Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20
ISSUES 1-2
January-February
2007

The kinetics of phase transformations during tempering of Cr-Mo-V medium carbon steel

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Received 16.10.2006; accepted in revised form 15.11.2006

Materials

ABSTRACT

Purpose: The reasons for writing this paper was to describe the kinetics of phase transformations during tempering of hardened Cr-Mo-V medium carbon steel. Moreover, the differences in hardness and microstructure of samples of the investigated steel in relationship to the heat treatment were evaluated.
Design/methodology/approach: CHT diagram was determined with dilatometric method. Samples were observed using with TEM.
Findings: During heating of the samples of the quenched Cr-Mo-V medium carbon steel the occurrence of 3 principal transformations was determined. These are: precipitation of ε carbide, M_3C precipitation and transformation of retained austenite. A TEM investigations focused on determination of a degree of phase transformations during continuous tempering, showed compatibility of the microstructure with CHT diagram for tested steel.
Research limitations/implications: The new CHT diagram of investigated steel was determined
Practical implications: The obtained CHT diagram may be used to design new technologies of tempering of this steel.
Originality/value: The new CHT diagram, characterization of tempering new Cr-Mo-V steel
Keywords: Tool materials; Tempering; CHT - diagram; Retained austenite

1. Introduction

The most important properties of hot working tool steels are: strength, hardness, abrasion resistance in temperature works and thermal fatigue. These properties can be obtained by controlling the chemical compositions and also by properly designed heat treatment [1÷3]. Better properties can be obtained in steels with complex chemical compositions than in steels containing more than one or two elements. [1,4,5]. In the case of hot working tool steels, besides designing their chemical compositions, very important issue it to predict their medium or high-temperature tempering conditions to get stable structure assuring stable properties during work.

Nowadays, a design of hot working tool steels involves designing complex chemical compositions, containing from 0,25 to 0,6%C and characterizing special kinetics of phase transformations during tempering. Only then a proper heat treatment, leading to the optimal combinations of mechanical properties and high fracture toughness, can be performed.

The CHT diagrams [5,6] contribute to advances related to successive transformations during tempering (e.g. by means of the change of heating rate, temperature and time of soaking) and respectively, to achieving advantageous properties, and high fracture toughness in particular. With help of CHT diagrams, the kinetics of phase transformations during tempering can be described. This, among other things, is specially important in respect to HS18-0-1 high-speed steels [7,8] and HS6-5-2 high-speed steels [9], in high carbon alloy steels, differing from investigated steels only in higher content of carbon [10], and also in steels with changeable content manganese [5], silicon [6], nickel [11] and vanadium [12].

2. Test material

The chemical composition investigated steel is presented in Table 1. For earlier investigations [4] it was found, that the optimal temperature of austenitizing should be between 850 and 870°C.

Table 1.
Chemical composition of the investigated steel

Grade	mass %					
	C	Mn	Si	Cr	Mo	V
35MnCrMoV8-6-4-1	0.37	1.93	0.35	1.60	0.43	0.12

Designing the tempering conditions for a new steel gives an opportunity to define the kinetics of phase transformations during tempering to obtain tools (rolls) made out of that steel having good fracture toughness. For this purpose, a knowledge of CHT diagram, illustrating a kinetics of phase transformations during tempering (heating from quenched state), is needed.

3. Experimental procedure

The dilatometric tests were performed using DT1000 dilatometer manufactured by Adamel in France. The samples (∅2x12 mm), after prior quenching from 870°C (austenitizing time 20min), were heated with various rates up to 700°C. The digitally recorded heating dilatograms enabled drawing the CHT diagrams of tested steel in temperature – time system, according to the characteristic points read out from differential curves.

Investigations were performed on quenched and subquenched samples to determine a retained austenite transformations temperature range. Samples were subquenched in liquid nitrogen (circa –196°C) by 1 h.

In the case of investigations of the microstructural changes, quenched samples were heated with a heating rate of 0.05°C/s to the temperatures of 210, 320 and 420°C. The microstructure of investigated steel were examined using and transmission JEM200CX microscope.

The measurements of hardness were performed using the Vickers HPO250 apparatus.

4. Research results and discussion

Fig. 1a shows an example of heating dilatogram of the investigated steel heated up rate of 0.05°C/s with the corresponding differential curve on which the temperatures of beginnings (letter s) and ends (letter f) of respective transformations are presented. This is the method of interpretation of the results that was used to make the CHT diagram of this steel. As it can be observed, this steel reveals a shrinkage at first, which is connected with the precipitation of ε carbide. This shrinkage starts at the temperature of ε_s and ends at the temperature of ε_f. The positive dilatation effect, connected with the transformation of retained austenite, is very clear. It is visible in the range of temperatures $RA_s \div RA_f$. The problem of remaining volume of retained austenite was described in works [9,13]. Cementite precipitates in the range of temperatures $(M_3C)_s \div (M_3C)_f$.

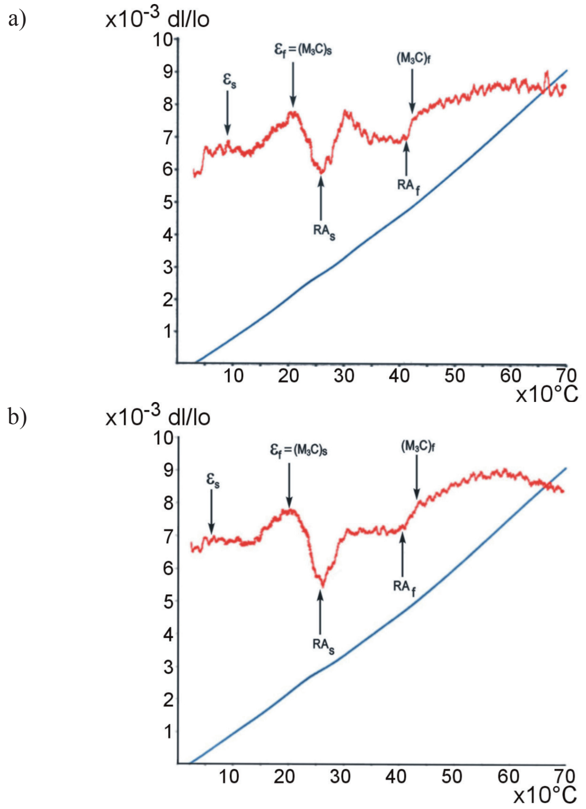

Fig. 1. Dilatograms of heating with the rate 0.05°/s for samples: a) previously hardened from 870°C, b) previously hardened from 870°C and in liquid nitrogen by 1 hour subquenched, with the corresponding differentiation curves

Fig. 1b shows compare heating dilatogram of the investigated steel quenched from 870°C, then subquenched in liquid nitrogen by 1 h and heated with 0.05°C/s rate with the corresponding differential curve. A difference between dilatations effects is shown on Figs 1a and 1b results from subquenching in liquid nitrogen (direct after quenched from 870°C). A difference in volume fraction of retained austenite of both samples is clearly visible. It is shown, that an effect of a positive dilatation in subquenched sample (Fig. 1b) is smaller than analogous effect in a sample solely hardened (Fig. 1a).

Fig. 2 presents a new CHT diagram for the investigation steel. The diagram contains the ranges of precipitation of ε carbide, transformations of retained austenite and precipitation of cementite. Due to the low austenitizing temperature, an effect relating to precipitation of alloy carbides of MC and M_2C type (c.f. [4]) wasn't found.

The microstructur of tested steel after quenched from 870°C are shown on Fig. 3.a. Directly after quenched from 870°C microstructure consist of martensite and retained austenite.

The microstructures of tested steel which was quenched from 870°C and subsequently heated with the 0.05°C/s rate (c.f. Fig.2) up to 210, 320 and 420°C are show on Fig. 3b÷d. These are the characteristic temperatures at which the following phenomena were observed on the tempering dilatograms for the 0.05°C/s

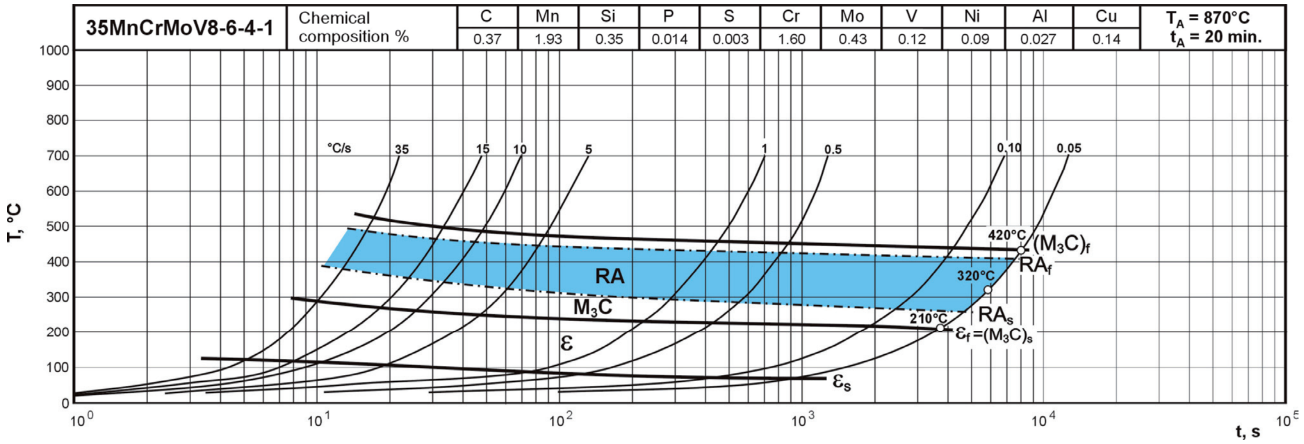

Fig. 2. CHT diagram of the investigated steel

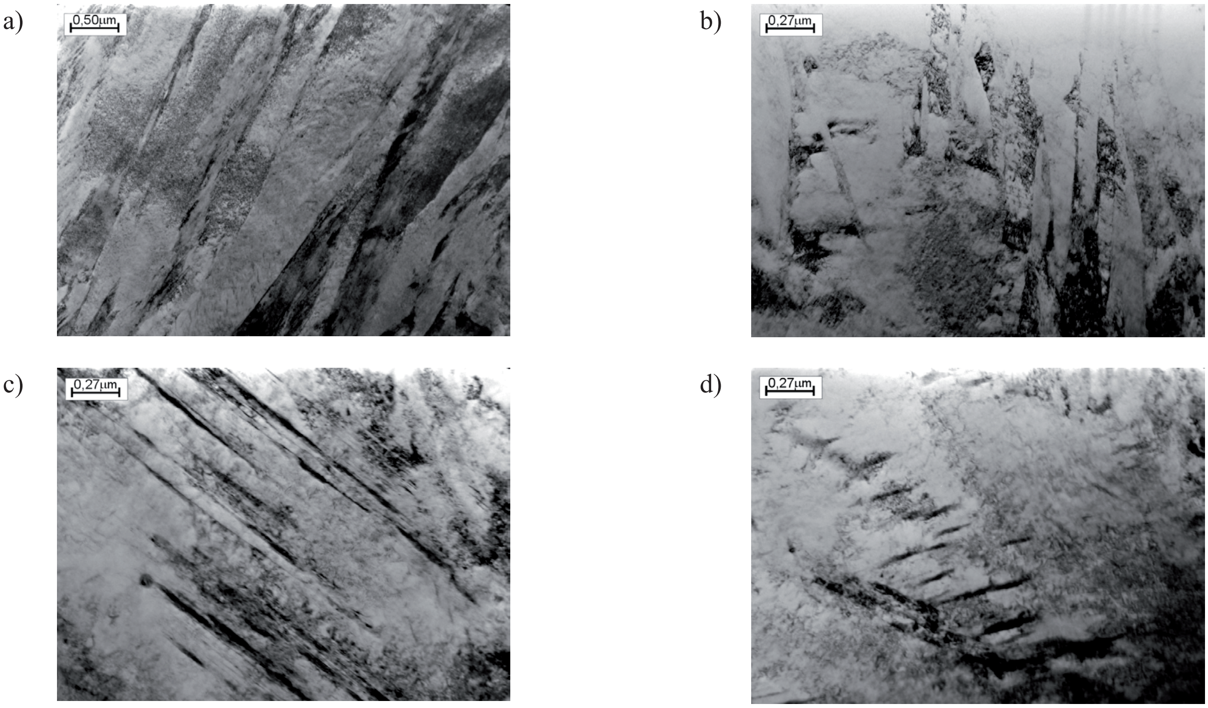

Fig. 3. Microstructures of the investigated steel a) after hardening from 870°C; after hardening from 870°C and heating with the rate 0,05°C/s to: b) 210°C, c) 320°C, d) 420°C, TEM

heating rate: the end of precipitation of ε carbide (before the beginning of transformation of retained austenite), maximum effect of transformation of retained austenite and the end of cementite precipitation. The presented microphotographs indicate a diversified rate of advancement of transformations during tempering depending on the temperature up which the quenched samples of the tested steel were heated.

Heating up to 210°C caused precipitating of ε carbides, which are visible as small dispersion particles on the pictures from TEM [15]. Heating to this temperature doesn't cause other changes in the structure of investigated steel. Heating the samples to the temperature of 320°C resulted in some further structural changes. On microphotography from TEM one can see a cementite precipitated in a form of long plates. However, a volume fraction of retained austenite observed in the structure was the same. The structure was submitted to tempering, what is clearly seen on microphotographs from TEM.

Whereas heating to 420°C caused complete transformation of retained austenite and precipitation of greater volume of cementite particles, visible even on the pictures from TEM.

Fig. 4 shows the change of hardness of samples of tested samples depending on the heating temperature after quenching.

As it can be seen, a hardness after quenching is 597HV10. After heating to 210°C, when precipitation of ε carbides from martensite ended, hardness decreased for about 37HV10. After heating the sample made of investigated steel to 320°C, despite proceeding precipitation of cementite (M_3C) and transformation of retained austenite, hardness additionally decreased for about 69HV10. After the end of transformation of retained austenite and precipitated cementite at the temperature of 420°C, hardness of investigated steel was still high (464HV10). Only heating up to 700°C caused considerable decrease in hardness to 306HV10, which was connected with the phenomena of spheroidization and coagulation of cementite.

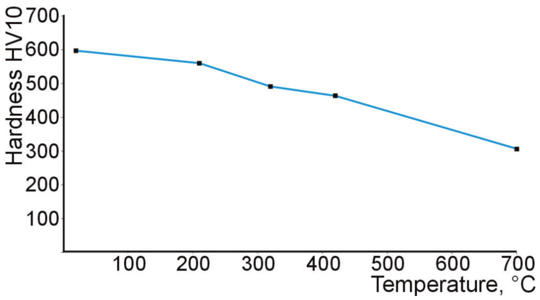

Fig. 4. Influence of hardness of samples made of tested steel on the heating temperature after quenching

5. Conclusions

During heating the samples from the quenched state, an occurrence of three principal transformations was determined: precipitation of ε carbide, M_3C precipitation and transformation of retained austenite. Although tested steel contains 0.37%C, and also Mo and V, a differential effect connected with precipitation of alloy carbides of MC and M_2C type wasn't found. However, it was found that the positive dilatation effect is connected with the transformation of retained austenite. The start and the end of this transformation was recorded during investigations (in all range of used heating rates) in the temperature range of cementite precipitation, that means between temperature $(M_3C)_s$ i $(M_3C)_f$. Application of subquenching the samples allowed on precise determination of the temperature range of transformation of retained austenite. A TEM investigations focused on determination of a degree of phase transformations during continuous tempering, showed compatibility of the microstructure with CHT diagram for tested steel. Investigations of changes of hardness with tempering temperature showed, that tested steel characterize small inclination to soften with tempering temperature.

Acknowledgments

Research financed by the KBN Ministry of Scientific Research and Information Technology, grant No. 3 T08A 031 28.

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