

The kinetics of phase transformations during tempering in high-speed steels

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Materials

ABSTRACT

Purpose: This work contains a detailed description of the kinetics of phase transformations during continuous heating from quenched state of HS18-0-1 and HS6-5-2 high-speed steels.

Design/methodology/approach: The kinetics of phase transformations during continuous heating (tempering) from as-quenched state of investigated steel, was elaborated using a DT 1000 dilatometer of a French company Adamel.

Findings: During heating of previously quenched HS18-0-1 and HS6-5-2 steel samples, the presence of four basic transformations was found, i.e. precipitation of ϵ carbide, precipitation of M_3C , transformation of retained austenite and precipitation of alloy carbides of MC and M_2C type. It was shown that in quenched high-speed steels a part of retained austenite transforms already during heating for tempering, but its significant part transforms only during cooling process after tempering.

Research limitations/implications: The substitution of tungsten with molybdenum in HS6-5-2 steel has influenced mainly the stability of retained austenite and the temperature of precipitation beginning of MC (MC_s) type carbides.

Practical implications: This results will be used to design new technologies of tempering of these steels.

Originality/value: Characterization of kinetics phase transformations during continuous heating from quenched state in high-speed steels.

Keywords: Tool materials; High-speed steel; Tempering; Retained austenite

1. Introduction

During heating from the quenched state (tempering) of unalloyed, medium and high carbon steels, an occurrence of three principal transformations can be observed: precipitation of ϵ carbide, transformation of retained austenite into lower bainite and precipitation of cementite. In steels containing alloying elements causing an effect of secondary hardening (V, Mo, W), a fourth transformation occurs: precipitation of MC and M_2C -type alloy carbides, that nucleate independently [1÷4].

During the first transformation in the temperature range of 100÷200°C, metastable ϵ carbide ($Fe_{2,4}C$) with hexagonal crystal structure precipitates from the supersaturated martensite [5,6].

Precipitation of highly dispersed ϵ carbide is believed to enhance strengthening in steel. However, the martensite with smaller carbon content is softer, what causes only a modest drop in strength and hardness of steel tempered in that temperature range [2,4].

Second transformation proceeding during tempering in the temperature range of 200÷320°C is a transformation of retained austenite. As a result of this transformation, a non-homogeneous mixture consisting of supersaturated ferrite and cementite, i.e. lower bainite forms. It should be noticed, that this transformation occurs only in steels containing more than 0.3%C because the amount of the austenite remaining in the steel after quenching strongly depends on carbon content. The austenite does not occur in steels containing less than 0.3%C [1,2,4].

Cementite is formed during the third transformation occurring during tempering in the temperature range of 200–420°C. This results in further decarbonization of the matrix and dissolution of metastable ϵ carbides allowing for recovery of the steel matrix [4,7]. The mechanism of the nucleation of cementite is, however, not fully understood yet. According to Ref. [4] precipitating cementite nucleates independently or “in situ” on ϵ carbide particles. Whereas according to Ref. [5] cementite nucleates independently, mainly on grain boundaries of former austenite or on subgrain boundaries of newly formed cell structure.

Above 400°C, diffusion of alloying elements such as V, Mo and W becomes occur as takes place. Then, the cementite gradually dissolves to make the nucleation of MC and M_2C carbides coherent with the alloy matrix possible. This leads to an increase of hardness of tempered steel and is thus referred to as secondary hardening [1–4,10–16].

2. Test material

The research was conducted on HS18-0-1 and HS6-5-2 high speed steels with the chemical compositions given in Table 1.

Table 1.
Chemical composition of the investigated steels

Grade	mass %						
	C	Mn	Si	Cr	Mo	W	V
HS18-0-1	0,85	0,27	0,31	4,26	0,50	17,0	1,26
HS6-5-2	0,85	0,30	0,31	4,14	4,61	6,55	1,94

Prior to testing the samples of investigated steels were soft annealed at 840°C/4hours, and successively cooled at the rate of 6°C/hour to 600°C, and after that to the room temperature together with the furnace.

3. Experimental procedure

The kinetics of phase transformations during continuous heating (tempering) from as-quenched state of investigated steels, was elaborated using a DT 1000 dilatometer of a French company Adamel. Samples with a diameter of 2 mm and a height of 12 mm, after quenching from 1260°C for HS18-0-1 and 1240°C for HS6-5-2 (austenitizing time of 150 s), were heated to 700°C with a heating rate in the range of 0.05 to 35°C/s. Digitally recorded dilatograms (engineering strain elongation $\Delta l/l_0$ in relation to the temperature T) for heated samples were differentiated, what facilitated determination of the start and end temperatures of consecutive transformations.

4. Research results and discussion

In quenched state the structure of HS18-0-1 steel consists of [eg. 14] partially twinned martensite, retained austenite in amount of 24,4% and M_6C carbides undissolved during austenitizing. Likewise the structure of HS6-5-2 steel according to [14] consists

of partially twinned martensite, retained austenite (in amount of about 27,9% vol.), and carbides undissolved during austenitizing, mainly M_6C and occasionally present MC.

Fig.1 presents HS18-0-1 steel dilatograms of heating from quenched state, together with corresponding differential curves, on which there are marked the temperatures of the beginning (letter s) and the end (letter f) of individual transition. Detailed description of phase transitions kinetics during tempering of HS18-0-1 steel in a form of CHT (Continuous Heating Transformations) diagram and change in the structure as a result of continuous heating from quenched state are present in studies [12,14].

Continuously tempered HS18-0-1 steel first exhibits the contraction related to precipitation of carbide ϵ . The contraction starts at temperature ϵ_s and ends at temperature ϵ_f . For the heating rate of 0.05°C/s, the beginning of ϵ carbides precipitation takes place at the temperature of about 80°C, which increases along with the heating rate increase up to about 150°C (35°C/s). The temperature ϵ_f approximately equals to the temperature of the beginning of cementite (M_3C)_s precipitation, therefore it was assumed that they are equal to each other. Within the range of temperature (M_3C)_s ÷ (M_3C)_f the cementite precipitates. Within the range of cementite precipitation, there is observed a positive dilatation effect connected with the transition of part of retained austenite. The effect is visible within the temperature range RA_s ÷ RA_f . For the heating rate of 0.05°C/s $RA_s = 220^\circ\text{C}$ while for 35°C/s $RA_s = 340^\circ\text{C}$, whereas RA_f increases from 320°C (for 0,05°C/s) up to 440°C (for 35°C/s). The temperature of end of cementite precipitation increases from 480°C (0,05°C/s) to 550°C (35°C/s). At temperature MC_s the independent nucleation of carbides of MC type begins. At temperature (M_2C)_s = MC_f the independent nucleation of carbides of M_2C type begins. This temperature has been determined for the heating rate of 0,05°C/s only. Application of higher heating rates makes this temperature to be higher than 700°C. As it can be noticed, the increase of heating rate from 0.05°C/s to 35°C/s results in the increase of temperatures of beginnings and the ends of individual transitions and in reduction of dilatation effects which accompany these transitions.

Fig. 2 presents cooling dilatograms at the rate of 1°/s of HS18–0–1 steel samples previously heated to 700°C at the rate of: a) 0.05°/s, b) 35°/s. A positive dilatation effect from transition of retained austenite for previously heated sample (tempered) at the rate of 0,05°C/s is lower but more spread out over the temperature axis than for the sample previously heated (tempered) at the rate of 35°C/s. It is most probably related to more advanced carbon and alloy elements diffusion from austenite (residual) to the boundary austenite – martensite (ferrite) at lower rate (0,05°C/s) of heating to 700°C and in this connection to transition of larger its amount during heating process (tempering). This fact is confirmed by lowering by about 75°C of temperature M_s with the increase of rate of previous heating to 700°C, from 400°C for $V_{\text{heat.}} = 0.05^\circ\text{C/s}$ to 325°C for $V_{\text{heat.}} = 35^\circ\text{C/s}$.

Fig. 3 presents HS6–5–2 steel dilatograms of heating from quenched state, together with corresponding differential curves. Detailed description of phase transitions kinetics during tempering of HS6-5-2 steel in a form of CHT diagram and the changes in structure as a result of continuous heating from quenched state are present in studies [13,14].

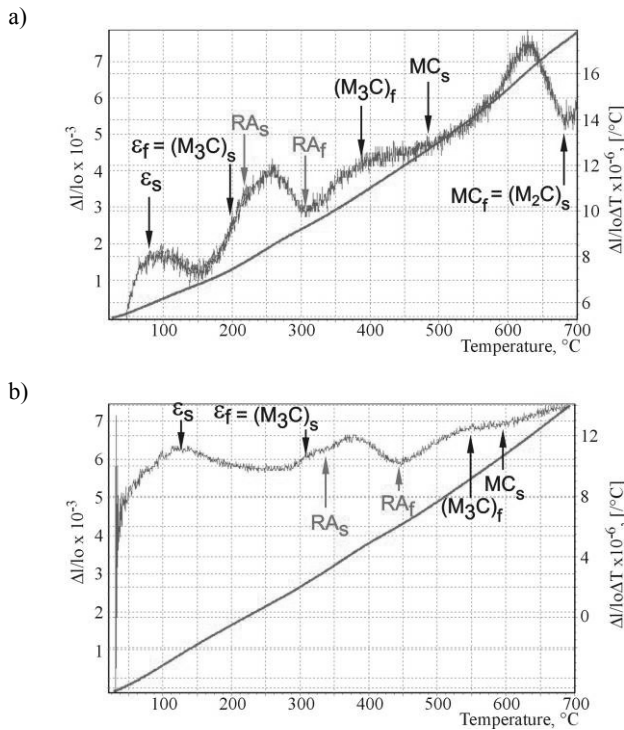


Fig. 1. Heating dilatograms of HS18-0-1 steel from quenched state at the rate of: a) 0.05°C/s, b) 35°C/s

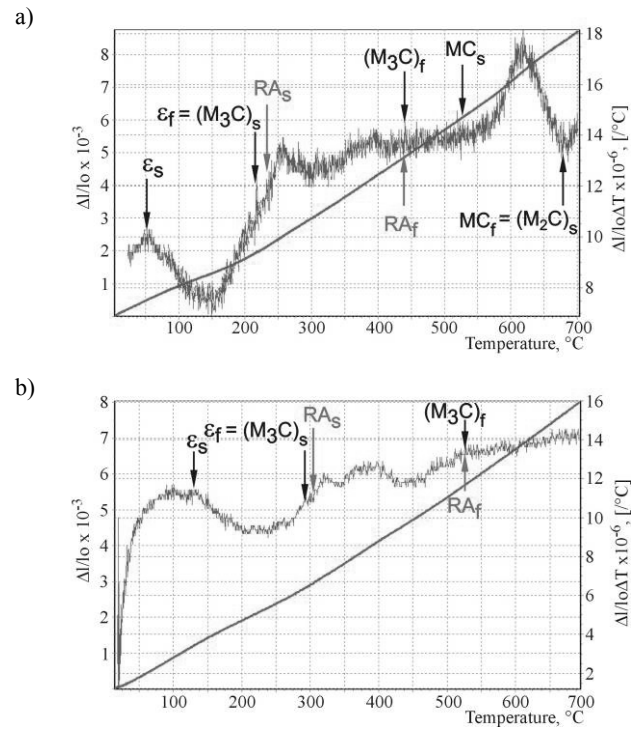


Fig. 3. Heating dilatograms of HS6-5-2 steel from quenched state at the rate of: a) 0.05°C/s, b) 35°C/s

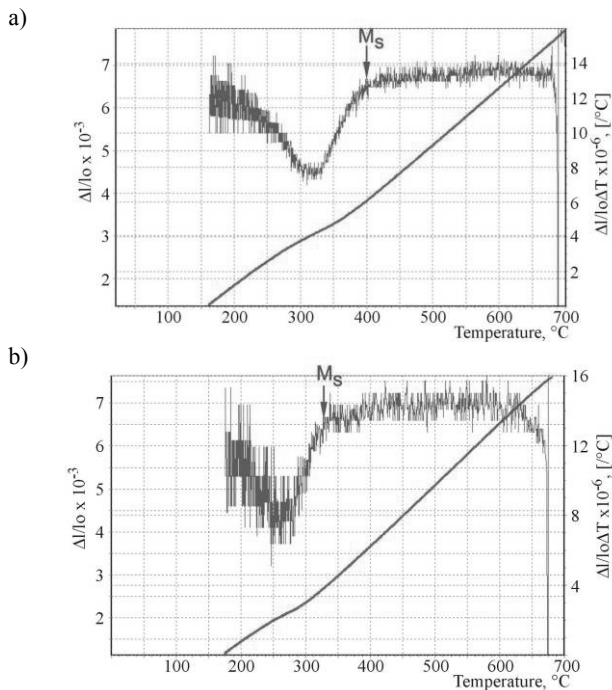


Fig. 2. Dilatograms of cooling at the rate of 1°C/s of quenched HS18-0-1 steel samples heated to 700°C at the rate of: a) 0.05°C/s, b) 35°C/s, together with corresponding differential curves

As it can be noticed, during heating from quenched state in HS6-5-2 steel first there is a contraction related to the precipitation of ϵ carbide. The temperature ϵ_s for heating rate of 0,05°C/s is about 50°C and for 35°C/s is about 140°C, whereas ϵ_f increases from 210°C to 290°C. The temperature ϵ_f approximately equals to the temperature $(M_3C)_s$ at which the cementite begins to precipitate. Within the temperature range of $RA_s \div RA_f$ a part of the retained austenite is transformed. It should be noticed that a positive dilatation effect from this transition is lower (less intensive) in comparison with the previously discussed HS18-0-1 steel, yet it spreads out over almost the whole range of contraction resulting from cementite precipitation (it significantly reduces the effect of contraction resulting from the precipitation of this carbide). It can be noticed, in cooling dilatograms after heating (tempering) to 700°C (fig. 4), that by far greater part of retained austenite is transformed only by cooling after tempering (heating to 700°C). The decrease of M_s temperature that was found during cooling with the increase of rate of first heating (tempering) to 700°C, from 400°C for $V_{heat.} = 0,05^\circ\text{C/s}$ to about 350°C for $V_{heat.} = 35^\circ\text{C/s}$ (i.e. about 50°C) is smaller than for HS18-0-1 steel, what also indicates that during heating to 700°C the chemical destabilization of retained austenite in HS6-5-2 steel takes place to a greater degree than in HS18-0-1 steel. It may be connected with higher diffusion coefficient of Mo than W and with higher diffusion coefficients of other elements (including carbon) in the presence of Mo than in the presence of W, what is indicated among other things by so called temperability of matrix standard

alloys of quenched rapid tool steels with diversified quotient of Mo and W content, described among others in work [14].

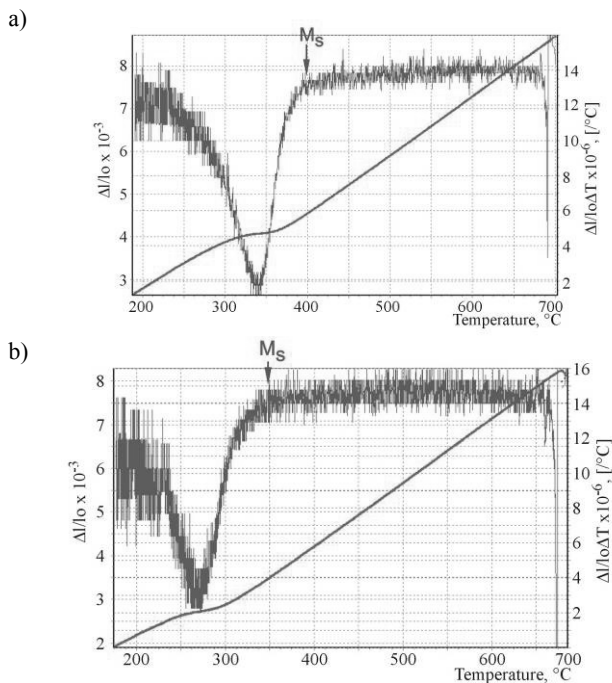


Fig. 4. Dilatograms of cooling at the rate of 1°C/s of quenched HS6-5-2 steel samples heated to 700°C at the rate of: a) 0.05°C/s, b) 35°C/s, together with corresponding differential curves

5. Conclusions

During heating of previously quenched HS18-0-1 and HS6-5-2 steel samples, the presence of four basic transformations was found, i.e. precipitation of ϵ carbide, precipitation of M_3C , transformation of retained austenite and precipitation of alloy carbides of MC and M_2C type.

It was shown that in quenched high-speed steels a part of retained austenite transforms already during heating for tempering, but its significant part transforms only during cooling process after tempering. Change of heating rate during tempering has strong influence on the temperatures of beginnings and the ends of individual transitions as well as on the accompanying dilatation effects.

The substitution of tungsten with molybdenum in HS6-5-2 steel has influenced mainly the stability of retained austenite and the temperature of precipitation beginning of MC (MC_s) type carbides. Whereas the precipitation ranges of ϵ carbide and cementite in both steels are close.

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