

Comparison of the secondary hardness effect after tempering of the hot-work tool steels

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Properties

ABSTRACT

Purpose: of this paper was to examine of the secondary hardness effect after tempering of the developed complex hot-work tool steel 47CrMoWVTiCeZr16-26-8 in relation to standard hot-work tool steel X40CrMoV5-1.

Design/methodology/approach: The investigations steels were made using the specimens made from the experimental steel, for which the working 47CrMoW-V-TiCe-Zr16-26-8 denotation was adopted, similar to the ones used in the ISO Standard on using the standard alloy hot-work tool steel X40CrMoV5-1. Both investigated steels were melted in a vacuum electric furnace. Specimens made from the investigated steels were heat treated with austenitizing in salt bath furnaces for 30 minutes in the temperature range of 970-1180°C with gradation of 30°C. Next, the specimens were tempered twice in the temperature range of 450-660°C for 2 hours.

Findings: The secondary hardness effect after tempering from temperature of 540°C in the 47CrMoW-V-Ti-CeZr16-26-8 steel and from temperature of 510°C for the X40CrMoV5-1 steel, which is caused by the carbides M_4C_3 and M_7C_3 in the 47CrMoWVTiCeZr16-26-8 steel and M_7C_3 in the X40CrMoV5-1 steel.

Practical implications: The developed complex hot-work tool steel 47CrMoWVTiCeZr16-26-8 can be used to the hot work small-size tools which requires higher strength properties at elevated temperature

Originality/value: The obtained results show the influence of the chemical compositions on the secondary hardness effect after tempering in the hot-work tool steel. The secondary hardness effect after tempering determined structure and mechanical properties in the this kinds of steels group.

Keywords: Heat treatment; Tool materials; Hot work tool steels; Structure; Secondary hardness effect

1. Introduction

The hot work tool steels used for tools in metals, composite, or ceramics processing technological processes decide to a great extent the reliability and throughout of entire production lines. Increase of the mechanical properties and thermal fatigue resistance of this steel group is realised currently in several main directions, by among others, development of new multi-component hot work steels, modification of chemical composition

of the standard hot work tool steels, deposition of coatings with the PVD and CVD methods and of laser alloyed gradient layer as well as alloying of the standard hot work tool steels [1-7]. Many year long research on development of the new multi-component hot work tool steels, carried out at the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology make it possible to state that the multi-component steels are characterised by high mechanical properties and thermal fatigue resistance comparable with the standard steels [8-12].

The purpose of this paper is to examine the influence of the chemical compositions on the secondary hardness effect after tempering in the investigated hot-work tool steel 47CrMoWVTiCeZr16-26-8 in relation to standard hot-work tool steel X40CrMoV5-1.

2. Experimental procedure

The investigations were made using the specimens made from the experimental steel, for which the working 47CrMoWVTiCeZr16-26-8 denotation was adopted, similar to the ones used in the ISO Standard [13] on using the standard alloy hot-work tool steel X40CrMoV5-1. Chemical compositions of these steels are given in table 1. Specimens made from the investigated steels were heat treated with austenitizing in salt bath furnaces for 30 minutes at the temperature range of 970-1180°C with gradation of 30°C and the preceding gradual heating up with holding at temperatures of 650 and 850°C for 15 minutes. Afterwards the specimens were tempered twice in a chamber furnace with the argon protective atmosphere, in the temperature range of 450-660°C for 2 hours. Investigations of structure were made on specimens in the soft annealed, quenched, as well as in the quenched and tempered states. Metallographic investigations were made using the Leica MEF4A metallographic microscope using the Leica-Qwin computerised image analysis system and using the Opton DSM-940 scanning microscope. Afterwards diffraction and chemical composition investigations in micro-regions and of the thin foils' and carbide extraction replica microstructures were made in the JEOL 200CX transmission electron microscope with the accelerating voltage of 200 kV, equipped with the Oxford EDS LINK ISIS energy dispersive X-ray spectrometer. Analyses of the crystallographic relationships occurring between the identified phases were made using the stereographical projections. Thin foils were made by mechanical thinning and electrolytical polishing in the Struers Tenupol-5 jet polishing machine. Hardness tests of the investigated steels were made using the Rockwell method in scale C on quenched, as well as quenched and tempered specimens, for all heat treatment variants, making 15 measurements for each material state and calculating their average value.

3. Results and discussion

The structure and properties of examined 47CrMoWVTiCeZr16-26-8 steel and of the X40CrMoV5-1 subject to significant alterations during tempering. As a result of hardness examinations performed it was found that as tempering

temperature increased commencing from 450°C the hardness of both examined quenched steel from temperature 970-1180°C increased, reaching the maximum value approximately 54 HRC after tempering at the temperature 540°C for 47CrMoWVTiCeZr16-26-8 steel, whereas the X40CrMoV5-1 steel reaches the maximum hardness value approximately 58 HRC after tempering at 510°C (Fig. 1). Thus, the tempering temperatures 540°C for 47CrMoWVTiCeZr16-26-8 steel and for X40CrMoV5-1 steel are the temperatures of secondary hardness effect occurrence during tempering.

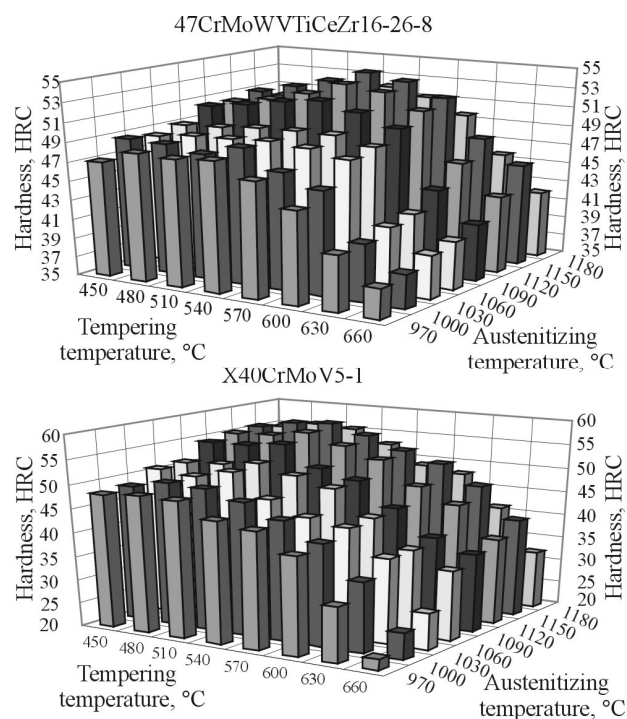


Fig. 1. Effect of the austenitizing and tempering temperature on the investigated steels hardness

The structure examinations accomplished by means of electron microscopy methods show that in steel under examination as quenched and tempered at the temperature 450°C – separation of alloy cementite from martensite occurs, which fact contributes to reduction of steel hardness as compared with quenched condition. The cementite being separated shows in most cases Bagariacki's orientation in relation to martensite matrix (Fig. 2) [14]:

$$\begin{aligned} (001) M_3C &\parallel \{211\} \alpha \\ [010] M_3C &\parallel \langle 111 \rangle \alpha. \end{aligned}$$

Table 1.

Chemical composition of the investigated steels

Steel denotation	Mass concentration of elements, %											
	C	Mn	Si	Cr	W	Mo	V	Ti	Ce	Zr	P	S
47CrMoWVTiCeZr16-26-8	0.47	0.13	0.27	4.04	1.97	2.60	1.10	0.26	0.1	0.06	0.012	0.008
X40CrMoV5-1	0.41	0.44	1.09	5.40	0.01	1.41	0.95	–	–	–	0.015	0.010

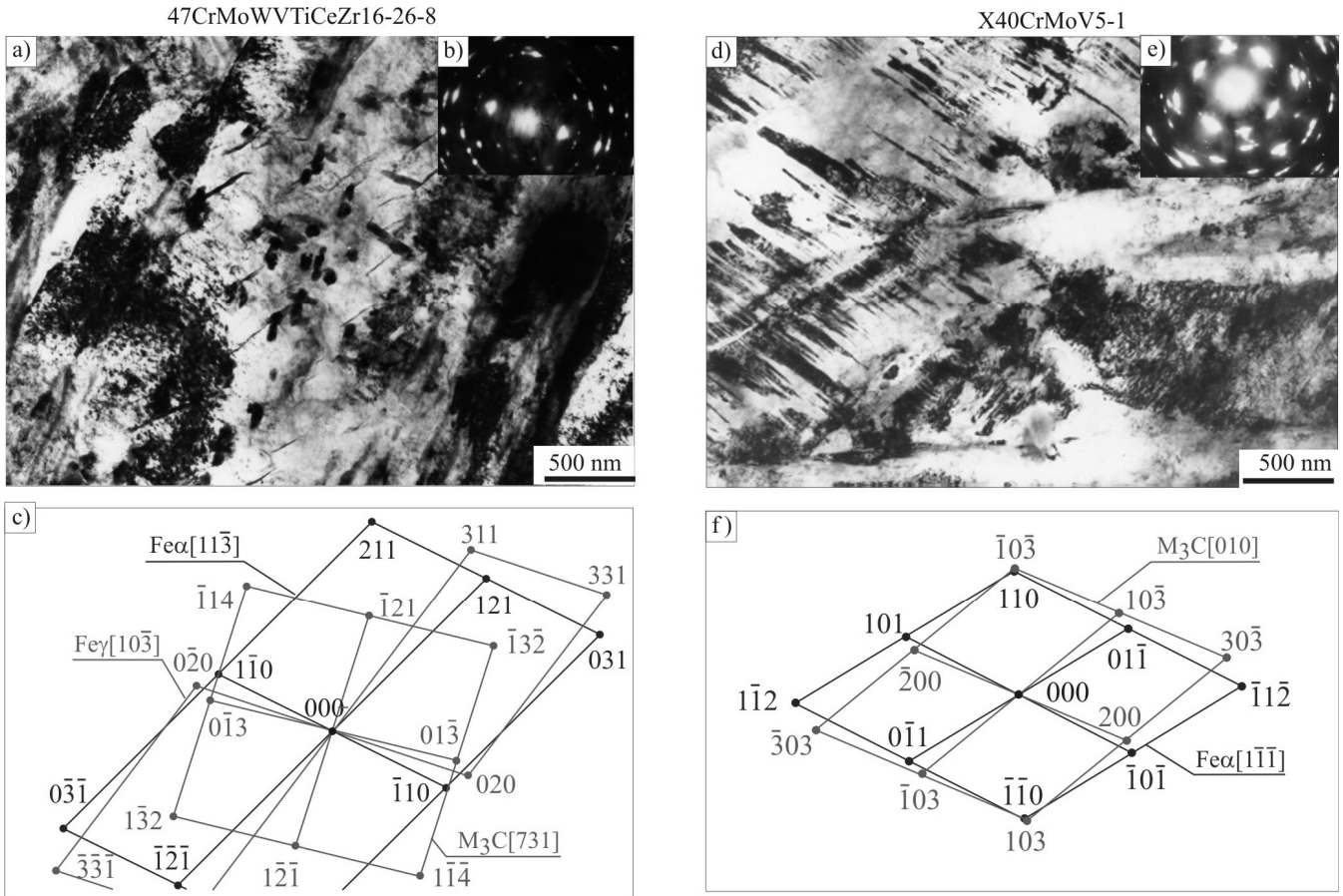


Fig. 2. a-c) Structure of the 47CrMoWVTiCeZr16-26-8 steel after quenching at 1120°C and tempering at 450°C, d-f) Structure of the X40CrMoV5-1 steel after quenching at 1060°C and tempering at 450°C

Starting from tempering temperature 480°C the coalescence occurs and dissolving the alloy cementite in solid solution as well as independent separation of M_7C_3 carbides starts in X40CrMoV5-1 steel as well as – above the temperature 510°C – also the M_4C_3 carbides in 47CrMoWVTiCeZr16-26-8 steel, causing the secondary hardness effect after tempering the 47CrMoWVTiCeZr16-26-8 steel in temperature 540°C, and X40CrMoV5-1 steel – at 510°C. The M_4C_3 type carbides are isomorphous with VC, and their determination proves also the presence of other carbide-creative elements as well as insufficiency of carbon atoms in crystal lattice. The M_4C_3 type carbides fulfil the Baker-Nutting crystallographic relationship in relation to martensitic matrix [15]:

$$\begin{matrix} (100) M_4C_3 \\ \langle 100 \rangle M_4C_3 \end{matrix} \parallel \begin{matrix} \{100\} \alpha \\ \langle 110 \rangle \alpha \end{matrix}$$

The presence of MC (M_4C_3) type carbides in steels under discussion, thermally treated under conditions providing the maximum effect of secondary hardness, were also confirmed by examination of carbon extraction replica. Increasing the hardness after tempering at the temperature of occurrence of the secondary hardness effect in both examined steel can be only slightly

affected by retained austenite transformation into α phase, because fraction of the γ phase in both examined steel is very small, i.e. below the limit of detection using X-ray radiography method. In thin foils of the 47CrMoWVTiCeZr16-26-8 steel the retained austenite has been identified after tempering at the temperature up to 510°C. In the X40CrMoV5-1 steel, during tempering at the temperature 540°C the M_4C_3 type dispersion carbides are separated, and their presence contributes to limitation of decrease of hardness of steel connected with decrease of carbon concentration as well as martensite matrix recovery (Fig. 3).

Increase the tempering temperature above 600°C causes advancing recovery in both examined steel and then commencing the recrystallization of the matrix as well as separation and coagulation of alloy carbides which fact is the reason for considerable hardness drop. Using the X-ray diffraction of carbides which were separated from the 47CrMoWVTiCeZr16-26-8 steel tempered at the temperature 660°C it was found that during tempering separation of M_6C , MC (M_4C_3) as well as M_2C type carbides occurs (isomorphous with Mo_2C carbides of hexagonal lattice and similar parameters $a \approx 0.295$ nm and $c \approx 0.463$ nm).

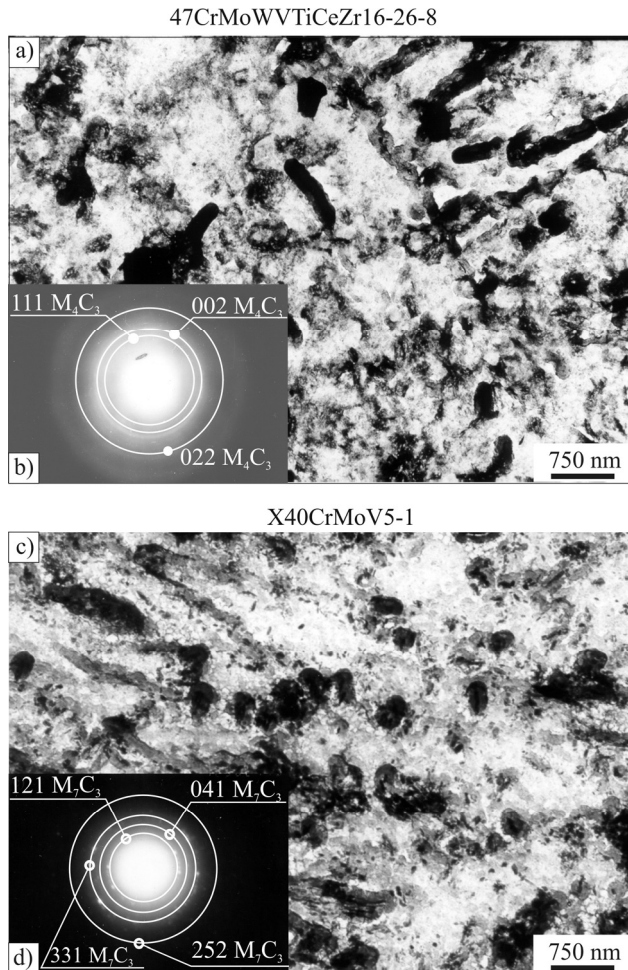


Fig. 3. Precipitated carbides extracted on the carbon replica: (a-b) the M_4C_3 type from the 47CrMoWVTiCeZr16-26-8 steel after quenching at 1120°C and tempering at 540°C, (c-d) the M_7C_3 type from the X40CrMoV5-1 steel after quenching at 1060°C and tempering at 510°C

4. Conclusions

Tempering the examined steels within the range of temperatures between 450-540°C results in starting the precipitation processes in martensite and the secondary hardness effect after tempering from temperature of 540°C in the 47CrMoWVTiCeZr16-26-8 steel and from temperature of 510°C for the X40CrMoV5-1 steel, which is caused by the carbides M_4C_3 and M_7C_3 in the 47CrMoWVTiCeZr16-26-8 steel and M_7C_3 in the X40CrMoV5-1 steel.

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