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STUDY OF THERMAL CONDUCTIVITY VARIATION DEPENDING OF THE HEAT TREATMENT FOR TOOL STEELS

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ABSTRACT

This paper studied the influence of quenching and tempering steel structures on the thermal conductivity for OSC 11 steel. For the experiment we used samples that were subjected to heat treatment quenching and tempering at 200˚C and at 500˚C. To emphasize the structure and structural changes in both the sample and the untreated samples, micrographs and photos were made by scanning electron microscopy. Measured conductivity results were presented graphically and studied to highlight their influence on the hardening structure.

KEYWORDS: thermal conductivity, heat treatment, steel, structure

1. Introduction

Thermal energy if found in metallic materials with privileged propagation medium. Thus, metallic materials have the property to transport thermal energy. An energy flow appears from the warmer part to the colder one into a material out of its thermal equilibrium. Heat propagation phenomenon into the mass of a metallic material is thermal conductivity, [1]. Thermal conductivity influences mechanical functioning of parts, because running mechanical coupling heat-up and expand. Heating depends of friction coefficient of the mobile parts, of internal friction, of the type of the metallic materials lattice, of material homogeneity and the discontinuities present within the lattice, such as lamellar metallographic component, point, linear and volume defects, [4].

Metallic materials have the highest thermal conductivity. Thermal conductivity for steels depends of the type of alloying elements and their percentage. Carbon percentage has a special influence. The alloying elements and their percentage in steel creates defects in the crystalline lattice of the material, and, conclusively thermal barriers.

2. Experimental results

Tool steel was used for the experiment as well as some standard test specimens were subjected to heat treatments to modify their properties. They were tested for impact bending resistance. The structure was after fracture with scanning electron microscope. Thermal conductivity tests were made for the tool steel as annealed, cold-worked, after quenching and low tempering and graphics for comparative analysis of thermal conductivity were made, too.

2.1. The analysis of the tool steel

The tool steed used for the experiment is OSC 11, STAS 1700-98, a type of Fe-C-Mn-Cr-Si alloy, which corresponds to the equilibrium structures from thermal diagrams. According to these, the structure contains pearlite, cementite and complex carbides of manganese and chromium, [2, 3, 5].

OSC 11 steel is used for tools, such as: punch, dies, milling tools, drills, tools for wood processing, screwdrivers, files, scissors for sheet, block cutters, gauges, saws for metal. This material has the chemical composition presented in Table 1 and it was established as means of a mass spectrometer (Foundry Masters) tests.

***Table 1**. Chemical composition, %*

Fe	C	Si	Mn	S	Cr	Cu
96.7	1.19	0.11	0.61	0.12	0.7	0.32

The specimens were subjected to martensitic quenching. Technological parameters were as follows:

- heating temperature 820°C;
- holding period ¼ hours;
- oil cooling at 50°C.

Two kinds of tempering were achieved after martensitic quenching:

- low tempering – heating at 200°C, holding for 1 hour in the furnace and air cooling for obtaining a structure with reduced great hardness relatively;
- high tempering – heating at 550°C, holding for 1 hour in the furnace and air cooling for obtaining a structure with a good resilience.

2.2. Microstructure analysis

Microstructure analysis was achieved by means of VEGA II LSH scanning electron microscope and was realized in fracture, after impact bending test. The resilience test was made on Charpy impact machine, [7].

2.2.1. Microstructure analysis of the untreated specimen

The untreated sample (in phase of equilibrium state) has a pearlite and cementite structure. Studying the micrography notices a fragile fracture with edgy well-defined grains. The small area of plastic deformation concentrates mainly on the edges of the grains. Figure 1 presents cleavage areas and sharp areas that characterize an intercrystalline fracture with crystallographic plans prominence. The EDX analysis of fracture surface, scale 50 μm, was measured at a concentration of 96.82% Fe, 1.008% C, 1.2% Cr and 0.96% Mn. The breakage area has a grainy, bright and shiny crystalline aspect.

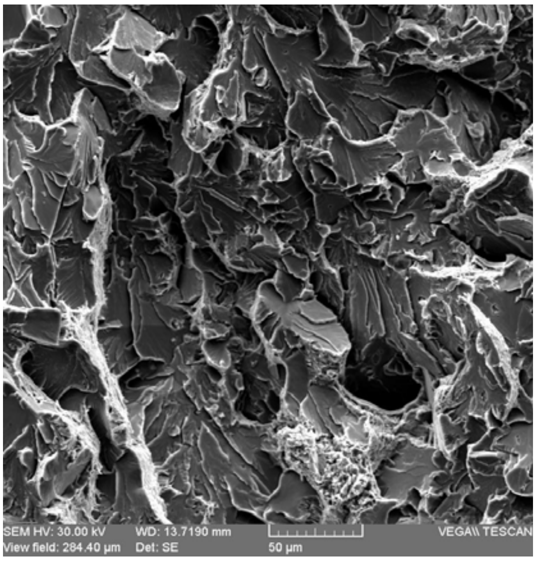

***Fig. 1.** Fractography of the untreated sample, after breakage, order of magnitude 2500 x*

Table 2 presents the chemical composition of the studied area.

***Table 2.** Chemical composition on the distribution area of the elements*

Bruker AXS Microanalysis GmbH. Germany. 22/04/2010		
Element	[norm. wt.%]	[norm. at.%]
Iron	95.15078	88.39028
Carbon	2.059743	8.896639
Chromium	1.477005	1.473683
Manganese	1.312477	1.239398

2.2.2. Microstructure analysis of the heat-treated sample martensitic quenching and tempering at 200˚C

The sample has a structure like tempering martensite and bainite. The breakage area has a crystalline, grainy aspect with hard formations.

Analyzing the structure with scanning electron microscope, it is noticed a brittle structure with an intercrystalline fracture. Table 3 presents the chemical composition of the studied section, with quantitative values of the elements both in mass percentages and in atomic ones.

***Table 3**. The chemical composition of the elements on the studied section*

Element	[norm. wt.%]	[norm. at.%]
Iron	96.8221	93.29203
Chromium	1.209581	1.2518
Carbon	1.007881	4.515438
Manganese	0.960439	0.940733

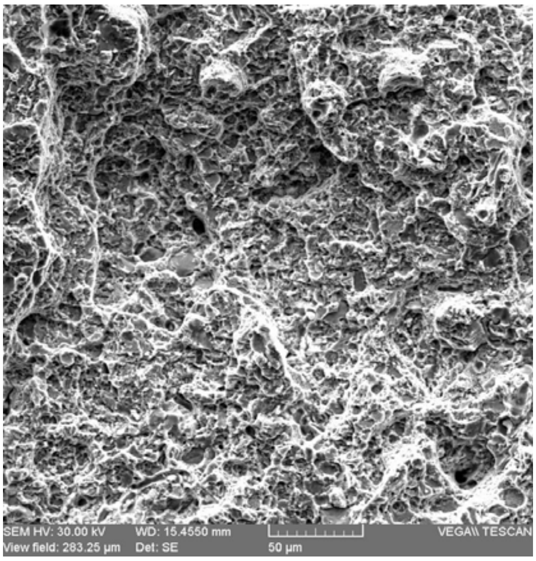

***Fig. 2.** Fractography of the heat-treated sample by martensitic quenching and tempering at 200˚C, after breakage; order of magnitude 2500 x*

Hard microformations distinguish between the types of iron, chromium and manganese complex carbides.

2.2.2. Microstructure analysis of the heat-treated sample through martensitic quenching and tempering at 550˚C

The material has a sorbite structure corresponding to high tempering. Breakage structure is semi fragile and there are areas with lattice cementite. For disappearing of the lattice cementite, a special treatment must be done and it consists in heating hypereutectoid steels over A_{ccem}, followed by water or oil cooling (quenching). Then it will be done a heating over A_{c1} with 20-50°C, the sample is hold in the furnace and then air-cooled. The sample presents a partially tough structure, partially brittle with intercrystalline breakages so that the grains edges are evident (especially in the area with lattice cementite). Chromium carbides of hexagonal shape are well distinguished.

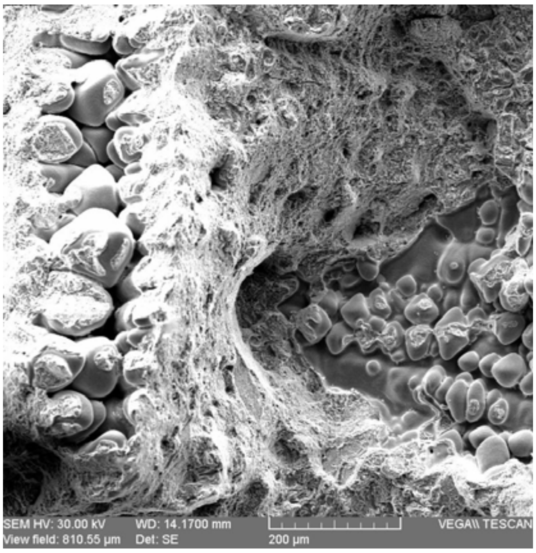

Fig. 3. *Fractography of the heat-treated sample through martensite quenching and tempering at 550˚C, after breakage, order of magnitude 300 x*

Table 4. *Chemical composition in point*

Element	[norm. wt.%]	[norm. at.%]
Iron	86.94674	73.80106
Chromium	5.418011	4.939456
Carbon	2.925038	11.54414
Manganese	2.019162	1.742238

At point analysis by means of EDX it can also be distinguished an area with complex carbides of Fe, Cr, Mn with percentages of 45.89% Mn, 28.83% Fe, 18.65% Cr and 6.64% C.

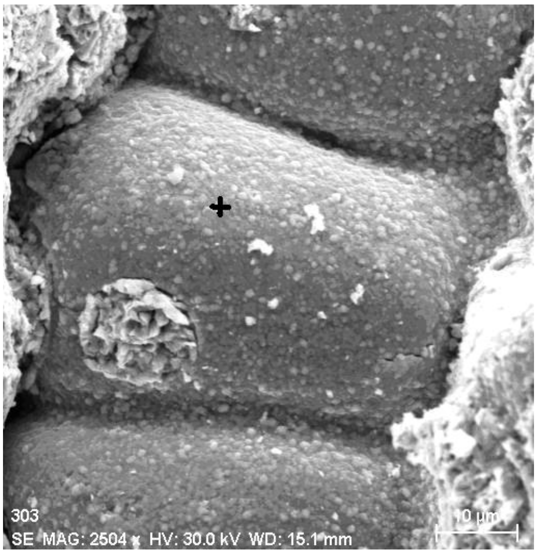

Fig. 4. *Point analysis, order of magnitude 2500 x*

2.3. Analysis of thermal conductivity

The analysis of thermal conductivity is realized by means of Mathis TCI apparatus, [6]. In order to determine thermal conductivity, a series of ten tests for an average of the final value will be done. By means of TCI system, thermal conductivity of the material is directly taken but diffusivity is achieved by applying the following relation

$$a = \frac{\lambda}{\rho \times C_p} \tag{1}$$

$$C_p = \frac{e^2}{\lambda \times \rho} \tag{2}$$

where λ = thermal conductivity, C_p = caloric capacity, ρ = density, a = thermal diffusivity , e = thermal inertia (effusivity).

Table 5. *Values obtained for OSC 11 steel*

Heat treatment	λ $[w/mk]$	**e** $\left[wS^{\frac{1}{2}}/m^2k\right]$	**C** $_p$ $[J/kgk]$	$\mathbf{a}\times 10^{-6}$ [m^2/S]
cold-worked	8.82	5381.3	421.6	2.69
annealed	11.6	6203.6	425.8	3.50
quenched and tempered 200°C	7.49	4969.1	423.2	2.27
quenched and tempered 550°C	8.18	5185.3	422.3	2.48

Thermal conductivity is influenced by quenching due to structural transformations that appear (transformation $A \rightarrow M$) being accompanied by the increase of defects quantity per unit volume. Thermal conductivity decreases if residual stresses and lattice defects appear which represent barriers and thermal blockages.

At low tempering (200°C) when the structure is made of tempering martensite and bainite, a part of the lattice stresses are loosening a part of the defects disappear and thermal conductivity has a slight decrease.

At high tempering (550°C) the structure of the material is sorbite and because of the transformations within, the structure, is more approached of equilibrium state so that, there are few lattice defects and, consequently, few thermal blockages and thermal conductivity is more increased than at low tempering.

From the graph of comparative analysis of the thermal conductivity, it notices that the biggest value is 11,615 [W/m K] and corresponds to phase equilibrium state of the material (annealed state).

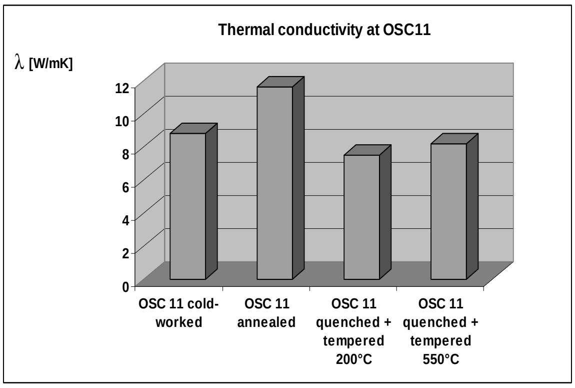

Fig. 5. *Variation graph of thermal conductivity at OSC 11*

In mechanical cold-worked state, thermal conductivity decreases because of increased the number of defects of the crystalline lattice per unit volume. These defects can be: point defects (vacancies, interstitial atoms etc), linear defects (supplementary reticular plans, dislocations) and volume defects (cylindrical defects).

The bigger number of defects corresponds at the more blockage situations of the dislocations and the number of thermal blockages and thermal barriers increases.

Conclusions

1. For OSC 11 steel, phase equilibrium state (annealed state) corresponds to a maximum value of conductivity, this is justified by the minimum number of defects and dislocations in the lattice per unit volume.

2. For the heat-treated OSC 11 steel, heat treatment, which consists in martensitic quenching, followed by low tempering, where the structural constituent is bainite, thermal conductivity has a lower value. This happens because of the phasic cold hardening, introduced after quenching is present after low tempering too.

3. For high tempering, where sorbite is the main constituent, the material approaches the equilibrium state of the material by achieving a decrease in the number of lattice defects per unit volume.

4. In case of mechanical cold hardening (resilience), it is noticed a decrease of thermal conductivity the increased number of dislocations and due to increased lattice defects. Lattice defects appear by the shifting of the reticular plans on atomic distances according to the theory of plastic deformation.

References

[1]. Bădărău Gheorghe - *Proprietăţile materialelor metalice*, Note de curs, 2007-2008.

[2]. Hopulele Ion, Alexandru Ion, Găluşcă Dan-Gelu - *Tratamente termice şi termochimice*, vol I, 1983.

[3]. Hopulele Ion, Alexandru Ion, Găluşcă Dan-Gelu - *Tratamente termice şi termochimice*, vol II, 1984.

[4]. Leinhard IV, J.H., Leinhard V, J.H. - *A Heat Transfer Textbook*, Editura Phlogiston Press, Cambridge.

[5]. Mitilea Ion, Budău Victor - *Studiul metalelor* - Editura Falca, Timişoara, 1987.

[6]. Ştefan Mihai, Vizureanu Petrică, Bejinariu Costică, Bădărău Gheorghe, Manole Vasile - *Studiul proprietăţilor termice ale materialelor*, Editura Tehnopress, Iaşi, 2008, ISBN 978-973-702-566-1.

[7]. Zaharia Luchian - *Teoria deformării plastice*, Editura „Gh.Asachi”, Iaşi, 2001.