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REDUCTION OF RETAINED AUSTENITE IN TOOL STEELS

László TÓTH

Óbuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Budapest, Hungary, toth.laszlo@bgk.uni-obuda.hu

Abstract

Tools are devices for machining materials which must have different properties depending on their intended application. These properties are determined by the chemical composition and microstructure of the tool steel. The desired steel microstructure can be achieved with suitable heat treatment technology. During this heat treatment, the microstructure of the tool steel may develop various lattice structural transformations which in turn can cause internal stresses, cracks and distortions. One possible reason for these undesirable results may be the retained austenite. These effects are most pronounced in tool steels. In this study, the possibilities for reducing the amount of residual austenite during the heat treatment of tool steel is investigated.

Keywords*: tool steel, heat treatment, retained austenite, high tempering temperature, subzero treatments.*

1. Introduction

Tool steels are high alloy steels of controlled chemical composition, the developement of which seeks to yield properties that are suitable for machining and forming various materials [1, 2]. The carbon content of tool steels can vary from 0.1 to 2.0 %. It may contain various alloying elements, Cr, Mo, V, W, Co, Ni, but microalloyed elements such as Nb may be present. Tool steels, according to their aplication, are classified on cold work tool steels, hot work tool steels, plastic mould steels and high speed steels. The materials of these groups must have different properties , eg. cold work tools must have high hardness, high wear resistance, but in some cases they even have to provide good toughness. The hot work tool steels, as they operate above 200°C, must also have good heat resistance, heat abrasion resistance and good tempering resistance. In order to achieve these properties, in addition to using the right alloying components, applying high quality heat treatment technology is important [3, 4, 5].

The tool steel raw material is normally delivered in soft annealed conditions, which means that is in an equilibrium state of structure. During tool manufacturing, thermal and mechanical internal stresses are generated inside the material, which can be reduced with stress relieving technology. It is advisable that this be done before the next heat treatment operation, because the structural transformations also produce stresses and distortions inside the material. These stresses, added to the internal stresses generated in the previous operations, can cause cracks or fractures.

The hardening consists of austenitization and quenching by cooling faster than the critical cooling rate. The austenitization consists of heating with different steps named preheatings to equalise the temperature between the surface and the centre of the part and holding it at austenitization temperature to form homogeneous austenite. The heating rate, the austenitization temperature and the holding time are very important parameters as these together affect the austenite grain size and homogeneity. The austenite grain size is important because it can determine the size of the phases and microstructures that form it, affects the properties of the product. Incorrectly defined parameters contribute to increasing the amount of residual austenite [6, 7, 8].

Another factor that determines the amount of residual austenite is the martensit start (M_s) temperature and the martensite finish (M_f) temperature, which depend on the carbon content and the chemical composition of the steel [9]. As tool steels are generally high carbon, high alloyed steels, their austenitic-martensitic transformation tempeatures are low, in the case of cold work tool steel, high speed steels, and powder metallurgical tool steels it is generally below 180°C, which means that the complete martensitic transformation is below room temperature, so the presence of residual austenite is unavoidable. The residual austenite is the biggest cause of stresses in the material, as it causes changes in density and volume. During toolmaking, three types of stresses are generated inside the material: stress caused by machining such as turning, milling, grinding or cold working, which can be reduced by stress relieving before hardening; thermal stresses caused by temperature differences depending on the cross section of the piece during heating or cooling, and transformation stresses when the phases and microstructure of the steel is transformed and causes volume changes. After quenching , three phases can be formed, ferrite, martensite and residual austenite, all of different volumes. In order to prevent stresses from causing greater damage, such as cracking or breaking, the tool must be tempered as soon as possible after hardening **[10, 11]**.

During tempering, the martensite decomposes, but some of the retained austenite is converted to martensite while the hardness of the steel decreases as a function of the tempering temperature. In the case of steels contaning carbide-forming alloys, the second tempering can be carried out at high temperatures, which can result in carbide precipitation leading to secondary hardening, setting the final hardness. In this case, the martenite is spheroidized and the retained austenite is converted to martensite. The precipitate, secondary carbides make the microstructure more homogeneous and result a toughness material. By using a third tempering, the amount of residual austenite can be further reduced. However , the cryogenic treatment is the most effective method for minimizing the residual austenite content. During cryogenic treatment, the cooling of the tool does not stop at room temperature, it continues at sub zero temperatures using liquid nitrogen **[12, 13, 14]**.

There are several ways to do this. One is when the quenched tool is taken out of the furnace and placed into a refrigerator chamber when the liquid nitrogen is pulverized, thus cooling the air space to minus 80°C. Another method is the ”cool plus” technique, where the ware cooling continues in the hardening furnace by injecting pulverized liquid nitrogen into the furnace chamber, thus cooling to minus 150°C. The third method is when the cryogenic treatment is performed by placing the cooled ware in the liquid nitrogen at minus 196°C. Cryogenic treatment increases the precipitation of secondary carbides, thus improving the toughness of the workpiece as a dispersed, homogeneous distribution, and of course completes the austenite-martensite transformation, thus ensuring the dimensional stability of the product.

In this study tests were perfomed on Uddeholm Sverker 21 high carbon and chromium cold forming tool steels. The specimens to be examined were subjected to three types of heat treatment, after each heat treatment operation, hardness tests were performed, and the different microstructures were examined using an optical microscope.

2. Materials and experimental methods

Uddeholm Sverker 21 is a ledeburitic cold working tool steel with a high carbon content, and alloyed with Cr, Mo, and V carbide-forming elements. Uddeholm Sverker 21 is a tool steel with excellent abrasion resistance, compressive strength, good through-hardening properties, high stability in hardening and good resistance to tempering-back. Highly nitriding and nitrocarburizing. This material application is for bending, deep-drawing, punching, cutting, but can be used as raw material for different knives. The hardness after hardening can reach 64 HRC. In practice after tempering the ususal hardness for use is 54-60 HRC.

The exact chemical composition of the specimen was analyzed with a Hitachi PMI spectrometer (**Figure 1**).

Figure 1. *HITACHI PMI spectrometer*

The chemical composition of the tested Uddeholm Sverker 21 steel specimen is shown in Table 1.

The raw material of the specimen was in a soft annealed condition with an average value of 212 HB. The hardness testing machine HPO 250 is shown in Figure 2.

The heat treatments were performed in an IU72/1F 2RV 10bar CP type Schmetz vacuum furnace (Figure 3), and the tempering treatment in a Muhel type furnace under protective nitrogen gas (Figure 4).

After hardening and tempering, the hardness was measured by the Rockwell C method on an ERNST AT 130D hardness tester (Figure 5).

The microscopic examinations of the prepared specimens were performed using an Olympus DCX1000 optical microscope (Figure 6).

Figure 2. *HPO 250 hardness testing machine.*

Figure 3. *Schmetz vacuum furnace.*

Table 1. *Chemical composition of the investigated steel grades*

	C	Si	Mn	Cr	Mo	V
Sverker 21	1.56	0.33	0.39	11.28	0.78	0.76

Figure 4. *Muhel tempering furnace*

Figure 5. *Rockwell C hardness tester machine.*

Figure 6. *Olympus DCX 1000 optical microscope*

Three types of heat treatment technologies were applied to the specimens. The hardening was performed in the Schmetz type vacuum furnace and the tempering in the Muhel type nitrogen gas protected furnace. In the first case, low temperature (1200 °C) austenitizing and low temperature (190 °C) tempering, in the second case, high temperature (1075 °C) austenitizing and three times high temperature tempering (525, 535, 515 °C) (Figure 7), while in the third case, after high temperature austenitizing cryogenic treatment quenching with liquid nitrogen (in minus 150 ° C) (Figure 8) was used, and which was perfomed three times at high temperature (525,535,515 °C) (Table 2).

Heat treatment diagram of the sample tempered at three times higher temperature is shown in Figure 7.

Table 2. *Heat treatment parameters*

Specimen nr.	Austenitizing (°C/min)	Cryogenic treatments (°C/min)	Tempering (°C/min)
1	650/15 850/15 1020/20	-	190/120
2	650/15 850/15 1075/20	-	525/120 535/120 515/120
3	650/15 850/15 1075/20	– 150/50	525/120 535/120 515/120

3. Results of experimental measurements

Between and after the heat treatment operations, a hardness measurement was performed. The measured hardness values are shown in Table 3.

Based on the results of the hardness tests, it can be concluded that the hardness values of specimens 2 and 3 are lower than those of the specimen 1 performed at a low hardening temperature. This is due to the fact that after high temperature hardening some of the primary chromium, molybdenum, vanadium carbides and their complex carbides are dissolved on the matrix and are more residual austenite quantities.

The microstructures of the specimens prepared by grinding, polishing, and etching using 2% Nital solution are shown in Figures 9.a–c. It can be seen from Figure 9.a, that the amount of primary carbides in the microstructure of low temperature tempered tool steel is quite high, reach-

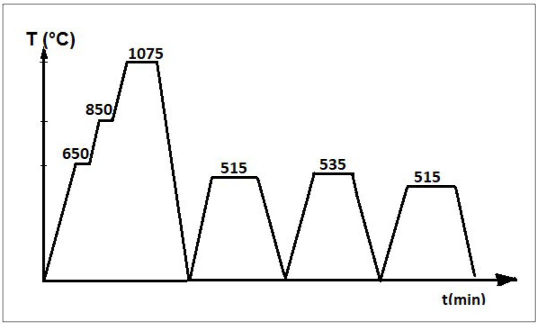

Figure 7. *Heat treatment diagram of specimen nr.2.*

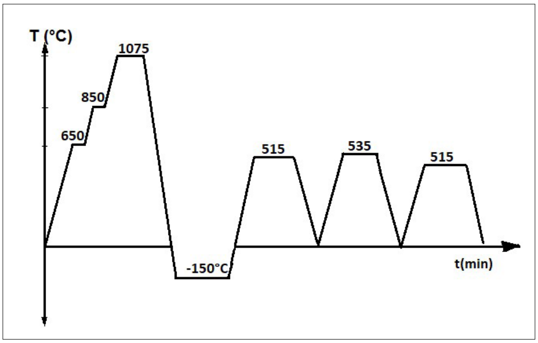

Figure 8. *Heat treatment diagram of specimen nr.3.*

Table 3. *Hardness values after heat treatments*

Specimen nr.	Soft annealed (HB)	After hardening (HRC)	After tempering (HRC)
1	212	62	60
2	212	61	60
3	212	61	60

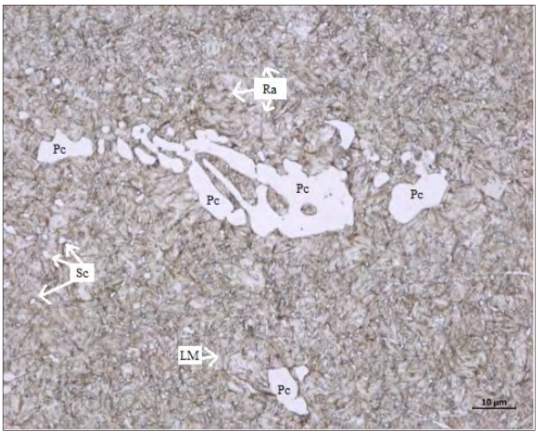

Figure 9.a. *Microstructures of specimen nr. 1.*

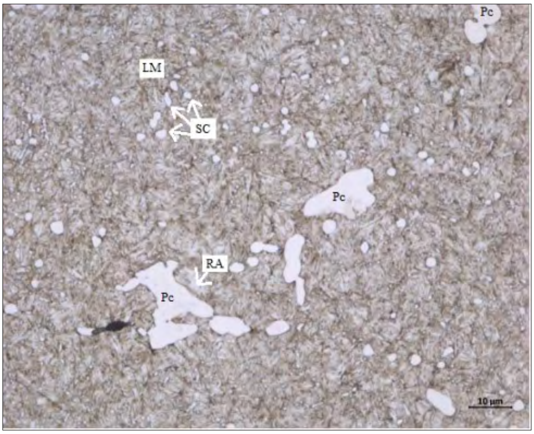

Figure 9.b. *Microstructures of specimen nr. 2.*

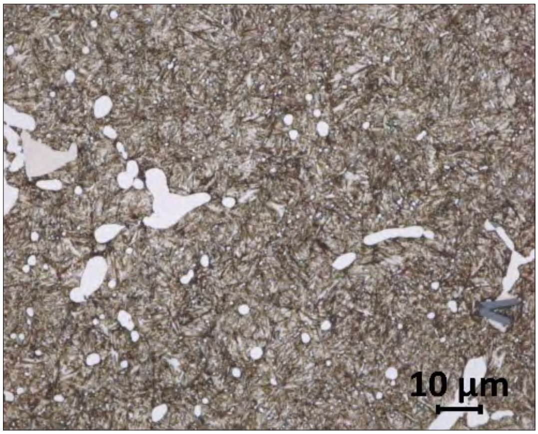

Figure 9.c. *Microstructures of specimen nr. 3.*

ing 60µm, and the amount of residual austenite reaches 8-10%. The microstructure of specimen nr. 2, which was austenitized at high temperture and tempered three times at high temperatures, shows that a part of the retained austenite was transformed in tempered martensite , and the amount and size of primary carbides were reduced by more than 50%, and at high temperatures precipitated secondary carbides are visible. The **Figure 9.c.** shows at a 1000x magnification a microstructures of specimen nr.3, cooled to minus 150°C and tempered three times at high temperatures . It can be seen that the amount of residual austenite has been reduced to a minimum af about 1 % by cryogenic treatment and the microstructure is characterized by fine, dispersed secondary carbides.

4. Conclusions

Uddeholm Sverker 21 grade is a ledeburitic cold working tool steel with a very good abrasive wear resistance, with good through-hardening properties, good toughness and dimensional stability after heat treatments. After low temperature hardening and one time tempering, a good hardness value was obtained, but the microstructure showed inhomogenity, in the presence of large primary carbides, and caracterised by residual austenite and martensitic structure. Specimen nr. 2 which was austenitized at high temperature and tempered three times at high temperatures, showed a homogeneous, uniform smaller carbide distribution in the microstructures. The amount of residual austenite was reduced to about 4%. Sample nr. 3 was cryogenic treated, resulting in a more dispersed, finer secondary carbide distribution on the microstructures, and the residual austenite was almost undetectabled. Using cryogenic treatment the best toughness properties and the longest service tool life of the product can be achieved.

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