Erratum to: Effect of Tempering on the Structure and Coercive Force in the AISI D3 (217H12WF) Ledeburite Chromium Steel

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Abstract The main purpose of the studies was to establish the effect of the tempering temperature on the changes of carbide and retained austenite contents. It has been found that the course of changes of the coercive force of hardened steel after austenitizing is qualitatively similar to the hardness changes. That means in practice it is possible to determine the 217H12WF steel hardness based on the measurement of the coercive force.

Keywords AISI D3/217H12WF steel · Tempering · Structure · Carbides · Hardness · Coercive force

1 Introduction

Extensive investigations concerned with the effect of tempering on mechanical properties of the steel of type 2% C and 12% Cr were carried out by many authors [1–12]. It results from the works that in these steels, hardened after austenitizing at 1,000–1,150°C, an increase in hardness after the tempering is achieved in the temperature range of 350–600°C, with the magnitude dependent on the type of steel. This effect is related to the bainitic transformation into

retained austenite, and in some steels also partly the transformation into martensite. According to Haberling and Schruoff [7], in three studied ledeburite chromium steels with the additives of Mo (0.66–0.79%), V (0.97–1.13%), and manganese (0.37–1.46%), hardened after austenitizing from 1,000 to 1,100°C, an increase in hardness is achieved after the tempering in the range of temperatures of 300–520°C. Depending on the Mo content and the tempering parameters, the secondary hardening may occur [13].

In the literature there is lack of data concerned with the effect of tempering on the coercive force of the steel of type of about 2% C and 12% Cr. Nykiel and Hryniewicz [14] revealed that the values of the coercive force of the steel rose with the austenitizing temperature increase up to about 122 Oe, at the rate of 1,150°C per 10 min.

The studies of the coercive force changes of high-speed steels as a function of the tempering temperature were carried out by Häfke et al. [15]. The steels D Mo5 and E Mo5Co5 in the hardened state indicate the coercive force of about 6,500 A/m (81.7 Oe) and 7,300 A/m (91.7 Oe), respectively. After three tempering operations at 700°C during the period of 60 min [15] the coercive force value of both steels was alike and equaled to about 1,800 A/m (22.6 Oe).

In the soft annealed steels containing about 2% C and 12% Cr, on the substrate of ferrite, the chromium–iron carbides of type M_7C_3 [16] occur with the percentage share dependent on the carbon content, varying in quite a narrow range [17]. During hardening the percentage share of carbides, due to the carbides dissolution in austenite, decreases with the rise of temperature and time of austenitizing up to 30 min [4, 18–21, 28]. It is known that, with the increase of contents of carbon and chromium in austenite during austenitizing, more retained austenite is obtained following the hardening. It is also known that the structure of the

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hardened steel is unstable and that during the tempering the process of carbides precipitation from the matrix takes place.

In the steel of type 165H12/NC10 (contents of 1.64% C, 12.35% Cr), hardened after austenitizing at 1,000°C throughout 15 min, the content of carbides rises successively with the increase of temperature of the tempering from 100 to 550°C whereas it slightly decreases in the temperature range of 550–750°C [1].

Głowacki et al. in their work [19–21] revealed that in the hardened steel of type AISI D3, after austenitizing at 950, 1050, and 1150°C with the tempering temperature rise up to 400°C, a slight increase of the carbide content had occurred. It appears the phenomenon to be more intensive just above 500°C. They indicated [19–21] that the tempering at 700°C did not lead to the precipitation of such amount of carbides as it used to appear in the annealed state.

It should be noted that no literature data was found dealing with the kinetics of precipitation of carbides during the tempering of the steel of type of about 2% C and 12% Cr with the additives of tungsten and vanadium.

The present aims of the investigations were to:

- reveal the effect of tempering of the hardened steel of type about 2% C and 12% Cr with additives of tungsten and vanadium on its hardness, coercive force, and structure;
- establish changes of the carbides contents as a function of the tempering temperature in the steel of type AISI D3 (of the composition given in Table 1);
- compare our own results with the results obtained on other steels of type of about 2% C and 12% Cr, including the additives of tungsten and vanadium.

The investigation results of the coercive force changes of this steel as a function of austenitizing and tempering temperatures may be helpful in determining the hardness of ready-to-use products (tools) of which the hardness cannot be determined by any commonly used method.

2 Experimental Procedure

2.1 Chemical Steel Composition

The studies were carried out for the steel of type AISI D3/217H12WF of chemical composition given in Table 1. The

Table 1 Chemical composition of the investigated D3 steel, in wt%

C = 1.95	Mo = 0.05	Mn = 0.44
Cr = 11.56	Ni = 0.122	P = 0.024
W = 1.32	Cu = 0.073	S = 0.022
V = 0.31	Si = 0.27	N ₂ = 0.016

samples for the studies were made of rods, forged and soft annealed, coming from the same heat.

The micrographs, with the structure of the studied annealed steel of type AISI D3 (as-received), are presented in Fig. 1.

2.2 Identification of Carbides in the Annealed and Quenched Steel

Identification studies of carbide isolates were carried out on X-ray diffractometer DRON-1.5. The isolate diffraction patterns were done using MoK_α, and to weaken MoK_β radiation, a zirconium filter was used. The lamp voltage was 45 kV, glow current was 18 mA.

The carbides identification was performed based on the values of d_{hkl} given in the works of Westgren [24], Andrews et al. [25], Narita [26], and Grafte and Lamont [27].

2.3 Heat Treatment

The scheme of the heat treatment is given in Fig. 2.

- Hardening** The steel was austenitized for 30 min at 950, 1050, and 1150°C (and 1,075°C) in the salt oven and then cooled down in the hardening oil. Samples austenitized at 950°C were heated up gradually with the sensitization at 550°C, whereas the austenitized ones at 1,050 (1,075°C), and 1,150°C with a few-minute sensitization at 550 and 850°C. The hardening operation was carried out at The Cutting Tools Plant VIS (Zakład Narzędzi Skrawających VIS).
- Tempering** The tempering of the steel at temperatures of 100–250°C was carried out in an ultrathermostat filled up with glycerin, and at temperatures of 300–700°C in the bath with lead in an electric chamber stove (two stands). The hardened samples were tempered successively in higher and higher temperatures in ultrathermostat and two stoves. A maximum time lapse from the hardening to the beginning of the tempering was about 8 h (for samples tempered at 250, 450, and 700°C). Samples were inserted in bath with the liquid lead. They were positioned and fixed in the especially prepared holder to ensure right conditions of heating and to avoid the flowing out the samples on the surface of liquid lead. Surface of the liquid lead was covered with fine-grained charcoal. The accuracy of the bath temperature control equaled about $\pm 5^\circ\text{C}$. After annealing the samples were air cooled, and afterwards the surface layer of about 0.5 mm thick was removed by a centreless grinding.

Fig. 1 Structure of studied D3 steel after soft annealing. Coarse primary carbides M_7C_3 and fine secondary carbides with trace/footprint amount of $M_{23}C_6$ on the background of ferrite alloy [4, 18, 28]. Microsections etched: **a** in 4% HNO_3 in amyl alcohol, **b** by Murakami's reagent (3 g potassium ferricyanide, 10 g NaOH, 100 ml H_2O destil.)

Fig. 2 Heat treatment of the studied AISI D3 steel schematic

2.4 Hardness Measurement

Hardness after the tempering was measured by means of a Rockwell hardness meter on C scale. The hardness measurements were carried out on four samples for each of the tempering temperatures. The average hardness was calculated based on at least 12 measurements.

2.5 Structure Investigation

The studies of structure was carried out by means of a metallographic microscope. The metallographic specimens of samples (dia. 12 mm, $l = 15$ mm), after the previous removal of a surface layer about 0.3 mm thick, were prepared by mechanical polishing using the abrasive papers of a grit size from 150 up to 1,000. Afterwards they were polished with the aqueous suspension of Al_2O_3 . The specimens were etched with a reagent of composition: 1 g picric acid, 5 ml HCl, 100 ml C_2H_5OH . The structure of the annealed steel was revealed with etching (a) in 4% HNO_3 in amyl alcohol, and (b) by the Murakami's reagent (3 g potassium ferricyanide, 10 g NaOH, 100 ml H_2O destil.).

2.6 The Retained Austenite

The content of the retained austenite in the steel matrix was determined based on the measuring of the saturation induction; the values of the saturation induction were measured by means of a magnetometer MAG-74WAT. The measurements were performed on samples of dia. 4 and 40 mm long (having a thread of 5 mm long). The contents of the retained austenite were calculated from the relationship:

$$\gamma_{\text{real}} = \frac{\alpha_0 - \alpha_1}{\alpha_0} \times 100\%$$

with α_0 being the deflection of galvanometer for a pattern/model sample, α_1 being the deflection for the studied sample. The experimental spread on the retained austenite measurement was 1.5%.

2.7 Coercive Force

The coercive force measurements were performed by means of a dr Förster's precision coercimeter of type 1094. The samples of dia. 11 and 60 mm long were used for the studies.

2.8 Determination of Carbides Contents

The determination of carbides contents was performed using the electrolytic isolation method (Fig. 3).

The carbides were isolated for the samples:

- hardened after austenitizing at 1,050°C and the tempering at temperatures of 100, 150, 200, ..., 600, and 700°C. The percentage share of carbides after the tempering at 100, 200, 300, ..., 600, and 700°C was determined based on six isolations out of four samples

Fig. 3 Scheme of electrolyzer for carbide isolation

and after the tempering at 150, 250, ..., 550°C based on at least four isolations;

- (b) hardened after austenitizing at 950 and 1,150°C and the tempering at temperatures of 100, 200, ..., 700°C. The weight share of carbides was determined on the basis of the isolation of four samples.

The electrolytic isolation of carbides was carried out in aqueous 5% solution of HCl (sp. grav. 1.19 g/cm³) at the current density of 10 mA/cm². The isolation time was about 20 h. The assumed conditions for the carbide fraction determination were close to those ones advised in the works [4, 20–23].

After the anodic dissolution of the steel matrix the samples were got out of the cell. Next the isolate from the samples surface was recovered mechanically and with the use of 5% solution of CH₃OH in H₂O. Afterwards the

recovered isolate was undergoing the following treatment by:

- double rinsing with methyl alcohol;
- scavenging with 5% NH₃ in H₂O;
- scavenging with methyl alcohol;
- drying at 100°C for 60 min.

The image of carbides isolated from the annealed AISI D3 steel is given in Fig. 4. Figure 4a presents the coarse carbides; then the fine carbides were obtained by a sedimentation method (Fig. 4b). They were not dissolving in the electrolyte used.

Each time after rinsing the isolate was centrifuged with the rotation of 6,000 rev/min. The determination of the percentage contents of carbides of the samples before the isolation and after it was performed; the isolates after drying and cooling down to the ambient temperature were prepared. Both, the samples and isolates were weighed with the accuracy of ±0.1 mg. The weight share of carbides in the steel was calculated acc. to the relationship: $w[\text{wt}\%] = \{m_w / (m_1 - m_2)\} \times 100\%$, where m_w is the weight of the dried isolate, m_1 is the weight of sample prior to the isolation, m_2 is the weight of sample after the isolation. In calculations of the confidence intervals, the significance level was assumed to $1 - \alpha = 0.95$ ($\alpha = 0.05$).

3 Investigation Results

3.1 Identification of Carbides in the Annealed and Hardened States of the D3 Steel

In Fig. 5 there are carbides identified after annealing and hardening of the D3 steel. The identification studies of carbide isolates obtained by the method of electrolytic extraction on the samples of investigated annealed D3 steel

Fig. 4 Image of carbides isolated from the studied annealed D3 steel after their coarse separation by a sedimentation method: **a** fraction with predominance of primary carbides and **b** fraction with predominance of fine secondary carbides. Carbides mounted in epoxy resin Epidian 5. Microsection prepared mechanically, magnification 700×

Fig. 5 Diffraction patterns obtained from: **a** annealed D3 steel and **b** hardened D3 steel after austenitizing at 1,050°C for 30 min

revealed the occurrence of carbides type M_7C_3 and some insignificant amount of $M_{23}C_6$. A fragment of the isolate diffraction pattern is presented in Fig. 5a. Apart from M_7C_3 carbides, the following reflexes from crystallographic planes: (420), (422), (622), and (644)(820), (555)(751), obtained at higher angles than those given in Fig. 5a, prove of the occurrence of $M_{23}C_6$ carbides.

According to Kuo [10] the presence of tungsten in chromium steels favours the occurrence of carbide $M_{23}C_6$ on the basis of carbide $Fe_{21}W_2C$. In the studied D3 steel, $M_{23}C_6$ carbides dissolve completely in austenite during austenitizing at 1,050°C for 30 min (Fig. 5b).

3.2 Effect of Tempering Temperature on the Hardness of Investigated Type D3 Steel

The effect of tempering temperature on the hardened steel hardness after austenitizing at 950, 1050, 1075, and 1150°C for 30 min is presented in Fig. 6.

It results from Fig. 6 that the studied steel, hardened after austenitizing at 950 and 1050°C, loses its hardness to a significant degree after the tempering at temperatures up to 300°C, whereas after the tempering in the temperature interval of 300–400°C the hardness practically does not change. Hardness of the steel hardened after austenitizing at temperatures of 1050, 1075, and 1150°C rises after the tempering in the temperature intervals of 400–500, 400–525, and 400–550°C, respectively. The highest growth of hardness, i.e. of 20.4 HRC was obtained for the steel samples hardened after austenitizing at 1,150°C, and the tempering them at 550°C, while the highest hardness after

Fig. 6 Effect of tempering temperature on hardness of the studied D3 type steel austenitized at: filled circle 950°C, open circle 1,050°C, open triangle 1,150°C, open diamond 1,075°C for 30 min; tempered generally at 100–700°C (400–550°C for samples austenitized at 1,075°C) for 120 min

the tempering in the temperature interval of 400–550°C for 120 min, equaling 62.1 HRC, was obtained for the hardened steel after austenitizing at 1,075°C, and the tempering temperature of 525°C.

A progressive drop of hardness of the steel hardened after austenitizing at 950, 1050, and 1150°C, and tempering at the temperatures above 450, 500, and 550°C, respectively, is the result of the occurrence of the processes of spheroidization, coagulation, and coalescence of carbides, and with this, also a simultaneous increasing the free course of ferrite.

3.3 Effect of Tempering Temperature on the Structure of Investigated Type D3 Steel

The structures of the hardened steel after austenitizing at 1,050 and 1,150°C and the tempering for 2 h are presented in Figs. 7 and 8, respectively. The effect of the tempering temperature on the retained austenite content was determined by a magnetic method (Fig. 9).

The steel AISI D3 hardened after austenitizing at 1,050°C and tempered at 100°C possesses the structure composed of big primary carbides and fine secondary carbides which had not dissolved during austenitizing on the matrix of fine-acicular martensite and retained austenite (Fig. 7a). The fraction of the retained austenite in the matrix equals about 39.5% (Fig. 9). With the temperature increase the content of carbides liberated from martensite has increased. The liberation of carbides from the retained austenite and the following transformation into bainite proceeds during the tempering in the temperature interval of about 400 up to 570°C (Fig. 9). After the tempering at 550°C there is still 6.9% of the retained austenite in the matrix. The tempering within temperatures of 600–700°C leads to the originating of the fine pearlite structure.

The studied AISI D3 steel, hardened after austenitizing at 1,150°C and tempering at 100°C, possesses the structure consisting of primary and secondary carbides on the matrix

of austenite (Fig. 8a). In the matrix, in some areas of segregation of the big primary carbides, the presence of trace amounts of coarse-acicular martensite may be noticed.

The fraction of this martensite determined by means of the magnetometer equals about 1.5% (Fig. 9). The austenite present in the AISI D3 steel undergoes the transformation into the fine pearlite, bainite and partly in martensite during tempering in the temperature interval from about 450°C up to about 610°C (Figs. 8, 9). During the tempering at 700°C the austenite undergoes transformation into the fine pearlite of higher homogeneity than that obtained after the tempering at 600°C (Fig. 8e, f).

3.4 Effect of Tempering Temperature on the Carbides Contents in D3 Steel

Variations of the carbides contents in the studied steel, as a function of austenitizing and tempering temperatures, have been presented in Fig. 10. The method of the electrolytic isolation was used for the studies.

It results from Fig. 10 that, for the studied hardened steel after austenitizing at 950 and 1,050°C, one may differentiate two ranges of temperatures differing by the intensity of carbides precipitation, namely the range of 100 to about 400°C, and the range of 400 up to 700°C. During

Fig. 7 Effect of tempering temperature on structure of studied D3 steel hardened after austenitizing at 1,050°C/30 min: **a** 100°C, **b** 400°C, **c** 550°C, **d** 700°C. Tempering time 120 min. Samples etched in 1 g picric acid, 5 ml HCl, 100 ml C₂H₅OH

Fig. 8 Effect of tempering temperature on structure of studied D3 steel hardened after austenitizing at 1,150°C/30 min: **a** 100°C, **b** 450°C, **c** 500°C, **d** 550°C, **e** 600°C, **f** 700°C. Tempering time 120 min. Samples etched in 1 g picric acid, 5 ml HCl, 100 ml C₂H₅OH

the tempering at temperatures up to 400°C the carbides precipitate from martensite only and their amount is rather small. During the tempering at that temperature of the hardened steel after austenitizing at 950°C only 1.81% of carbides precipitate, and after austenitizing at 1,050°C that amount is even less, i.e. 1.3%. Distinctly higher growth of the carbides contents as a function of the tempering temperature in the temperature range of 400–700°C results first of all from the residual austenite transformation and the higher diffusion rate of carbon and alloying elements.

During the tempering of the steel of such structure the carbides do not begin to precipitate before the temperature

of about 400°C, and then, above 500°C, they precipitate with a high intensity.

The characteristic phenomenon is that after the tempering at 700°C throughout 120 min of the studied steel, hardened after austenitizing at 950, 1050, and 1150°C, the contents of carbides are lower than that in the annealed steel. For the austenitizing temperatures as given above, the carbides contents are lesser than 1.26, 1.41, and 2.11%, respectively.

The investigation results, concerning the effect of the tempering temperature on the contents of carbides in the steels of type of 2% C and 12% Cr, hardened after

Fig. 9 Effect of annealing temperature on retained austenite content in the matrix and D3 steel hardened after austenitizing at 950, 1050, and 1150°C determined with magnetic method

Fig. 10 Effect of tempering temperature on the carbides contents in steel of type AISI D3/217H12WF hardened after austenitizing in temperatures of 950, 1050, and 1150°C

austenitizing at temperatures of 950, 1050, and 1150°C for 30 min, are presented in Fig. 11.

In the studied steels, after the tempering at 100°C, no increase of carbides contents was found. It results from Fig. 11a that the weight share of carbides in the steels with the additives of tungsten and vanadium in AISI D3/217H12WF is higher than that in the steel 195H12/NC11, and lower than that in the steel NC11N, with a higher nitrogen content. In the steel of type NC11N, hardened after austenitizing at 950 and 1,050°C (Fig. 11b), the weight share of carbides rises successively up to 500°C and then, after a deflection, rises again from 600 to 700°C. In the hardened steels after austenitizing at 1,050°C (Fig. 11b) the course of changes of carbides contents as a function of tempering temperature is different, i.e. in NC11N steel the intensity of carbides precipitation (not before the tempering at temperatures above 300°C) is very small.

A similar phenomenon occurs in the steels of type 217H12WF/AISI D3 but in the temperature ranges up to 400°C. After the tempering at that temperature the following amount of carbides 1.6% D3(a) and 1.3% D3(b) precipitates from martensite, and 0.9% from NC11N (after tempering at 300°C). Quite different is the course of changes of carbides contents in the investigated steels hardened after austenitizing at 1,150°C (Fig. 11c). In the steel 195H12/NC11 the carbides do not begin to precipitate from austenite before the tempering at temperature above 300°C, and in NC11N and 217H12WF/AISI D3 above 400°C, and very intensively above 500°C. In the temperature range of 400–500°C the highest amount of carbides precipitates in the steel NC11N and the least amount in the steel 217H12WF/D3(a).

One may assume that tungsten and vanadium present in the steels of type 2% C and 12% Cr, alike the nitrogen in NC11N steel, are shifting the temperature of intensive precipitation of carbides during the tempering into higher values. Tungsten is believed to play a dominating part because its concentration in the matrix of the hardened steel is considerably higher than the vanadium concentration. For example, the matrix of the steels of type 217H12WF/AISI D3 hardened after austenitizing at 1,050°C for 30 min contains 0.82% of tungsten and only 0.023% of vanadium, and after austenitizing at 1,150°C it contains 1.1% W and 0.065% V, respectively [4, 18, 28–31]. A similar phenomenon, concerning tungsten and vanadium contents in the matrix, was also found in the other steel of this type 217H12WF/AISI D3(b) hardened after austenitizing at 900 to 1,150°C [13, 15].

Some characteristic phenomenon is that after the tempering at 700°C throughout 120 min in each of the analyzed steels, apart from NC11N steel, the contents of carbides are lower than in the steels under soft-annealed state. In the steel NC11N after the tempering at 700°C the carbides contents are significantly higher than the contents in the steel under annealed state.

3.5 Effect of Tempering Temperature on the Coercive Force of Investigated Steel of D3 Type

The coercive force of a steel is dependent on its chemical composition, structure, elastic stresses, the presence of plastic deformation, and contaminations [9, 10, 31–34]. The value of the coercive force of D3 steel in the annealed state equals about 11 Oe [31]. In the processes of heat treatment not only the structure of the treated parts undergoes transformation but also the state of the own internal stresses as well. The biggest stresses arise during the austenite–martensite transformation. They may be decreased or removed completely during tempering. The appearance of the internal stresses in the steel results in the

Fig. 11 Effect of tempering temperature on the carbides contents in the steels: 195H12/NC11 (2.14% C, 11.5% Cr, 0.017% N₂) [19, 20], and of increased nitrogen contents NC11N (2.20% C, 12.48% Cr, 0.06% N₂) [19, 20], and of type 217H12WF/AISI D3(a) [4, 21], and AISI D3(b) [30] for hardening temperature: **a** 950°C, **b** 1050°C, **c** 1150°C; austenitizing time 30 min, tempering time 120 min

increase of coercive force. The effect of the tempering temperature on the coercive force of D3 steel is presented in Fig. 12.

The confidence semi-intervals calculated for the coercive force studied have been presented in Table 2.

It results from Fig. 12 that the coercive force of the studied steel hardened after austenitizing at 950°C throughout 30 min decreases in a small degree with the increase of the tempering temperature up to 450°C, i.e. from 66.5 to 59.4 Oe, and afterwards at higher

Fig. 12 Effect of tempering temperature on coercive force of D3 steel hardened after austenitizing at 950, 1050, and 1150°C throughout 30 min

temperatures, after the tempering at 700°C, it sharply decreases down to the value of 15.7 Oe.

The coercive force of the steel hardened after austenitizing at 1,050°C decreases with the growth of the tempering temperature of 100–200°C from 69.3 to 64.9 Oe, respectively, whereas in the temperature interval of 200–500°C it rises up to the value of 75.1 Oe. At higher temperatures, alike in the hardened steel from the temperature of 950°C, the coercive force decreases rapidly.

It is most probable that the increase of the coercive force of the steel after the tempering at temperatures of 200–500°C results from the formation of very fine carbides ϵ , χ and M_3C (Fe_3C), and first of all (at higher temperatures) from the proceeding of bainitic transformation of the retained austenite. The available literature does not provide any data on the effect of the above mentioned microconstituents on the coercive force. In the hardened steel, after austenitizing at 1,050°C, there is much more retained austenite than in the hardened steel after austenitizing at

950°C. Thus there is a different course of changes in the coercive force as the function of the tempering temperatures of 200–500°C.

As discussed previously the studied steel, hardened after austenitizing at 1,150°C throughout 30 min, possesses the austenite–carbide structure. The coercive force of this steel of that structure equals about 119 Oe. It results from Fig. 12 that after the tempering at the temperature of 300°C a slight decrease of the coercive force of about 7 Oe occurs. On the other hand, after the tempering at 500°C, the coercive force of the steel rises up to the value of 122.2 Oe and it is only of about 3 Oe higher than that in the hardened state. After the tempering at the temperatures above 500°C the coercive force of the steel decreases with the most intensive decrease after the tempering at 600°C. It should be also noted that the changes of the coercive force of the steel, hardened after austenitizing at 1,150°C and tempering at the temperature range of 500–550°C, are distinctly lower than the hardness changes.

A rapid fall of the coercive force of the steel, hardened after austenitizing at 950, 1050, and 1150°C and tempering above 450, 500, and 550°C, respectively, is the result of the progressive changes (with the temperature growth, the coagulation and coalescence of carbides), in the structure of matrix and the diminishing the internal stresses. In case of samples of the steel hardened after austenitizing at 1,150°C, apart from the mentioned above factors, the pearlitic transformation of the retained austenite have a decisive influence on the drop of the coercive force after the tempering above 550°C. It is worthy to note that the changes of the coercive force of the steel, hardened after austenitizing at 1,150°C and tempering at the temperatures of 500–550°C, are considerably less than the changes in hardnesses. To clarify this phenomenon some additional further studies are needed in the future.

An increase of the steel hardness after the tempering in the higher given temperature intervals is the effect of

Table 2 Confidence semi-intervals calculated for coercive force studied

Tempering temperature	Austenitizing temperature/time (°C/min)					
	950/30		1,050/30		1,150/30	
	Average coercive force	Confidence semi-interval	Average coercive force	Confidence semi-interval	Average coercive force	Confidence semi-interval
100	66.5	1.0	69.3	1.8	119.1	2.2
200	63.9	1.7	64.9	3.2	120.0	5.0
300	59.6	1.4	68.0	2.0	114.3	8.0
400	61.0	1.9	71.6	0.3	111.0	6.2
500	47.1	2.1	75.1	3.6	122.2	4.7
600	25.4	2.4	34.8	5.9	43.1	4.4
700	15.7	1.2	19.5	3.5	27.0	2.2

transformation of the retained austenite into bainite as well as partly into martensite (see Fig. 8) during the cooling after isothermal heating. The occurrence of transformation of the retained austenite into martensite is clearly apparent in the hardened steel after the high-temperature austenitizing, that is at 1,150°C.

4 Discussion

Based on the literature available and the results presented above, concerning the structure after tempering of the AISI D3 steel with the additives of W and V, one may state:

(a) concerning the carbides

- there are some fragmentary data on the carbides contents only concerning the changes of structure as a function of the tempering temperature; there are no results available such as those presented within this work in Fig. 10;
- a big number of measuring points (on tempering), especially of hardened steel after austenitizing at 1,050°C, makes it possible to determine the empirical dependence of carbides contents versus the tempering temperature; the empirical dependences will be possible also for the temperatures 950 and 1,150°C (for the tempering temperature interval of 500–700°C) after supplementing the determination of carbides contents for intermediate tempering temperatures (see Fig. 10);
- determination of carbides contents by the electrolytic extraction, is rarely used though well known; it is not a simple method, requiring a great experience and attention. It is superior over a quantitative method because the carbide isolates obtained with the method may be subjected to different examinations (chemical composition, carbides identification, etc.);
- influence of the substrate structure on the adhesion of thin films; the final results of the studies carried out by the Authors may be useful in the technology of thin films such as TiN, Ti(C,N), etc., deposited on the working surfaces of tools;

(b) concerning the coercive force

- it results from our investigations there is lack of works available on the coercive force; our attempt is to establish the relationship between the coercive force and temperature and time of austenitizing [9];
- one may assume it is possible to determine the hardness of the steel of type 2% C and 12% Cr (in this with the alloying additives) after the

tempering based on the coercive force measurement results; it may be applied to the steels hardened after austenitizing at temperatures up to about 1,100°C;

- establishing of such a relationship needs quite extended studies to be carried out taking into account the tempering of hardened samples, first of all after austenitizing at 1,000°C which is an optimal temperature of austenitizing of the studied steel.

5 Conclusions

The following conclusions may be drawn based on the results of investigations carried out:

1. Hardness of the studied steel of type 217H12WF, hardened after austenitizing at 950 and 1,050°C for 30 min, distinctly decreases with the temperature increase up to about 300°C. Hardness of the hardened steel after austenitizing at 1050, 1075, and 1150°C for 30 min rises with the increase of the tempering temperature in the ranges of about 400–500, 400–525, and 400–550°C, respectively. The highest hardness, after the tempering in the temperature range of 400–550°C, that is 62.1 HRC was obtained for samples hardened after austenitizing at 1,075°C, and tempering at 525°C (for the tempering time of 120 min).
2. The intensity of carbides precipitation during the tempering of the studied steel 217H12WF/AISI D3 hardened after austenitizing at 950 and 1,050°C distinctly rises at the temperatures above 400°C. On the other hand, in the hardened steel after austenitizing at 1,150°C, the carbides begin to precipitate during the tempering at 400°C, and with a high intensity above 500°C. The contents of carbides in the studied steel, hardened after austenitizing at 950, 1050, and 1150°C throughout 30 min and the tempering at 700°C and time of 120 min, are lower than the contents of carbides in the soft-annealed state.
3. The contents of carbides in the studied steel in annealed, hardened state, and the state after the tempering at 100–700°C are lower than the contents occurring in the steels NC11N (of higher nitrogen contents) and AISI D3/217H12WF(a), and higher than in the steel 195H12/NC11. The course of changes of carbides, as a function of the tempering temperature, is qualitatively similar to the course of changes in the steels AISI D3/217H12WF and NC11N and in the steel 195H12/NC11 but for the tempering temperatures above 300°C.

4. The tungsten and vanadium present in the hardened steel matrix result in shifting the temperature of the beginning of intensive precipitation of carbides into the temperatures higher of about 100°C in comparison with the beginning of the intensive precipitation of carbides in the steels 195H12/NC11 and NC11N.
5. The course of changes of the coercive force of the studied hardened D3 steel after austenitizing at 950 and 1,050°C for 30 min as a function of the tempering temperature is qualitatively similar to the changes of hardness. That means in practice, there is a possibility to determine the hardness of steel after the tempering based on the measurements of the coercive force. It should be stressed, however, that extensive investigations are required to take into account, used in the technological practice, the parameters of heat treatment of this steel. After the tempering of the steel, hardened after austenitizing at 1,150°C, at temperature of 550°C, a big rise in its hardness occurs; such an effect does not appear in the coercive force.

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