

DESTABILIZATION OF RETAINED AUSTENITE DURING MULTIPLE TEMPERING OF HIGH-SPEED W-Mo-V STEEL

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ABSTRACT

Constant demands for quality improvement of high-speed steels have contributed to the prolonged importance of tests, such as test in structural changes and properties derived from the applied heat treatment. Generally, tools from high-speed steel are treated by multiple tempering after quenching in order to reduce amount of retained austenite and value of internal stresses to the lowest level. A review of literature shows that processes taking place during the first tempering have been studied comprehensively and in great detail while very little attention has been paid to testing structural changes in the succeeding tempering cycles. Having this in mind, the differential dilatometric method has been used to test the influences of quenching temperature (1170-1230°C), tempering temperature (540-605°C), and the number (1 to 5) and tempering time, on the process of destabilization of retained austenite at circumstances of multiple continuous tempering of quenched W-Mo-V high-speed steel. The acquired results have contributed to the conviction that the customary regime of tempering for this type of high-speed steel could be rationally modified. We emphasize that the change in tendency of the dilatometric cooling curve in the austenitic-martensitic transformation region is the result of self-tempering of secondary martensite. The explanation proposed in literature for this dilatometric effect is from our point of view totally incorrect.

1 INTRODUCTION

When tempering wolfram-molybdenum high-speed steels at temperatures higher than 500°C, simultaneously with the process of martensite decomposition, the degree of alloying tends to fall, and also the stability of retained austenite owing to the precipitation of dispersed particles of special carbides. There are certain beliefs that altogether with the reduction of C and alloying elements inside the γ solid solution, the transformation into pearlite also takes place (Karagoz at al. [1], Wang at al., [2], Kupalova at al. [3], Заблотский at al. [4], Kulmburg at al. [5]). Besides numerous problems of characterizing the tempered structure, if one bears in mind that phenomena connected to the austenitic phase have been insufficiently studied (particularly at repeated tempering, influence of heating rate in reaching tempering temperature, and the cooling procedure from this temperature, and also the volume fraction of phases in the initial structure), yet the optimal temperature-time tempering conditions are still not defined, that would provide successful development of the mentioned diffusion processes: destabilization of retained austenite and martensite tempering. Hence, the aim of this paper is to contribute to the knowledge of the behavior of retained austenite during multiple continuous tempering of high-speed W-Mo-V steel while varying the selected parameters of the quenching and tempering processes.

2 EXPERIMENTAL PROCEDURE

Tests were performed with W-Mo-V high-speed steel having the chemical composition shown: C - 0,88%, W - 6,10%, Mo - 5,20%, Cr - 3,89%.

Dilatometric specimens were treated in the following manner:

1. Quenching from 1200°C/2min – triple continuous heating up to various temperatures in the range 550-605°C (for 540°C – quintuple) and cooling to room temperature - additional continuous tempering to 690°C,
2. Quenching from 1170, 1200, and 1230°C/2 min – triple continuous heating up to 550°C, and cooling down to room temperature,

3. Quenching from 1200°C/2 min - continuous heating up to 550, and 570°C, and cooling to 500°C, followed by double heating and cooling in the range 500-550 (570°C) with final cooling to room temperature (cyclic tempering).

Specimens were in a stepwise manner heated up to the quenching temperature, with three preheats: 450°C/15 min, 860°C/2min and 1050°C/2min. In all of the cases quenching was interrupted – with a salt bath at 560°C/5 min./air.

Tempering was performed by continuously heating the specimens at the rate 4°C/min in furnace of the Chevenard differential dilatometric. After reaching tempering temperature (without delay), cooling started and ended at room temperature at the rate of cooling of the dilatometric furnace.

Dilatometric curves were recorded with a magnification $K_1= 150 \times$ (temperature) and $K_2= 600 \times$ (change of length), etalon - pyros.

3 RESULTS AND DISCUSSIONS

3.1 Influence of temperature and the number of tempering

The results, on Figures 1-2, and in Table 1, show that the chemical composition - M_s point, and the amount of retained austenite, transforming into martensite by cooling from the tempering temperature - ΔI_A , essentially depend on both the temperature and the number of tempering.

Table 1: Dilatometric effects of continuous tempering of W-Mo-V high-speed steel depending on the temperature and number of tempering

Temperature of tempering, [°C]	Number of tempering	ΔI_A [μm]	M_s, B_s [°C]
540	1	-	-
	2	-	-
	3	-	-
	4	0.15	70
	5	0.22	85
550	1	-	-
	2	-	-
	3	-	-
560	1	-	-
	2	0.49	115
	3	0.70	150
3x560+690		0.87	360
570	1	0.52	120
	2	0.94	170
	3	0.25	160
3x570+690		0.40	345
580	1	1.20	165
	2	0.44	185
	3	0.22	135
3x580+690		0.26	290
595	1	1.56	240
	2	0.32	185
	3	0.15	140
3x595+690		0.17	270
605	1	1.63	265
	2	0.29	190
	3	0.12	140
3x605+690		0.15	265

The fact that even after triple-wise heating up to 540 and 550°C, austenite does not decompose during cooling, and the low M_s temperature and small intensity of austenitic-martensitic transformation after the fourth and fifth tempering at 540°C, Table 1, regarding the cyclic treatment at 550°C, Table 2, point out the limited possibility of precipitation of special carbides from retained austenite in the given tempering conditions.

Except by multiple tempering, a more complete destabilizing γ phase is gained at these temperatures by choosing a proper isothermal holding time. Although at 560°C, secondary martensite forms already at the second tempering process, yet after the third tempering there is about 40% of austenite retained, that has not been decomposed (this is indicated from the final tempering to 690°C, Table 1).

From Figures 1 and 2 it is clear that, depending on the tempering temperature, the observed characteristics of the austenite phase differ for each tempering cycle. Hence, after the first tempering, the onset temperature and dilatometric effect of $\gamma \rightarrow M$ (martensitic) transformation, both have a continuous and intensive increase with rise in temperature from 570 to 605°C. In the second tempering, the M_s point rises when heated up to 580°C, and practically having no change thereafter, while the amplitude of the recorded dilatation D during cooling, Figure 3a, is depicted by a declining curve starting from 570°C. The values of M_s points and Δl_A up to the tempering temperature of 580°C, or 570°C, are located on a higher level, compared to the first tempering, while an opposite tendency of their behavior appears for temperatures being above the mentioned values. The described tendency and the reached levels for parameters of austenitic destabilization in the second tempering cycle agree with the volume fraction and composition of the austenite phase, that are retained within the structure after the first tempering of the quenched steel (Andjelic et al. [6]). In the third tempering, the location of M_s point shifts to lower temperatures, when heated from 570 to 580°C. With a further rise in temperature, the location remains constant, while the dilatometric effect Δl_A continuously decreases. This draws a conclusion about the composition and amount of retained austenite, undergoing tempering in the third cycle.

Table 2: Dilatometric effects of cyclic continuous tempering to 550 and 570°C of W-Mo-V high-speed

Temperature of tempering, [°C]	Δl_A [μm]	M_s , [°C]
550	0.44	85
570	1.65	230

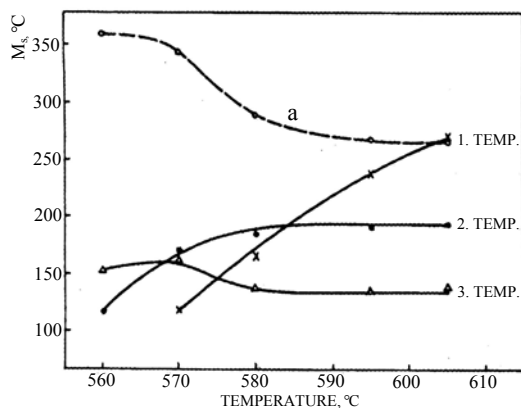


Figure 1: M_s point position of W-Mo-V high-speed steel depending on the temperature and number of tempering; curve a - final tempering to 690°C

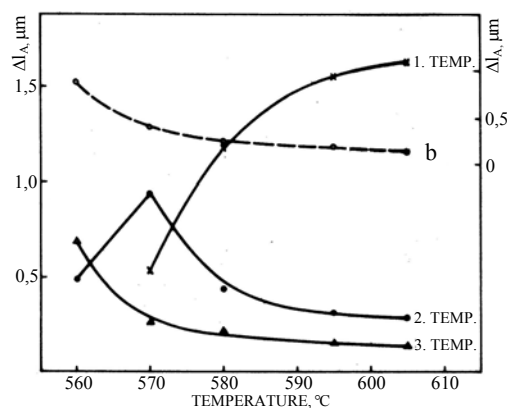


Figure 2: Dilatometric effect of austenitic transformation of W-Mo-V high-speed steel depending on the temperature and number of tempering; curve b - final tempering to 690°C

The temperature range in which the M_s points are located during tempering within 560-605°C decreases with the increasing number of tempering, being 145°C for the first, 75°C for the second, and only 25°C for third tempering. This results from a lesser amount of retained austenite (thereby having lesser possibility for compositional differentiation), and also because of its rising stability - from the first to the third tempering cycle. The range for the indicator Δl_A changes in the same manner. Starting from the second cycle, there are no differences in values recorded between tempering temperatures 595 and 605°C, because of the small and approximately the same amount of retained austenite that remains after first tempering capable for decomposing in the following cycles.

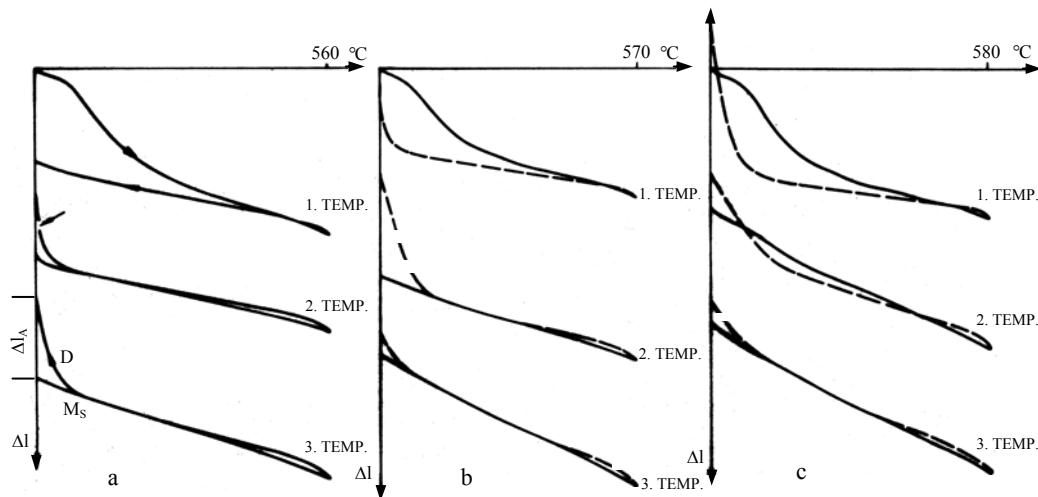


Figure 3: Triple continuous tempering dilatometric curves of W-Mo-V high-speed steel to: a - 560°C, b - 570°C and c - 580°C; — heating; - - - cooling

The final tempering to 690°C (Figure 1, curve a and Figure 2, curve b) shows that the same structural state of the steel is reached (having in mind the retained austenite) after triple-wise tempering at temperatures higher than 580°C. Values in Table 1 indicate that the degree of decomposing of retained austenite, corresponding to the first tempering at 595°C, is achieved at 580°C in double tempering, and for 570°C after triple tempering.

In spite of the upper stated, a smaller effect of secondary $\gamma \rightarrow M$ transformation in the second tempering at 560°C (the initial amount of retained austenite corresponds to the quenched state), and also from its sudden jump while heated up to 570°C (in the first tempering, a relatively small amount of secondary martensite is formed), and regarding the noticeable when changing to 580°C (the most amount of austenite has transformed during the first tempering, and is also the case for temperatures 595 and 605°C), in Figure 3a-c, all has pointed out the high significance that the tempering temperature has on the destabilization of retained austenite for W-Mo-V type steels.

Since the intensity of the transformation of retained austenite is not negligible in the lower temperature region (e.g. the interruption in recording of the dilatometric curve when the temperature of 50°C is reached, while cooled from 560°C in the second tempering, and the continued recording at 25°C, depicted by the arrow in Figure 3a), in order to allow a more complete formation of secondary martensite, the cooling from tempering temperature must always be executed to room temperature, as contrary to authors' statements (Kulmburg at al. [5]).

3.2 Influence of quenching temperature

The dilatometric curves in Figure 4a-b show that after quenching from 1170°C (identical to quenching from 1200°C) destabilization of austenite does not take place by triple tempering to 550°C, while quenching from 1230°C, austenite partially transforms into martensite when cooled in the third tempering cycle.

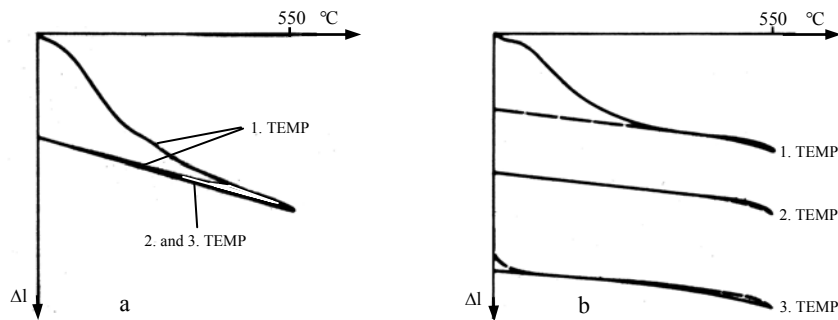


Figure 4: Triple continuous tempering dilatometric curves to 550°C of W-Mo-V high-speed steel after quenching from 1170°C - a and 1230°C - b; — heating; - - - cooling

A higher degree of alloying of the solid solution γ in the other case is the reason for an earlier onset of special carbide precipitation (Barreau et al. [7]). At the same time, there is a higher probability to form a region with lesser alloyed austenite, because of the higher amount of austenitic microconstituent. The larger alloying degree of destabilized austenite, is indicated by the value of its M_s point of 75°C and the dilatometric effect Δl_A having the value 0,21 μm . Analysis of dilatometric curves shows that already during the first tempering to 550°C, independent of quenching temperature, structural changes in martensite have ended, that display a feature for this temperature interval (a coincidence of the heating and cooling curves in the second and third tempering with the cooling curve from the first tempering). This is obvious, in particular, in the example of quenching temperature of 1170°C, Figure 4a.

3.3 Cyclic tempering

Results in Table 2 and Figure 5a and b, representing the austenite phase state achieved by cyclic treatment, have shown that the time difference, in dilatometric specimen keeping of 30 minutes in the region 500-550°C, between the singular continuous tempering and cyclic tempering has provoked formation of secondary martensite. The means that precipitation of special carbides from austenite requires a certain time, which is clear owing to the type and amount of alloying elements in the γ phase. However, the low temperature of onset and the small effect of $\gamma \rightarrow M$ transformation (about 20% of the initial amount), in Table 2, certify on the still very high stability of retained austenite, regarding the low rate of the diffusion process responsible for its deficiency.

The rise in cyclic tempering temperature for just 20°C and the extension of specimen keeping for 25 minutes leads to a considerable decrease in the stability of austenite. This is manifested through rise in the intensity of its transformation to about 4 times and the rise of M_s point from 85 up to 230°C. If just the influence of the time factor is to be observed for temperature 570°C, the comparance of relevant indicators of austenite stability from Table 2, depicts that the time interval of 40 minutes is sufficient to provoke an increment in the M_s temperature of the newly created secondary martensite to about 200%.

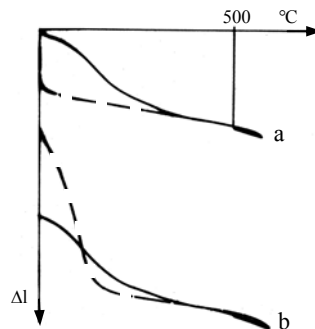


Figure 5: Cyclic continuous tempering dilatometric curves to 550°C - a and 570°C - b of W-Mo-V high-speed steel; — heating; - - - cooling

4 CONCLUSIONS

- The highest degree of destabilization of retained austenite by multiple tempering is achieved within the very tight temperature interval (560-580°C), which depicts a high rate of special carbide precipitation out of austenite in the given conditions.
- Due to a known high in homogeneity of the austenitic phase, we find that the intensity of dilatometer effects on the austenitic-martensitic transformation is a more reliable indicator of the degree of destabilization than are the M_S temperature that always depict the onset of transformation within the poorest regions in austenite.
- In the effort of a more complete elimination of retained austenite from the structure of the high-speed quenched steel of the tested type, it is necessary to perform cooling to room temperature from the tempering temperature in each cycle, particularly when the case is with transformation of retained austenite having a higher chemical stability. This attitude denies opinions of authors preferring optimization of tempering by interrupted cooling at temperatures considerably higher than room temperature. This recommendation is based on the erroneous interpretation of the cause for change in slope of dilatometric cooling curve in the austenitic-martensitic transformation region (it is explained with position of M_S temperature). We emphasize that the mentioned dilatometric effect is the result of self-tempering of secondary martensite.
- Despite of the specific tempering procedure (continuous) performed in this paper, and based on acquired results, an impression says that the tempering regime usually practiced for W-Mo-V high-speed steels can be rationally improved by the choice of temperature, and by time intervals and the number of repeated tempering.
- The applied differential dilatometric method appeared to be very useful for determining the appearance and effects of destabilization of retained austenite. Based on knowledge, gained by applying the dilatometric technique (both absolute and differential) in the study of structural changes in the heat treatment of various types of steel, we consider that this technique, on account of possibilities it offers, should be applied in greater extent in for experimental analyses.

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