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Effect of carbon content upon the early stage of tempering of steel with Mn and V addition

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ABSTRACT

Purpose: In this paper the effect of carbon content on the transformations taking place at the early stage of tempering (precipitation of the ε carbide) of the model alloys with manganese and vanadium addition is evaluated.

Design/methodology/approach: The alloys with specially designed chemical composition (constant content of alloying elements and varied carbon content) were investigated by means of dilatometric method. The range of temperature of the early stage tempering was established on the basis of differentiated dilatogram curves digitally recorded during heating up step of the previously hardened specimens. In order to unify the experimental conditions, only one heating rate was chosen.

Findings: It was shown that carbon has a similar influence on the first stage of the tempering of the model alloys containing manganese and vanadium addition when considering a qualitative way of the effect. But when a quantitative way is taken into account, the effect of carbon content is different.

Research limitations/implications: Investigations of the early stage of the tempering will be continued for its more accurate quantitative analysis. Authors are expecting that there is a relationship between an intensity of this stage of tempering and steel's properties.

Practical implications: The results of the research have strong cognitive meaning. It is possible that in the future they may be used for designing of chemical composition of steels for which presently only the low-temperature tempering is provided.

Originality/value: The results contained in this paper have very high cognitive significance and in the future it may be possible to use them for elaboration of detailed heat treatment technology of new steels, which are anticipated to be subjected to low-temperature tempering only.

Keywords: Metallic alloys; Dilatometric method; Tempering; ε carbide

MATERIALS

1. Introduction

The process of martensite tempering consists of a few stages: carbon segregation, precipitation of carbides, transformation of retained austenite, recovery and recrystallization of the matrix [1-3].

During the first (so called early) stage of tempering taking place within the temperature range up to 200ºC [1,3,4,5] transient carbides may precipitate in the structure of tempered martensite. One of them is ε carbide with hexagonal close packed (HCP) structure and formula $Fe_{2.4}C$. In steels containing less than 0.2% of carbon the precipitation of this carbide does not take place, because significant part of carbon atoms is bounded with dislocations [1,4,5]. Whereas in high-carbon steels tempered in the temperature range of 200÷300°C the Hägg's carbide having $Fe_{2.2}C$ formula and monoclinic lattice may be created [6,7]. At lower temperatures of high-carbon steels tempering (i.e. about 150ºC) η carbide of orthorhombic lattice and Fe_2C formula may also be created [6].

Table 1.
Chemical composition of the manganese model alloys

Alloy	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	N
$C1_{Mn}$	0.17	1.97	0.11	0.023	0.023	0.12	0.10	0.04	0.20	0.006
$C2_{Mn}$	0.40	2.00	0.12	0.022	0.022	0.13	0.10	0.04	0.21	0.006
$C3_{Mn}$	0.59	2.00	0.12	0.025	0.025	0.13	0.10	0.05	0.21	0.006

Table 2.
Chemical composition of the vanadium model alloys

Alloy	C	V	Mn	Si	P	S	Cr	Ni	Mo	Al	Cu	N
$C1_V$	0.31	0.44	2.05	0.17	0.025	0.015	1.68	0.05	0.42	0.040	-	0.005
$C2_V$	0.72	0.39	2.15	0.17	0.011	0.018	1.55	0.04	0.36	0.004	0.04	0.005
$C3_V$	1.25	0.44	2.05	0.25	0.020	0.015	1.61	-	0.39	0.025	-	0.005

There is presented in the works [8÷11] a quantitative evaluation of influence of alloying elements: vanadium and nickel on the early stage of tempering of steels with ca. 0.3% carbon content.

There is presented in the works [12,13] a quantitative evaluation of influence of carbon on the early stage of tempering of a steel containing nickel, silicon and chromium. The results obtained have revealed the complexity of influence of the above mentioned elements on this stage of tempering as the influence has been dependent not only on the carbon content in test steels, but on the background of other alloying elements as well.

The present work is a continuation of previous research [12,13], and its objective is a quantitative evaluation of carbon influence on the early stage of tempering of steels containing manganese and vanadium. The evaluation has been made on the basis of model alloys with particular chemical composition designed in order to receive a concentration of single element (carbon) as variable and constant concentration of the other alloying elements.

2. Research materials

In order to evaluate the influence of carbon on the transformations taking place during the early stage of tempering of steels with manganese and vanadium the digitally recorded heating dilatograms from quenched state in works [14,15] have been used.

Chemical compositions of model alloys with manganese are presented in table 1, while model alloys with vanadium in table 2.

3. Experimental procedure

The research of carbon influence on the early stage of manganese and vanadium steels has been carried out by a dilatometric method using Adamel DT1000 dilatometer.

ϕ2x12 mm samples of test alloys have been first heated in argon atmosphere at the rate of 3°C/s to austenitizing temperatures $T_A = A_{C3}$+30°C (for hypoeutectoid steels), $T_A = A_{C1k}$ + 50°C (for eutectoid and hypereutectoid steels)held for 20 minutes, and cooled down to room temperature at a rate higher than critical (in water).

Then the as-quenched samples have been heated in a dilatometer to 700°C at 0.5° C/s.

Digitally recorded dilatograms of heating have been differentiated, what resulted in the possibility of quite precise determination of the temperatures of the beginning and the end of first stage of shrinkage during tempering, i.e. ε_s and ε_f depending on the rate of heating.

In order to increase the analysis accuracy of temperature range, in which the first stage of shrinkage occurs, the analysis of dilatograms has been limited to the temperature of 550°C. Within this range there have been visible two shrinkage ranges, i.e. the first – connected with precipitation of ε carbide from martensite, and the second – connected with cementite precipitation. Only the first stage of shrinkage has been analyzed.

Three characteristic temperatures of this shrinkage have been determined numerically:

- temperature of shrinkage start (beginning of differential decrease) - ε_s;
- temperature of maximum intensity of shrinkage, i.e. a point at which the first derivative reaches minimum, and there is a point of inflexion on dilatograms - ε_{max};
- temperature of a point at which the first derivative reaches maximum again, i.e. the temperature of the end of first shrinkage stage - ε_f.

For each of the test alloys included in present work the original differential curves in $(\Delta L/\Delta T)/Lo = f(T)$ configuration have been inserted. In order to facilitate comparison of the dilatational effects corresponding to the same transformations, the differential curves have been put together for each "set" of alloys.

4. Results and discussion

Fig. 1 presents a hypothetical heating dilatograms to 550°C with corresponding differential curve of the model manganese alloy containing 0.59% carbon, 2% manganese and weak background of other elements (table 1). The figure presents also the way of determination of ε_s, ε_f and ε_{max} temperatures being the subject of present paper.

Fig. 2 compares the differential curves of heating dilatograms of three alloys containing 0.17÷0.59% carbon, ca. 2% manganese and weak background of other alloying elements.

The two first $C1_{Mn}$ and $C2_{Mn}$ alloys containing respectively: 0.17% and 0.40% C have not exhibited the characteristic shrinkage during first stage of tempering (Fig. 2), probably due to a low content of this element. Whereas in case of $C3_{Mn}$ alloy containing 0.59% C the heating dilatogram reveals a strong sample shrinkage most probably related to precipitation of ε carbide.

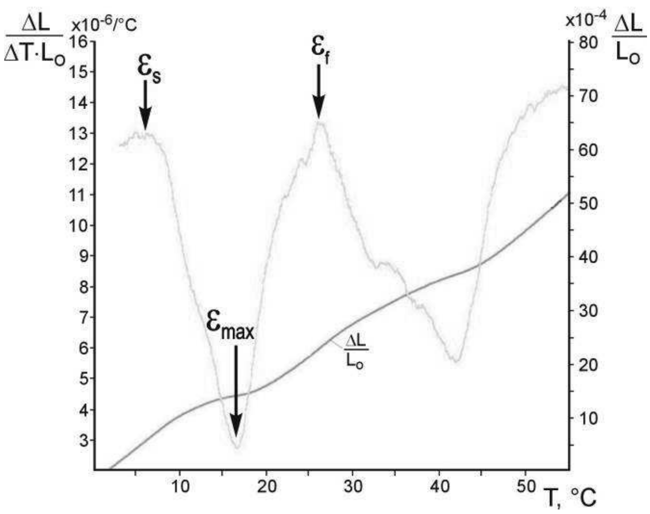

Fig. 1. Example of the dilatogram $\Delta L/L_0$=f(T) recorded during heating up step (V=0.5ºC/s) of a tempered specimen made of the $C3_{Mn}$ model alloy (0.59% C, 2% Mn), first differential curve $(\Delta L/\Delta T)/L_0$=f(T) and method of determination of the ε_s, ε_f, ε_{max} temperatures

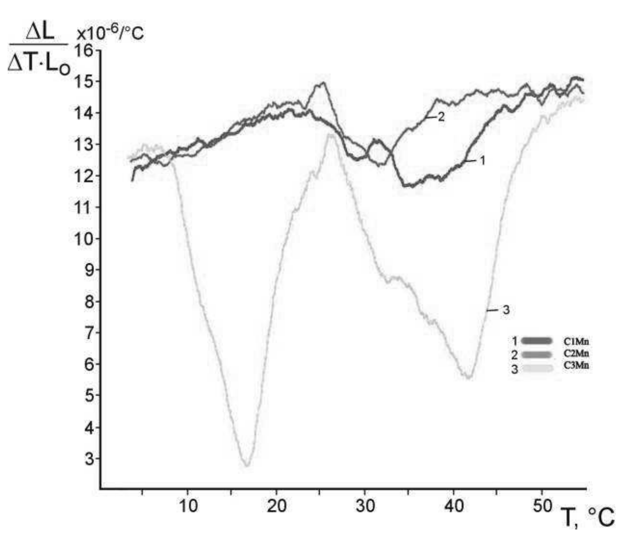

Fig. 2. First differential curves $(\Delta L/\Delta T)/L_0$=f(T) of the model alloys containing 0.17÷0.59% C, about 2% Mn and weak background of the other alloying elements

The increase of carbon concentration from 0.17 to 0.59% results in intensification of cementite precipitation and widening of the precipitation range, and shifts this process towards higher temperatures of tempering. Therefore one may state (comparing the research results in work [13]), that carbon in the above mentioned alloys by widening the range of cementite precipitation is acting inversely than in the case of alloys with silicon, where it has caused its narrowing.

Table 3 matches ε_s, ε_f, ε_{max} temperatures read out in numbers for model alloys with manganese. For the alloy containing 0.59% of carbon the start of sample shrinkage (ε_s) has been recorded at the temperature of 60°C, while the temperature of end of the shrinkage (ε_f) has been 260°C. The temperature of the highest precipitation intensity (ε_{max}) during early stage of tempering of this alloy has been estimated at 160°C.

Fig. 3 compares the differential curves of heating dilatograms of three alloys containing 0.31÷1.25% carbon, ca. 0.4% vanadium and strong background of the other alloying elements.

Table 3.
The ε_s, ε_f, ε_{max} temperatures in model alloys with manganese addition, evaluated by means of the dilatometric method

Alloy	The characteristic temperatures of early stages of tempering, °C		
	ε_s	ε_f	ε_{max}
$C1_{Mn}$ (0,17% C)	-	-	-
$C2_{Mn}$ (0,40% C)	-	-	-
$C3_{Mn}$ (0,59% C)	60	260	160

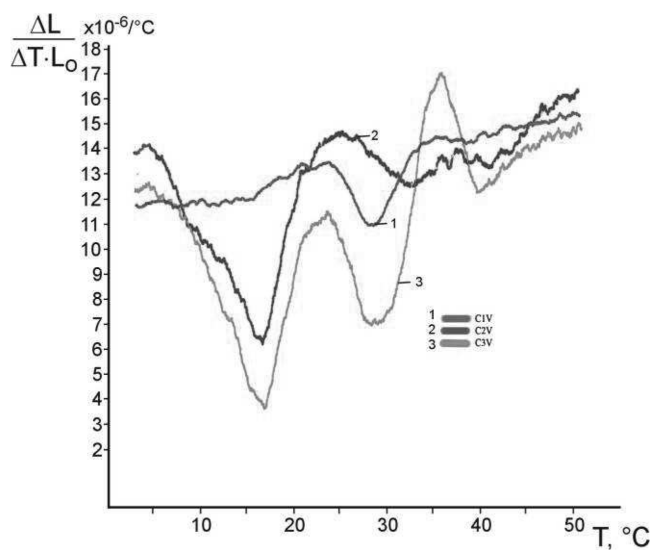

Fig. 3. First differential curves $(\Delta L/\Delta T)/L_0$=f(T) of the model alloys containing 0.31÷1.25% C, about 0.4% V and strong background of the other alloying elements

Table 4.
The ε_s, ε_f, ε_{max} temperatures in model alloys with vanadium addition, evaluated by means of the dilatometric method

Alloy	The characteristic temperatures of early stages of tempering, °C		
	ε_s	ε_f	ε_{max}
$C1_V$ (0,31% C)	-	-	-
$C2_V$ (0,72% C)	60	210	175
$C3_V$ (1,25% C)	50	210	175

From Fig. 3 it is evident that in the case of the first alloy with vanadium ($C1_V$) there has been no shrinkage typical for the first stage of tempering even if it contained 0.32% carbon. However the negative dilatational effect has also been recorded for the alloys: eutectoid ($C2_V$) as well as hypereutectoid ($C3_V$) – containing 0.72 and 1.25% carbon respectively.

The beginning of sample shrinkage (ε_s) in $C2_V$ medium-carbon alloy has been recorded at around 60ºC and the end at around 210ºC, while in the alloy with the highest carbon content ($C3_V$) at 50^0C and 210ºC, respectively (Fig.3, table 4**)**. The highest intensity of ε carbide precipitation (ε_{max}) has been recorded at about 175ºC both in the medium- and high-carbon alloy.

Along with the increase of carbon content from 0.31 up to 1.25% the intensity precipitation during the first stage of tempering increases. Starting from 0.31% C also the intensity of cementite precipitation increases. The shrinkage connected with its precipitation is the highest in the case of hypereutectoid $C3_V$ alloy (1.25%C). In this alloy the significant part also plays a high share of retained austenite, the transformation of which manifests with a strong positive dilatation effect. It is important to point out that carbon in the model alloys with vanadium does not affect the temperature of maximum intensity of precipitation during the first stage of tempering (ε_{max}) and the temperature of the end of the first stage of shrinkage (ε_f) and insignificantly shifts the start (ε_s) of the first stage of shrinkage towards lower values. Comparing the data from Figs. 2 and 3 it shows that intensity of shrinkage during the first stage of tempering in alloys containing 0.72 and 1.25 % of as well as ca. 0.40% V is much lower than in case of the alloy containing 0.59% C and ca. 2% Mn.

5. Conclusions

1) In the case of the test model alloys with manganese containing 0.17 and 0.40% carbon the negative dilatation effect is not observed during the first stage of tempering. A strong dilatation effect has been recorded for carbon concentration of 0.59%.
2) Carbon in alloys with manganese causes a distinct increase in the cementite precipitation intensity, widens the range of its precipitation and shifts it towards higher temperatures.
3) In the case of the model alloys with vanadium the shrinkage of the sample during the first stage of tempering has been recorded from 0.72% carbon.
4) The intensity of shrinkage during the first stage of tempering is lower in alloys containing vanadium than in alloys with manganese.
5) The investigations of the first stage of tempering will be continued in the future in order to provide more detailed analysis and to determine the correlation between the results obtained and the steel properties.

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