

## The kinetics of phase transformations during the tempering of HS6-5-2 high-speed steel

**P. Bala\*, J. Pacyna, J. Krawczyk**

Faculty of Metals Engineering and Industry Computer Science,  
AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland  
\* Corresponding author: E-mail address: pbala@agh.edu.pl

Received 15.03.2006; accepted in revised form 30.04.2006

### Materials

#### ABSTRACT

**Purpose:** The reasons for write this paper was described the kinetics of phase transformations during tempering of hardened HS6-5-2 high-speed steel. Moreover, the influence of the heating rate on the retained austenite transformation.

**Design/methodology/approach:** CHT diagram was with dilatometric method determined. The influence of the heating rate on the retained austenite transformation as well as the results of threefold tempering at 560°C were also determined.

**Findings:** During heating of the samples of the quenched HS6-5-2 steel the occurrence of 4 principal transformations was determined. These are: precipitation of  $\epsilon$  carbide,  $M_3C$  precipitation, transformation of retained austenite and precipitation of alloy carbides of MC and  $M_2C$  type. It was shown that in the quenched high-speed steels a part of retained austenite is already transformed during heating for tempering, but its significant part is transformed only during cooling after tempering as well as during consecutive heatings for temperings.

**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

**Keywords:** Tool materials; Tempering; CHT - diagram; Retained austenite

### 1. Introduction

On reheating as-quenched martensite, the tempering takes place in three distinct but overlapping stages, i.e. precipitation of  $\epsilon$  carbide, transformations of retained austenite into lower bainite (fresh martensite), and transformation of  $\epsilon$  carbide into cementite [1,2]. In the steels containing the elements which evoke the secondary hardness effect (V, W, Mo) there is the fourth stage of tempering, i.e. precipitation of alloy carbides of MC and  $M_2C$  type, nucleating independently [1÷3].

In the first stage of tempering, in the range of temperatures 100÷200°C, the  $\epsilon$  ( $Fe_{2.4}C$ ) carbides of compact hexagonal structure are precipitated. Precipitating  $\epsilon$  carbide of high dispersion results in decreasing the martensite tetragonality and strong

strength erring of steel. Nevertheless, the fall of carbon content in martensite results in its softening and, consequently, the strength of steel tempered in this range decreases slightly [1,2,4,5].

The second stage of tempering in the range of temperatures 200÷320°C is dominated by the transformation of retained austenite. This process results in the origin of a heterogeneous mixture consisting of oversaturated ferrite and iron carbide, called lower bainite. It should be observed that this transformation occurs only in steels containing C>0.3% because the amount of austenite which remained in the steel after quenching depends precisely on the carbon content [6,7].

In the third stage of tempering in the range of 200÷420°C cementite is precipitated and the carbon content decreases in the martensitic matrix. Iron transient carbides ( $\epsilon$ ) are dissolved and it enables the steel matrix to recover whereas the precipitating

cementite, according to [8], nucleates independently on grain boundaries of the former austenite and on some particles of transient carbides (in situ nucleation) and, according to [9], also on the boundaries of the newly formed cellular structure.

Above 400°C the diffusion of alloy elements becomes possible. Cementite, unstable in these conditions, dissolves and the carbides of alloy elements nucleate independently or in situ i.e. cementite transforms gradually in a carbide of another type. The carbides of MC and  $M_2C$  type, precipitated during tempering, which nucleate independently and which are tiny and coherent with the matrix, increase hardness and strength properties [3,10]. High-speed steels are described in literature [10,14,15,16,17,18].

The first diagrams of kinetics of phase transformations at tempering, the so – called CHT diagrams (Continuous Heating Transformations) of HS18-0-1 and HS6-5-2 high-speed steels were published in ref. [11]. According to the investigations [11,12,13] the CHT diagrams contribute to interfering in the degree of advancement of 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, in particular high fracture toughness.

## 2. Test material

The investigations were performed on the HS6-5-2 high speed steel whose chemical composition is presented in Table 1. The material was in the form of bars which had been soft annealed and whose crosswise dimensions were 10x20 mm.

Table 1.

Chemical composition of the investigated steel

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

## 3. Experimental procedure and heat treatment

The dilatometric test were performed with the DT1000 dilatometer manufactured in France by Adamel. The samples of  $\varnothing 2 \times 12$  mm, after prior quenching from 1240°C (austenitizing time 150s), were heated with various rates up to 700°C. The digitally recorded heating dilatograms enabled the CHT diagrams of the tested steel to be executed in the system temperature – time, according to the characteristic points which were read out from differential curves.

Moreover, the heating dilatograms enabled  $M_s$  temperature of retained austenite of the tested steel to be read out which were the base to construct the diagrams of dependences of  $M_s$  temperature of retained austenite on the heating rate of tempering. Multiple tempering was carried out to illustrate the stability of retained austenite in the investigated steel. It consisted in consecutive heatings with the same rate 0.05°C/s up to 560°C, holding for 1h and then cooling the sample with 1°C/s.

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

## 4. Research results and discussion

Fig. 1 shows an example heating dilatogram of the investigated steel at heating 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 interpretations of results which were used to make the CHT diagram of this steel. As it can be observed, this steel reveals at first the shrinkage connected with the precipitation of  $\epsilon$  carbide. This shrinkage starts at the temperature of  $\epsilon_s$  and ends at the temperature of  $\epsilon_f$ . The positive dilatation effect, connected with the transformation of retained austenite, is very clear. It is visible in the range of temperatures  $RA_s \div RA_f$ . Cementite precipitates in the range of temperatures  $(M_3C)_s \div (M_3C)_f$ , independently nucleating carbides of MC type precipitate from the temperature  $MC_s$  to  $MC_f$  and the temperature  $(M_2C)_s$  process of precipitation of  $M_2C$  carbides starts. The alloy carbides which precipitate in the process of tempering of the HS6-5-2 steel comprise mainly the carbides of tungsten, vanadium and molybdenum.

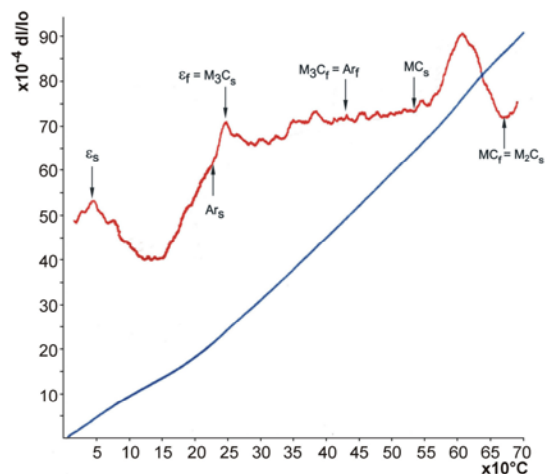


Fig. 1. Dilatogram of heating with the rate 0.05/s of a sample previously hardened from 1240°C with the corresponding differentiation curve

A new CHT diagram for the HS6-5-2 steel is presented on Fig. 2. The diagram contains the ranges of precipitation of  $\epsilon$  carbide, transformations of retained austenite, precipitation of cementite and alloy carbides of MC and  $M_2C$  type.

The dilatation effect from the transformation of retained austenite during cooling (Fig.3) is higher than during heating (cf. Fig.1) which proves that only after tempering a larger amount of austenite is transformed.

The diagram of dependences of  $RAC_s$  and  $RA_s$  temperatures on the heating to 700°C for the HS6-5-2 steel is presented on Fig. 4. As it can be observed, the temperature of the beginning of transformation of retained austenite ( $RAC_s$ ) increases with the rise of heating rate from 0.05°C/s to 35°C/s. However, at the rates over 15°C/s this parameter does not affect so strongly the  $RAC_s$  temperature as it happens for lower heating rates.

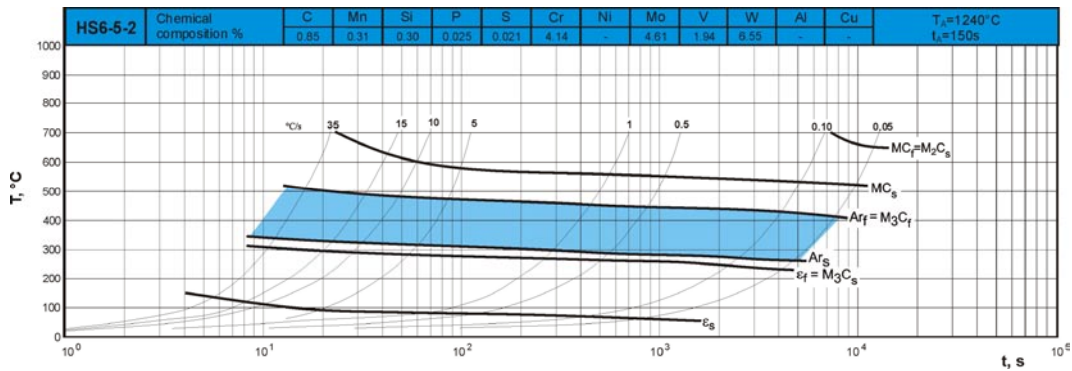


Fig.2. CHT diagram of the investigated steel

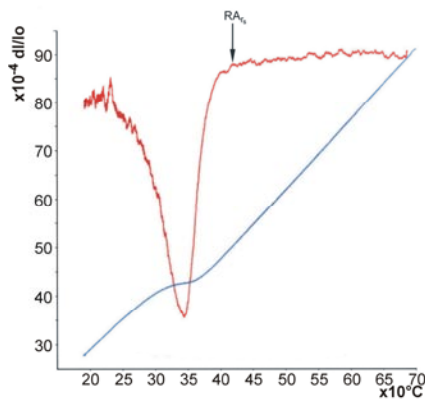


Fig. 3. Dilatogram of cooling of the HS6-5-2 steel sample with of cooling rate of 1°C/s, previously quenched from 1240°C and heated up to 700°C with of heating rate of 0.05°C/s, together with the corresponding differential curve with the marked temperature of the beginning of retained austenite transformation during cooling  $RAr_s$

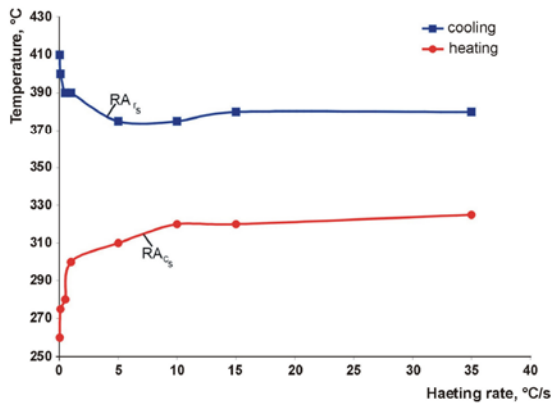


Fig. 4. The effect of heating rate up to 700°C after quenching from 1240°C on the temperature of beginning of transformation of retained austenite at heating ( $RAc_s$ ) and at the next cooling with 1°C/s ( $RAr_s$ ) for the HS6-5-2 steel

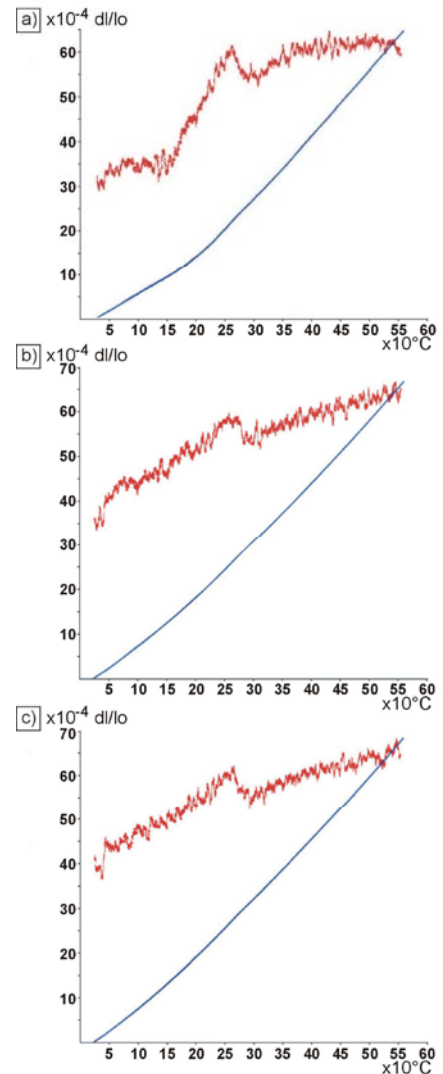


Fig. 5. Dilatograms of heating with the 0.05°C/s velocity up to 560°C for the HS6-5-2 steel: a) from the quenched state, b) second tempering, c) third tempering

Multiple tempering was performed to investigate the stability of retained austenite in the tested steel. Fig. 5 shows 3 dilatograms of consecutive temperings of the HS6-5-2 steel. As it can be noticed, the second and third tempering, according to the generally accepted procedure of heat treatment for these steels can be justified from the point of view of transformation of retained austenite because minimum dilatation effects can be observed on dilatation curves, originating most probably from the transformation of the phase.

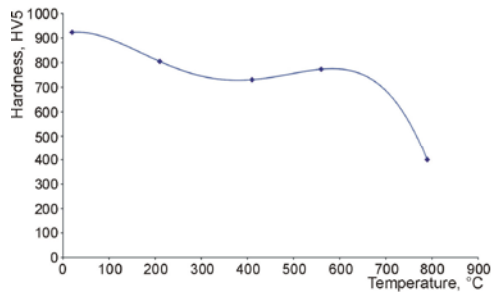


Fig. 6. Dependence of hardness of samples made from the tested steel on heating temperature after quenching

Fig. 6 shows the change of hardness of samples of the tested depending on the heating temperature after quenching. The heating after quenching to temperature 560°C doesn't caused vehemently increase of hardness, like for example in HS18-0-1 [19], what may be the reason for precipitations of MC carbides is only initiate. The highest hardness was shown by the sample quenched, while the lowest belonged to the sample heated up to 790°C, when the coherence of precipitations of MC carbides was broken and the advanced precipitation of  $M_2C$  occurred.

## 5. Conclusions

During heating of the samples of the quenched HS6-5-2 steel the occurrence of four principal transformations was determined: precipitation of  $\epsilon$  carbide,  $M_3C$  precipitation, transformation of retained austenite and precipitation of alloy carbides of MC and  $M_2C$  type.

It was shown that in the quenched high-speed steels a part of retained austenite is already transformed during heating for tempering, but its significant part is transformed only during cooling after tempering as well as during consecutive heatings for temperings. It is worth noting that the change of heating rate during tempering has a strong effect upon the temperatures of the beginning of transformation of retained austenite  $RA_{Cs}$  and  $RA_{r_s}$ . Because of this, the evaluation of these temperatures must be carried out at strictly determined heating rate. In this steel, stabilization of retained austenite is higher than in HS18-0-1 [19].

## Acknowledgements

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

## References

- [1] A. K. Sinha, Physical metallurgy handbook, The McGraw-Hill Companies, Inc. 2003
- [2] R.W. K. Honeycombe and H. K. D. H. Bhadeshia, Steels. Microstructure and properties. Great Britain 1981.
- [3] W. Rong and G. L. Dunlop, The crystallography of secondary carbide precipitation in high-speed steel, Acta met. Vol. 32, 1984, No 10, p.1591-1599
- [4] S. Murphy and J. A. Whiteman, The precipitation of epsilon-carbide in twinned martensite, Met. Trans. Vol. 1, 1970, p.843-848
- [5] Y. Ohmori and I. Tamura, Epsilon carbide precipitation during tempering of plain carbon martensite, Met. Trans. Vol 23A, 1992, p.2737-2751
- [6] J. Pacyna: The effect of retained austenite on the fracture toughness of high speed steels. Steel Research, vol. 58, 1987, no 2
- [7] A. Kokosza, J. Pacyna, Evaluation of retained austenite stability in heat treated cold work tool steel, Journal of Materials Processing Technology 162-163 (2005),p.327-331
- [8] M. Blicharski, Steel, WNT 2004 (only in Polish)
- [9] J. Pacyna, B. Pawlowski, Effect of tempering temperature on 30HGSNA steel toughness. Metallurgy and Casting, Vol. 10, 1984, No 4, p.409-421
- [10] L. A. Dobrzański et. al., Structure and properties of W-Mo-V-Co 11-0-2-5 type and W-Mo-V 11-0-2 type high-speed steels, Journal of Materials Processing Technology, Vol. 64, 1997, p.93-99
- [11] J. Pacyna, Physical metallurgy of tool steels cracking. Metallurgy and Casting, No 120, Krakow 1988
- [12] J. Pacyna, A. Jędrzejewska-Strach, M. Strach, The effect of manganese and silicon on the kinetics of phase transformations during tempering – Continuous Heating Transformation (CHT) curves. Journal of Materials Processing Technology 64 (1997), no 1, p.311-318
- [13] G. Zając, J. Pacyna, The kinetics of phase transformations during tempering in structural steels with nickel, Journal of Materials Processing Technology 162-163 (2005),p.442-446
- [14] L. A. Dobrzański, A. Zarychta, The structure and properties of W-Mo-V high-speed steels with increased contents of Si and Nb after heat treatment, Journal of Materials Processing Technology 77 (1998), p.180-193
- [15] L. A. Dobrzański, Effect of chemical composition and processing conditions on the structure and properties of high-speed steels, Journal of Materials Processing Technology 48 (1995), p.727-737
- [16] J. Richter, M. Hetmańczyk, J. Cwajna, Characterization of carbide phase in nonledeburitic high-speed steel containing Ti and Nb, Journal of Materials Processing Technology 53 (1995), p.341-348
- [17] L. A. Dobrzański, A. Zarychta, M. Ligarski, High-speed steels with addition of niobium or titanium, Journal of Materials Processing Technology 63 (1997), p.531-541
- [18] L. A. Dobrzański, M. Ligarski, Role of titanium in the W-Mo-V high-speed steels, Journal of Materials Processing Technology 64 (1997), p.101-116
- [19] P. Bała, J. Pacyna., J. Krawczyk. The kinetics of phase transformations during the tempering of HS18-0-1 high-speed steel. Contemporary Achievements in Mechanics, Manufacturing and Materials Science. Gliwice–Zakopane 6th–9th December 2005, p.20-29