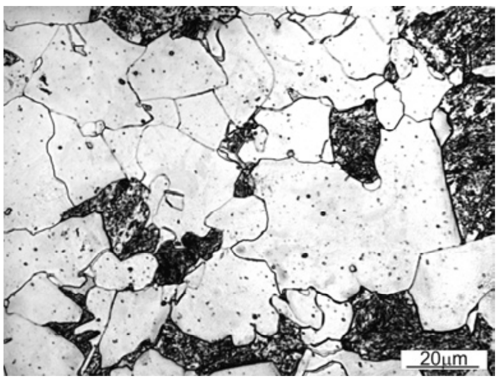


Fig. 1. Microstructure of the investigated steel: a) in as-delivered condition, b) after annealing. Etched by 2% nital

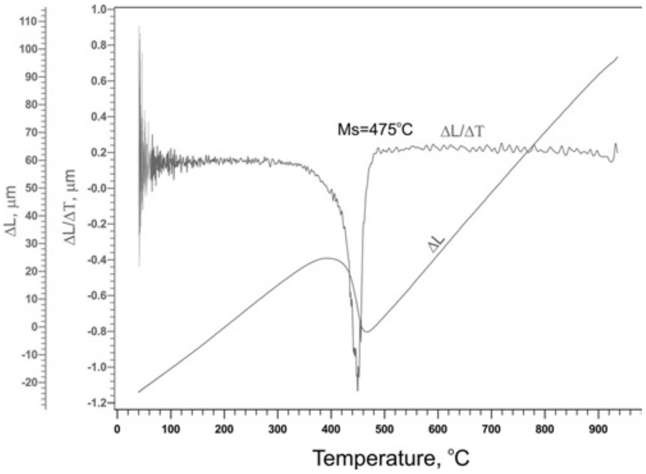


Fig. 2. The dilatometric curve with the corresponding differential curves of hardening the sample in the R.I.T.A. dilatometer with marked Ms temperature

The differences in the microstructures after two types of quenching are slightly. All above the differences are in susceptibility to nital etching.

The previously quenched samples were heated with the following rates: 0.05; 1; 10; 15°C/s to 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.

The Fig. 4 contents the results from the dilatometric investigation on the kinetics of phase transformations during continues heating from as-quenched state. The dilatometric curves ($\Delta L/L_0$) are shown together with the corresponding differential curves ($\Delta L/L_0\Delta T$).

Very small contraction effect in the first stage of the tempering process for investigated steel visible only on the differential curve can be associated with the rearrangement of carbon atoms or clusters. But this effect is very small, and cannot be taken into account. During heating with rate 0.05°C/s the shrinkage, starting at 200°C ($(M_3C)_s$), related to the cementite precipitation, occurs. The cementite precipitation ends at a 340°C/temperature ($(M_3C)_f$).
With the heating rate increase the range cementite precipitation shifts to higher temperatures. This can effect on the occurrence of the phase transformations.

The Fig. 5 contents the results from the dilatometric investigation on the kinetics of phase transformations during heating (Fig. 5a) and isothermal holding (Fig. 5a) from as-quenched state samples from investigated steel. The dilatometric curves (ΔL) are shown together with the corresponding differential curves (ΔL/ΔT, ΔL/Δt). There are curves of heating (a) and isothermal holding for 2 h at 350°C (b) of the dilatometric samples. On the curves of heating and isothermal holding the occurred phase transformations are marked.

These dilatometric curves show that during heating of the as-quenched samples with the rate of 5°C/s the contraction effect associated with the rearrangement of carbon atoms or clusters formation can be marked. However, in the case of heating with the rate of 100°C/s it cannot be seen any effects that may be associated with the phase transformations. These difference significantly effects on the phase transformations during isothermal holding.

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

	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Fe
WI	0.05	1.58	0.13	0.009	0.009	1.90	0.01	0.28	0.17	0,022	bal.

a) b)

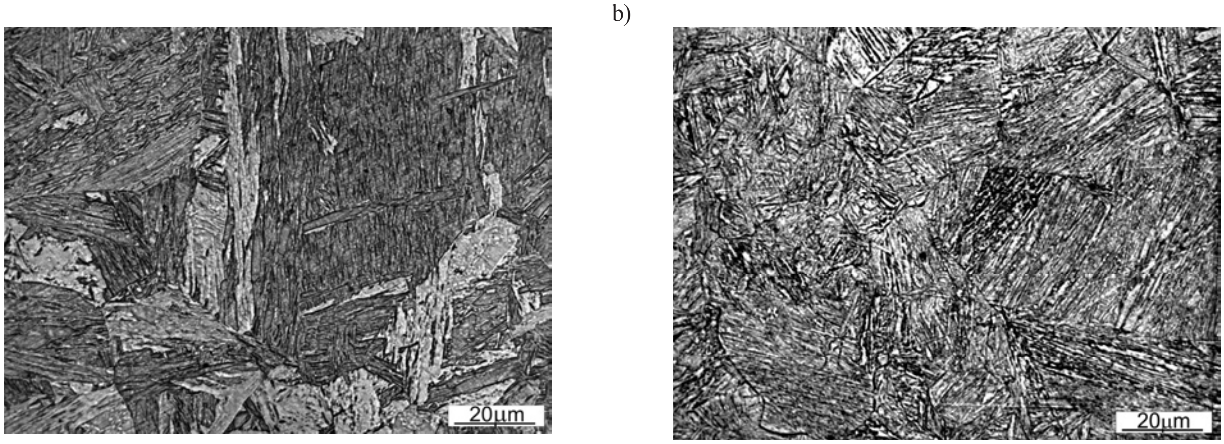


Fig. 3. The microstructure of the steel after: a) water quenching, b) after quenching in the R.I.T.A. dilatometer (blowing with the inert gas helium). Etched by 2% natal

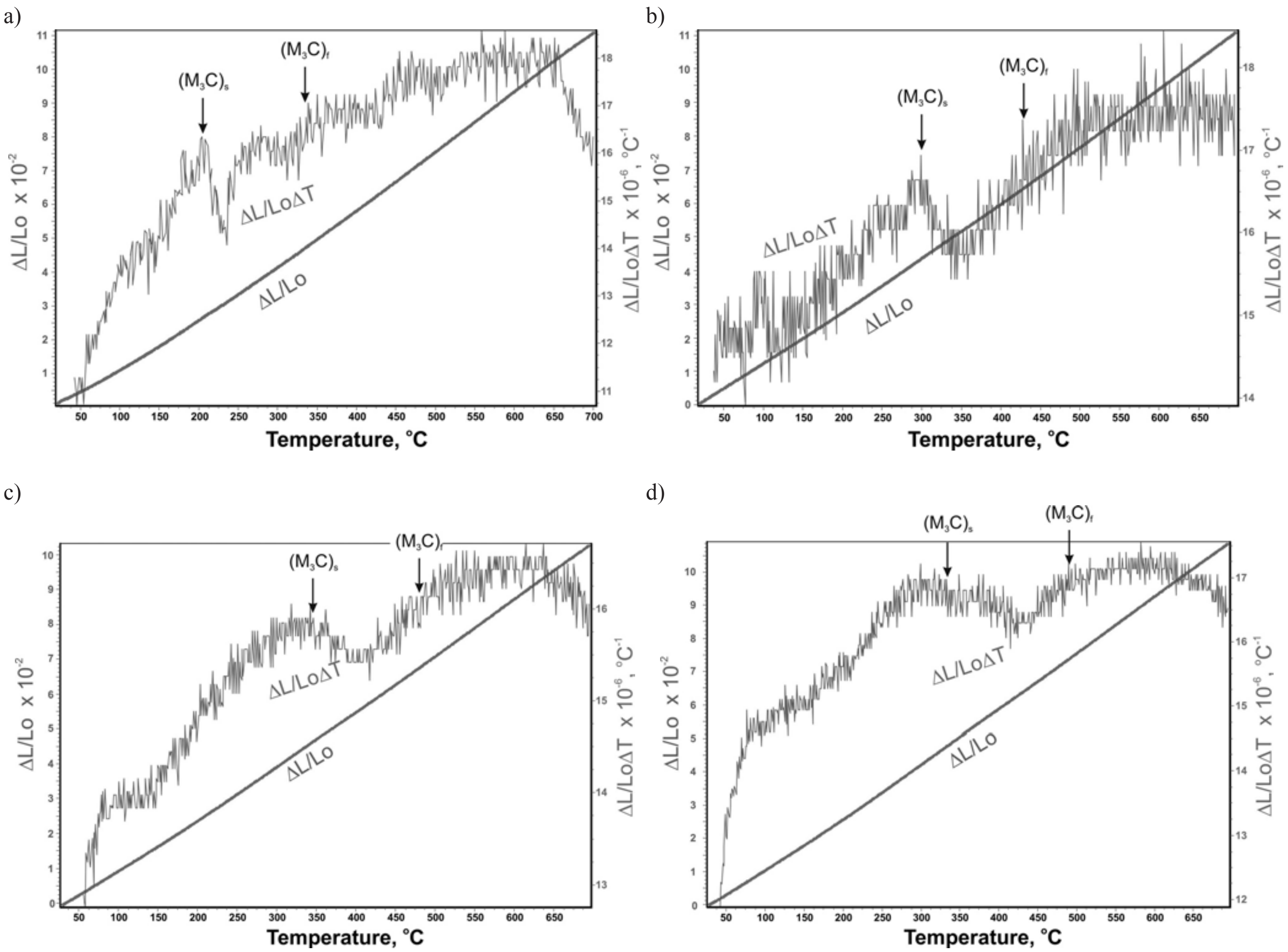


Fig. 4. The dilatometric curve with the corresponding differential curves during continues heating with rate a) 0.05, b) 1, c) 10 and d) 15°C/s from as-quenched state with marked temperature of phase transformations

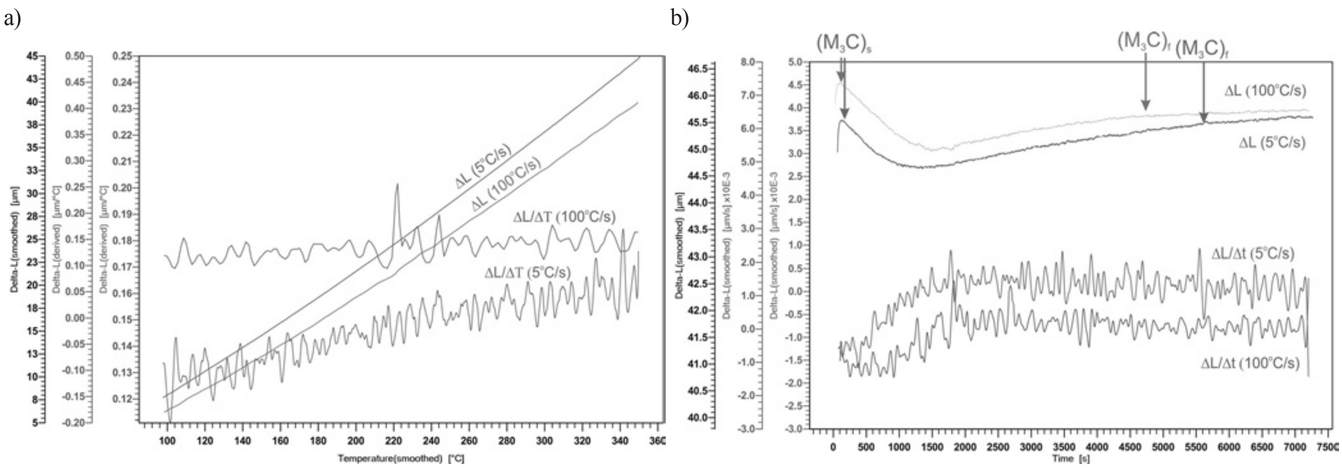


Fig. 5. The dilatometric curves with the corresponding differential curves of heating the samples with two different heating rates a) to the isothermal holding b) for 2 h at 350°C

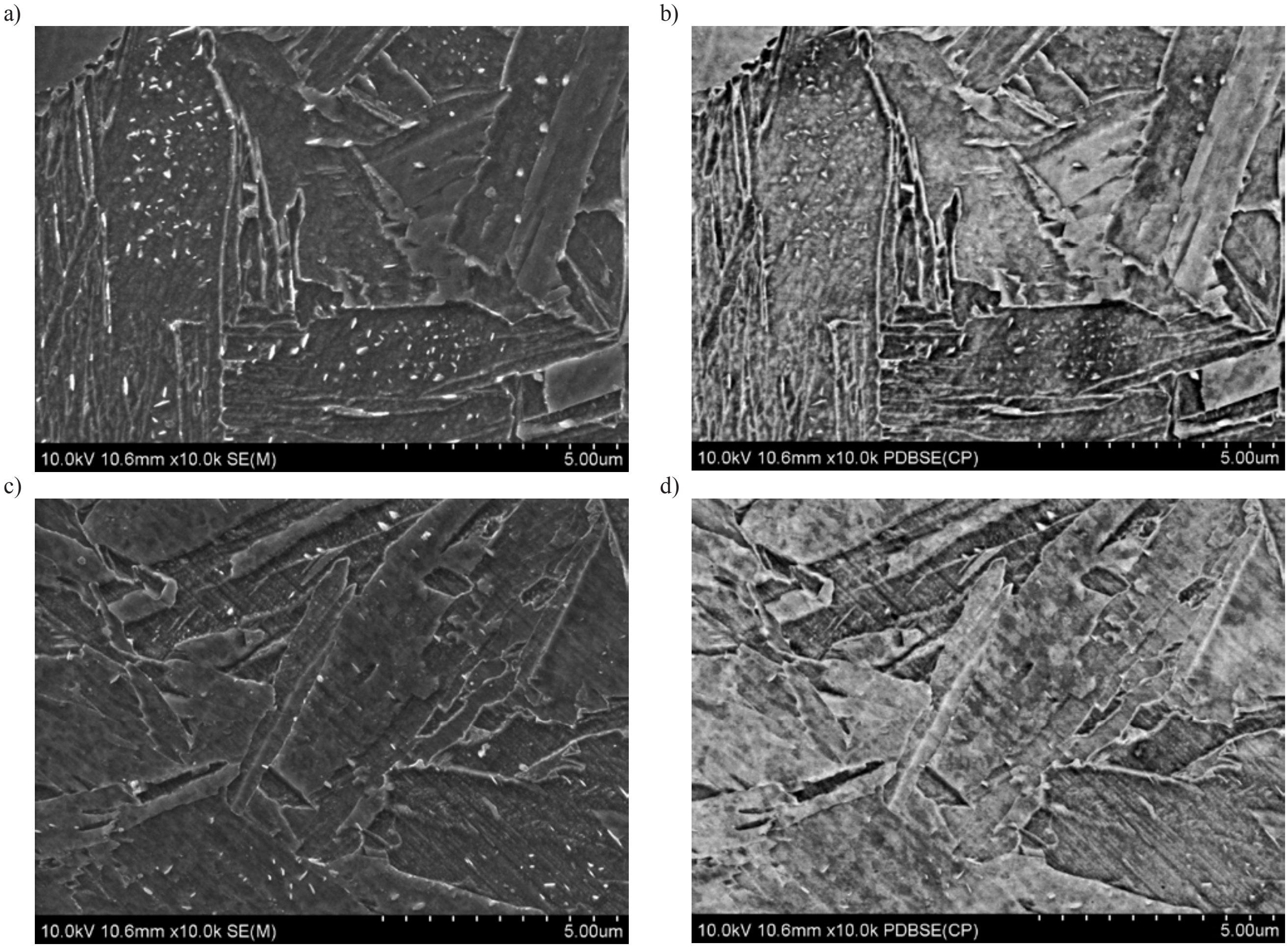


Fig. 6. The microstructure of the steel heated with heating rate: a) 5°C/s, b) 100°C/s to the isothermal holding at 350°C holding in the R.I.T.A. dilatometer. Etched by 2% natal

The increase in heating rate to the isothermal holding, shifts the end of cementite precipitation to shorter time. This difference in the time of the cementite precipitation effects on the morphology of cementite (Fig. 6). This may significantly effect on the mechanical properties.

Fig. 6 presents the photos of the microstructure of the dilatometric samples after dilatometric investigation, photos were taken using the scanning electron microscope HITACHI SU-70.

The microstructure of the samples from WI steel after described heat treatment consists of tempered lath martensite and fine carbides formed during tempering in the structure resembling a bainite. It can be seen that for the samples heated with heating rate 5°C/s (Fig. 6a, b) results that the amount of the precipitated carbides during tempering is higher than in the case of samples heated with heating rate 100°C/s (Fig. 6c, d).

The Fig. 7 contents the results of the heating rates effect during tempering (isothermal holding) on the hardness of the samples. The hardness measurements were performed with the Vickers HPO250 apparatus. The increase of heating rate to the isothermal holding has affected on the morphology of cementite precipitates and an increase of hardness.

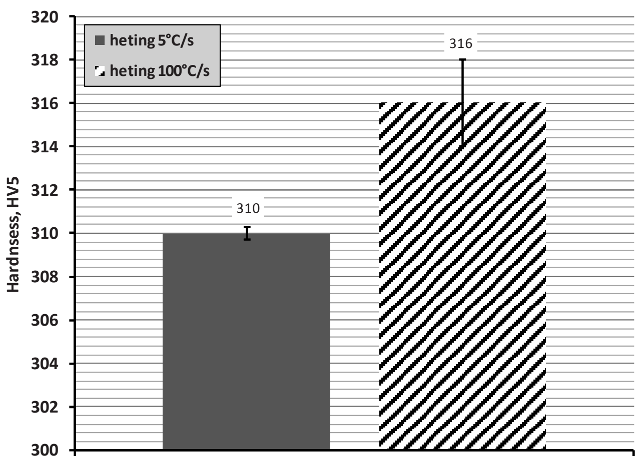


Fig. 7. The heating rates effect during heating from as-quenched state to the isothermal holding on the hardness of the samples

4. Conclusions

The kinetics of phase transformation for quenched and isothermal held at 350°C steel was investigated at two different heating rates 100°C/s and 5°C/s. The following results were obtained:

Very small contraction effect in the first stage of the tempering process for investigated steel visible only on the differential curve can be associated with the rearrangement of carbon atoms or clusters. During heating with rate 0.05°/s the shrinkage, starting at a 200°C ($(M_3C)_s$), related to the cementite precipitation, occurs. The cementite precipitation ends at a temperature of 340°C ($(M_3C)_f$).

With the heating rate increase the range of cementite precipitation shifts to higher temperatures.

During heating hardened samples with the rate of 5°C/s we can marc contraction effect associated with the rearrangement of carbon atoms or clusters formation. However, in the case of heating with the rate of 100°C/s it cannot be see any effects that may be associated with the phase transformations.

The increase in heating rate to the isothermal holding, shifts the end of cementite precipitation to shorter time this effects on the morphology of cementite.

The microstructure of the samples after isothermal holding treatment consists of tempered lath martensite and fine carbides formed during tempering in the structure resembling a bainite. It can be seen that for the samples heated with heating rate 5°C/s results that the amount of the precipitated carbides during tempering is higher than in the case of samples heated with heating rate 100°C/s. The increase of heating rate to the isothermal holding has affected on the morphology of cementite precipitates and an increase of hardness.

Acknowledgements

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