ANALYSIS OF PLASTICITY OF QUENCHED TOOL STEEL DURING STRESS RELAXATION AT ELEVATED TEMPERATURE

Assoc. Prof. Kandrotaitė Janutienė R. PhD[1], Lect. Mažeika D. PhD[1], Doc. Žvinys, J., PhD[2]
Faculty of Mechanical Engineering and Design – Kaunas University of Technology[1], Lithuania; Emeritus of Kaunas University of Technology[2]
E-mail: raskand@ktu.lt, darius.mazeika@ktu.lt

Abstract: *Phase transformations in metals have a major influence on the material behaviour in several common engineering applications. Steels exhibiting enhanced response to transformation-induced plasticity (e. g. high strength TRIP-steels for automotive production) are examples of the important role martensite formation can play. An externally stressed specimen in the process of a phase transformation may show a significant nonlinear behaviour, which is known as transformation plasticity. Even under an externally applied load stress with the corresponding equivalent stress being small in relation to the "normal" yield stress of the material, plastic deformation occurs.*

An aim of a research was to determine relaxation and transformation plasticity properties of alloyed tool steel while is tempered at elevated temperatures and for different tempering duration.

Keywords: TRANSFORMATION PLASTICITY, TOOL STEEL, TEMPERING, STRESS RELAXATION.

1. Introduction

Quenched steel is in a metastable state. When martensite is tempered at higher temperatures and in some cases, retained austenite as well, carbon is precipitated in carbides form. After cooling, secondary martensitic transformation is possible [1]. Transformation plasticity effect can also be observed during these processes [2-5]. When first heated, the tempered steel is relatively ductile; after reheating at the same temperature the ductility is negligible.

Changes in the properties of quenched steel due to time and temperature have long been observed. According to Geler [6], by maintaining 9XC quenched but not tempered steel at 20°C temperature, its strength initially decreases and then increases. Since the carbon concentration and martensite workability do not change under these conditions, this phenomenon can be explained as a result of stress relaxation processes.

These issues are particularly relevant in the manufacture of tools, as most of them must be straightened to eliminate quenching distortions. Straightening can be performed in various ways: at cold state, after hot washing and often after tempering. Although the tools that are tempered are less brittle than the ones that have just been quenched, they are harder to smooth because quenched and low-tempered steels are very elastic and spring-like. Great force must be used to bend the bent tool to the opposite side. If smoothed, the geometrical parameters of such tool are not stable. Over time, and especially after heating during operation, the straightened tool or part will be distorted again.

The most effective method of the straightening of curved quenched parts is to make them straight during the transformations while tempering. The parts are bent and pressed inside the device for the fixed deflection and then tempered. During the transformations of tempering, the steel becomes very plastic for a short time, the elastic strains partly relax and the part of the elastic deflection changes to the plastic [7]. The form of the straightened parts is not geometrically stable and changes in time, especially when the parts are heated. This phenomenon, called self-deformation was also researched.

The article presents investigation of relaxation properties during tempering of low alloyed tool steel ХВГ (GOST standard). This steel is used for cutting tools with increased resistance to quenching distortions, thread gages, matrix and punches for cold forming.

2. Methodology

Investigation of relaxation properties was performed using low alloyed tool steel. Its chemical composition is presented in Table 1 and critical points of the steel grade are listed in Table 2.

The specimens of rectangular cross section with parameters of 6×8×100 mm were oil quenched from 840°C temperature (Fig. 1). Then, cooled specimens were bent elastically and fixed inside the special device with the deflection of 0.5; 1.0 or 1.5 mm (the value of y_e) and tempered at the temperature of 200-400°C for 10 min till 4 h (Fig. 2). After tempering at this fixed position, the specimens were withdrawn out of the device, the plastic deflection y_p of the specimens was measured. Then the coefficient k of the elastic stress relaxation was calculated:

$$\boldsymbol{k} = \frac{\boldsymbol{y_p}}{\boldsymbol{y_e}} \quad (1)$$

The self-deformation of the elastically bent specimen was observed during the tempering at the same temperature as they were bent for 1 hour. Then the change of the plastic deflection Δy_p was measured in accuracy of 0.01 mm and the relative self-deformation $\Delta\varepsilon$ was calculated:

$$\Delta\varepsilon = \frac{\Delta y_p}{y_p} \quad (2)$$

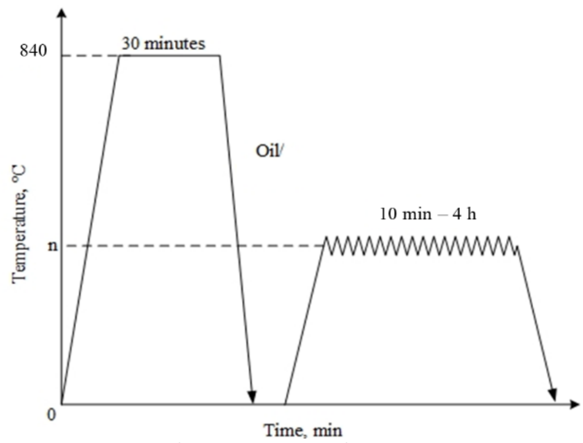

***Fig. 1** The circle of heat treatment of steel during investigation of relaxation properties*

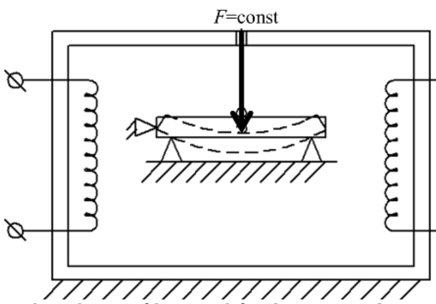

Fig. 2 *The schema of bent and fixed specimen during tempering in the furnace*

Table 1: *Chemical composition of investigated low alloyed tool steel (% wt)* [8]

Grade (GOST)	Elements, %					Equivalent of alloy grade
XBГ	C	Si	Mn	Ni	S	107WCR5 EN
	0.9-1.05	0.1-0.4	0.8-1.1	max 0.4	max 0.03	
	P	Cr	W	Cu	Fe	
	max 0.03	0.9-1.2	1.2-1.6	max 0.3	Bal.	

Table 2: *Temperature of critical points for steel XBГ* [8]

Critical point	A_{c1}	A_{cm}	A_{r1}	M_s
Temperature, °C	750	940	710	210

The microstructure of steel used for experiments was examined by optical microscope optical microscope Nikon equipped with video camera Nikon DS-2 16 MP and objectives Nikon TU Plan Fluor 10×/0.30 and Nikon TU Plan Fluor 100x/0.90.

The temperature of specimen during tempering was measured by welded chromel-alumel thermocouple of 0.3 mm wire diameter.

3. Results and Discussion

The microstructure of quenched steel XBГ consists of martensite, retained austenite and carbides (Fig. 3). Amount of retained austenite can vary from 18 % to 20 % [9].

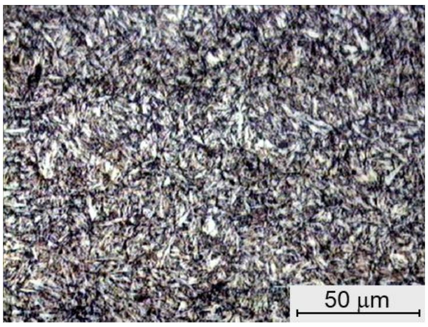

Fig. 3 *Microstructure of oil quenched steel XBГ: dark martensite and white retained austenite*

The influence of tempering duration at 250°C temperature on the remained plastic deflection of specimens is shown in the Table 3.

Table 3: *Values of elastic and plastic deflections of steel specimens before and after tempering at 250°C when initial fixed elastic deflection is 1 mm*

Tempering duration, min	Fixed elastic deflection y_e, mm	Remained plastic deflection after tempering y_p, mm	Coefficient of stress relaxation, k
10	1.05	0.03	0.03
30	1.03	0.14	0.14
60	1.02	0.51	0.49
120	1.02	0.59	0.59
240	1.05	0.77	0.73

In the same way, the results were obtained at tempering temperatures 200, 225, 275, 300 and 400 °C and at fixed initial elastic deflections of 0.5 mm and 1.5 mm. The graphic expression of the results is presented in Fig. 4.

Transformation plasticity of quenched steel, which causes the relaxation of elastic strains, depends on the microstructural metastability and progression of tempering transformations. Therefore, the maximum effect of plasticity (in our way – relaxation of elastic strains) was then, when the specimens were quenched from the temperature, which can be characterized by martensite with enough of carbon and not much of retained austenite, and then tempered at sufficiently high temperature. On the contrary, when the specimens were bent at low temperature, especially those, which were already tempered, the plastic properties were obtained minimal.

Investigating influence of the magnitude of retained plastic deflection after tempering of stressed specimens, it was determined, that the biggest effect of the progress of relaxation is then, when the duration of tempering is 1 hour (Fig. 5).

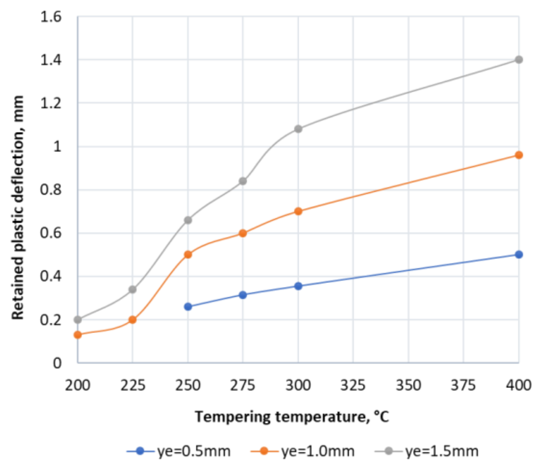

Fig. 4 *Influence of tempering temperature on retained plastic deflection of elastically bent specimen when tempering duration is 60 min*

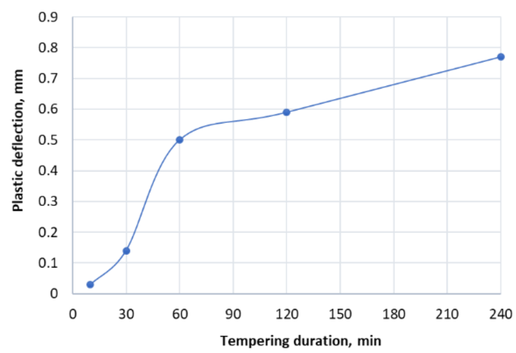

Fig. 5 *Influence of tempering duration on relaxation properties of steel XBГ specimens*

The second (stabilizing) tempering of already tempered in stressed state specimens was performed for the reason to clarify, if the microstructure of tempered specimens was stable. The change of the plastic deflection of steel specimens after stabilizing tempering is shown in Fig. 6. After second tempering at stabilizing 170 °C temperature, the certain part of plastic deflection eliminated due to metastability of microstructure. The lower tempering temperature was set, the higher percentage of eliminated plastic deflection occurred.

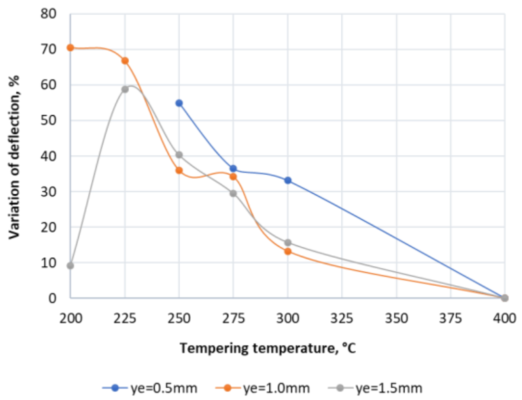

Fig. 6 *Magnitude of percentage of plastic deflection elimination after the second tempering (stabilizing) at 170 °C temperature*

The biggest variation of plastic deflection is then, when tempering temperature is low (less 300°C). This shows that at the lower tempering temperature stresses in steel microstructure have the biggest influence on tempering transformations, e.g. tension stresses stop mostly the transformation of martensite. That is why martensite has heterogeneous structure after tempering and, therefore, increased self-deformations. The continuance of tempering also makes the same influence: after the short-term tempering the self-deformation is rather big – up to 40-75 %.

4. Conclusions

Following the investigation of the relaxation properties of steel ХВГ during tempering, the following conclusions were formulated:

1. The quenched steel becomes significantly plastic during tempering; therefore, the part of elastic stresses relaxes – the part of elastic deflection becomes plastic. Relaxation properties of steel increase with the increasing of tempering temperature and heating duration.

2. For the straightening the tools must be tempered at the temperature 170°C for 1 hour, bent in the device (evaluate relaxation properties), heated in the furnace at the certain temperature for 1 hour, then cooled in the air and tempered at the same temperature for 1 hour. The initial fixed elastic deflection of tool in the device is calculated considering the relaxation properties of steel at the temperature of tempering and self-deformation during the stabilizing tempering.

5. References

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