The Retained Austenite Content Reduction in Tool Steels due do Vibratory Tempering Applying

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Abstract
The presence of residual austenite in the tool steels determine hardness and durability reducing of the tools. In order to reduce the residual austenite content can be applied the quenching below 0 °C, but in these conditions increase the manufacturing costs. A more advantageous to reduce the residual austenite is the vibration of the tools during the tempering treatment. In the research was used a vibratory tempering bath excited with a resonant bar calibrated on the network frequency. The steel C80U kept after tempering 10.49% Ar. After the normal tempering (190 °C - 1h) are preserved Ar 3.2%. Under the vibration action, it produces a more advanced transformation, resulting only 2% Ar. The material vibrated at tempering is high quality and the additional costs are insignificant.

Keywords
tool steel, vibration, heat treatment, tempering, retained austenite, eddy current

1. Introduction

In the category of non-alloyed steels, the steel C80U (1.1525) is most commonly used. From this steel is made relatively cheap tools having a simple geometry and are subject to knocks and therefore requires a good toughness. This steel is used for molds and dies for forming and punching, molds for plastic materials injection, woodworking tools, pneumatic hammers tools, centering peaks, pins, hand tools, pliers, scissors, chisels, mandrels and others.

The high-carbon steels have a finish martensitic transformation temperature (Mf) lower than the ambient temperature. Thus, after hardening these steels are preserved a certain proportion of residual austenite, called routinely retained austenite. Retained austenite is a steel structure that during cooling at martensite transformation temperature is not completely converted into martensite and remains unchanged at room temperature together with martensite.

The presence of retained austenite is undesirable because it has a low hardness and therefore reduces the tool life. Also, the retained austenite is metastable, during exploitation it may partially transform into bainite and this leads to changes of tools dimensions [1, 13…17]. The transformation of retained austenite into bainite is connected with volume change, whereas diminishing the content of austenite in martensite by 1% causes a 0.07% increase of its volume [2, 3].

Also, between martensite and retained austenite differences exist of electrical conductivity and magnetic properties. These differences allow the use of nondestructive method for determining with eddy current the retained austenite content in hardened tools [3, 4].

To reduce the retained austenite content of non-alloyed tool steels, after quenching is applied tempering at 190-200 °C. During the tempering occurs the martensitic transformation from the tetragonal martensite to the martensite with cubic lattice and also produce reduction of retained austenite content. This increases the hardness and dimensional stability of tools. To reduce the retained austenite more advanced, may be applied cryogenic treatment but it increases manufacturing costs.

A cheaper method by which may be reduced the retained austenite content refers to vibration of the parts during the tempering. Under the vibrations influence will increases the retained austenite instability, and thus increase the diffusion speed and in these conditions the austenite transformation occurs faster and more advanced.

2. Heat treatments

To achieve of samples was used steel C80U – pulled bar, Φ10 ± 0.05mm, annealed (230÷240 HV30). Chemical composition: 0.83% C, 0.22% Si, 0.31% Mn, 0.020% and 0.022% P, 0.12% Cr, 0.08% Ni, 0.12% Cu. Full hardening diameter (average values): 10 mm.

From this material was made 10 samples for determination of retained austenite (Φ10x15mm) on quenching and tempering with and without vibration.

- Quenching: it is in steps heating, T_1 = 600 °C (v = 600 °C/h); T_{qench} = 800 °C (v = 800 °C/h); maintaining t = 10 min.; water cooling. After hardening all the specimens showed roughly similar retained austenite content, Ar = 10.26÷10.53 % with mean, Ar_{med} = 10.49%. Hardness measured on both flat sides of all samples showed very similar values, 820÷840 HV30. The results are similar to those reported in [5, 6].
- Classic tempering: T_t = 190 ± 5 °C was made in hot oil. Five quenched samples were introduced simultaneously in the tempering basin and extracted by one at time 15', 30', 45', 60', 90'. Was measured hardness, retained austenite content and analyze the microstructure.
- Vibratory tempering: Tt = 190 ± 5 ° C. While maintained in the hot liquid samples were subjected to the action of elastic waves generated by a resonance bar (Fig.1). Control conditions were the same as in classical tempered samples.

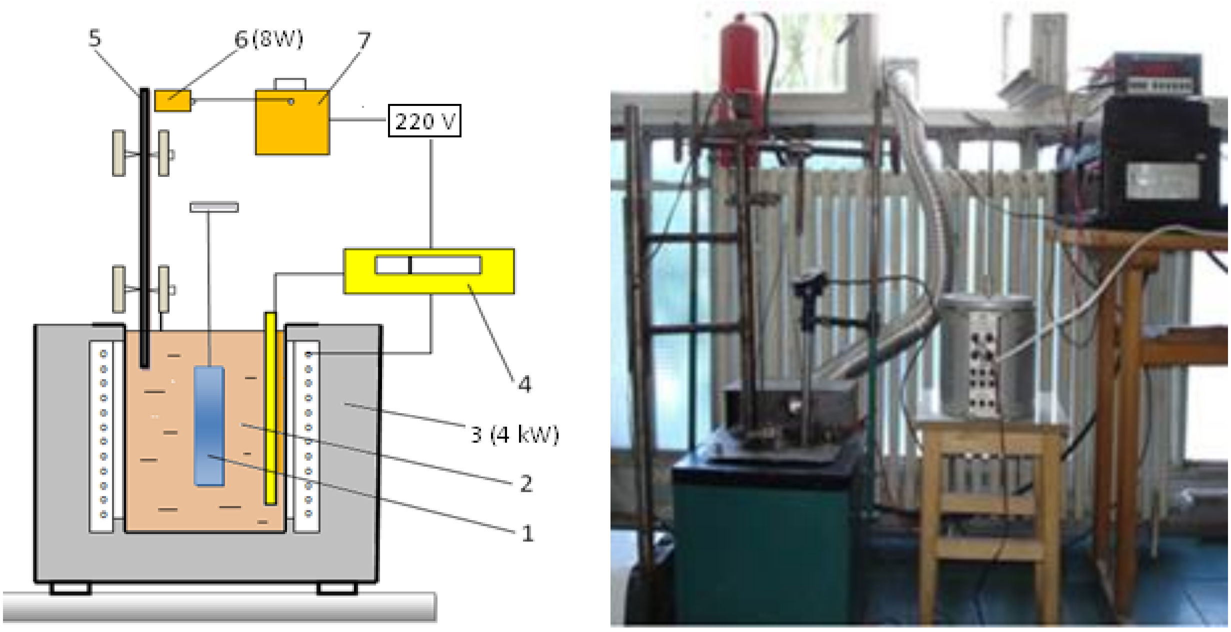

Fig. 1. Plant for tempering in mechanical oscillations field

The specimens (1) are immersed in the liquid medium (2) - oil or molten salt. The oven (3) provides the heating of the tempering environment. Constant temperature is achieved by the thermoregulatory system (4). In the tempering bath is immersed end of the resonating bar (5) which oscillates at electrical network frequency. The resonance bar excitation is performed by the electromagnet (6). The vibration amplitude adjustment is made by adjusting the voltage transmitted from the autotransformer (7).

The resonant bar end was immersed in hot oil to a depth of 85mm and the oscillation amplitude was ± 1,8mm so as not to throw splash outside of the treatment bath. Under these conditions the power consumption of the electromagnetic excitation was 8W. The bar vibrations generate elastic waves that are transmitted of the specimens immersed in the liquid medium. In these circumstances, are influenced the microstructural transformations that occur during the tempering treatment.

3. Retained austenite content measurement

In specialized literature, there are several techniques for quantifying of the retained austenite content existing in hardened steels: metallographic analysis, scanning electronic microscopy, density measurements, X-ray or neutron beam diffraction, Moessbauer spectroscopy or measurements of magnetic properties [6...9, 20...26].

Magnetic methods for determining the amount of retained austenite can be applied quickly, even if the various calibrations are required [10, 11]. In the present research was used the eddy current analysis method [21, 22, 23]. The method consists in the induction of eddy currents in the test material. The magnetic field induced eddy currents, due to the presence of discontinuities and inhomogeneities in the material, the coil impedance changes, which affect the amplitude and phase eddy currents (Fig. 2).

The amplitude, phase angle and penetration depth of the currents eddy depend on the amplitude and frequency of the excitation current, the electrical conductivity, the magnetic permeability, the object shape, the relative coil position to the workpiece, as well as the material homogeneity.

The eddy currents are concentrated near the material surface and it has a maximum value in the vicinity of the primary coil that generates an electromagnetic field. With distance increasing from the induction coil, eddy current density decreases according to the relationship:

$$\delta = \frac{1}{\sqrt{\pi \cdot f \cdot \sigma \cdot \mu}} \tag{2}$$

where: f – frequency, σ- electrical conductivity, μ- magnetic permeability.

The induced eddy currents generate a second magnetic field. This secondary field opposes of the primary field, according to Lenz's law and is influenced by the tested material properties. Modifications of these properties causes in the pickup coil induced current changes.

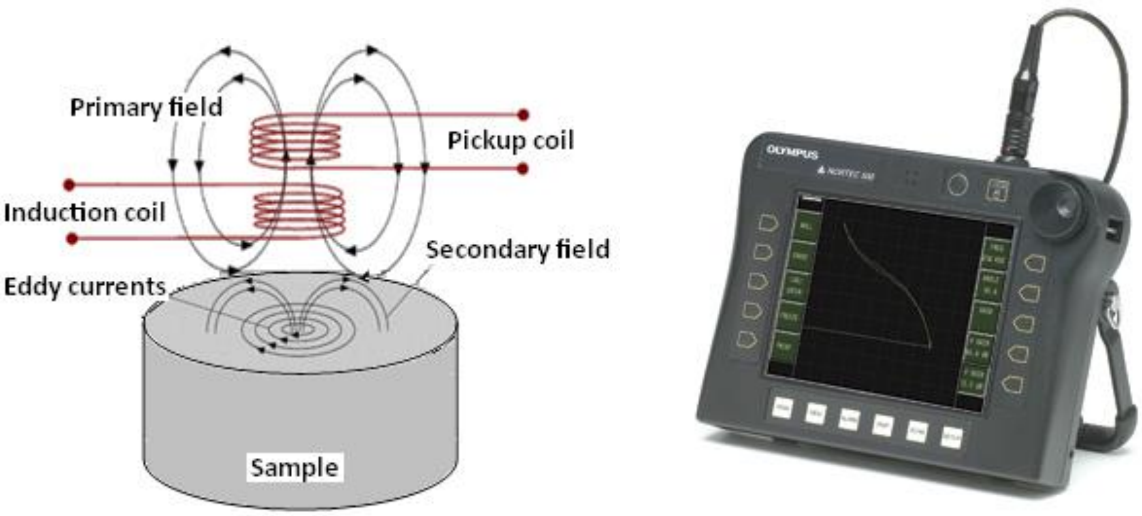

Fig. 2. Principle of eddy current control and NORTEC 500 apparatus for the retained austenite content measuring

4. Experimental results

In case of a uniform structure, when the material conductivity is high, the intensity of the induced magnetic field is big and the signal received by the pickup coil is small. The discontinuities from the tested material causes electrical conductivity reducing and thus the induced magnetic field intensity is low and the received signal by the pickup coil is large. The retained austenite has a low electrical conductivity, and its presence in the martensite matrix represents a microstructure defect. The ratio of the magnetic characteristics of the austenite and martensite is 1:5 [12]. Due to this difference can be determined the proportion of retained austenite in hardened steels.

Unalloyed steels in equilibrium state (annealed) have a structure that contains two phases with ferromagnetic properties, ferrite and cementite. After quenching, obtain a martensite (ferromagnetic) and austenite (paramagnetic) structure. For determining the retained austenite it is necessary to calibrate the eddy current inspection equipment. For research was used the eddy current flaw detector NORTEC 500 Olympus.

In the research for calculating of residual austenite content was considered:

- ten annealed samples - Ar = 0%;
- one specimen of austenitic steel X10CrNi18-8 - Ar = 100%.

Measurements were made in an annealed state, after quenching and after recovery with or without vibration. By interpolation of 0 – 100 % Ar it was determined the retained austenite content. After hardening all the specimens showed similar retained austenite content, Ar = 10.26÷10.53 % with a mean Ar_{med} = 10.49 %. The retained austenite variation resulting after classic and vibratory tempering is shown in Figure 3.

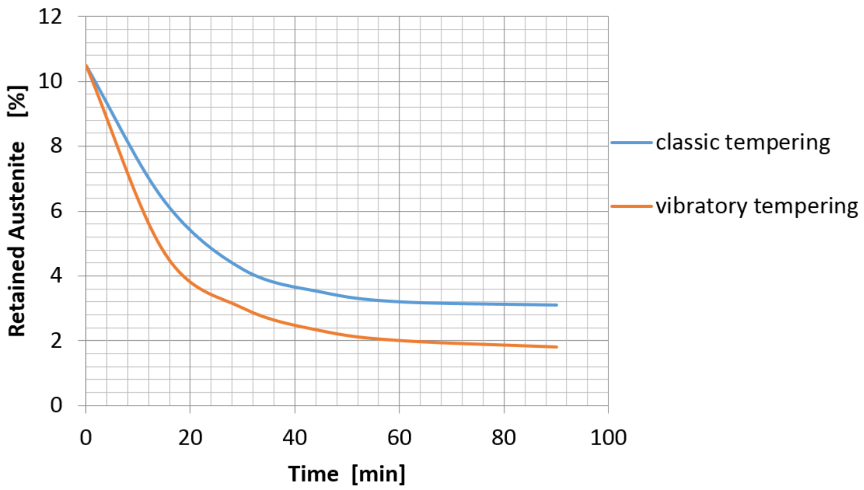

Fig. 3. Residual austenite content variation while classical or vibratory tempering (temperature 190 ± 5 °C)

It is evident the vibration influence on the tempering transformation mechanism. In the presence of the mechanical oscillation field produced by the resonant bar and transmitted through the liquid medium to samples, martensite and retained austenite transformation is accelerated [28, 29, 30]. This can be attributed to the oscillations field on the materials atoms that is in a non-equilibrium state. The energy input brought by the mechanical oscillation field favors the acceleration of diffusion.

Under the action of the mechanical oscillation field the tempering processing is accelerated, making it possible to reduce the heat treatment duration. Austenite content decreases by more than 1% and thus increases the durability of tools [17, 30, 31]. Hardness measurements revealed no significant differences between the samples tempered with and without vibrations.

From the analysis of Figure 3 follows that prolonging the tempering time over 50 minutes does not lead to a significant decrease in retained austenite content. It is also found that the vibrating tempering effects for 30 minutes is comparable to those produced from classical tempering in 60 minutes. This results in economic efficiency of application of vibration tempering. The vibration system has have negligible energy consumption and the tempering time reducing increases the productivity in parallel with reducing of the manufacturing costs and increase the tools quality.

5. Conclusion

After quenching steel C80U records an average of retained austenite Ar = 10.49 %. Upon the classical tempering (190 °C/1h) decreases the retain austenite Ar = 3.2 % and if the samples are vibrated during tempering, residual austenite decreases to 2 %.

By vibrating the diffusion processes are accelerated and thus transformations occur faster and be conducted at a more advanced level

Due to reduction of retained austenite content increase the tools quality by increasing the durability and dimensional stability.

Vibratory tempering can increase the productivity and reduce energy consumption, by the fact that the effects at classical tempering for one hour are made to vibration tempering in 30 minutes.

Tempering in liquid medium has advantages: protection of the parts surfaces, uniform heating of the load, adjusting and maintaining the temperature within narrow limits, the possibility of transmitting vibrations to all pieces immersed in the hot liquid.

The vibration-generating system is simple and reliable. The resonance bar has very low energy consumption and does not require a cooling system to protect the electromagnet excitation. The vibratory tempering equipment was tested up to 600 °C. In these circumstances, this tempering equipment can be applied to all alloyed tool steels.

Method for measuring of residual austenite using eddy currents is simple and provides a sufficiently good precision. Hardness measurements and metallographic analysis revealed no differences between the samples tempered with and without vibrations.

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