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UDC

STUDIES OF THE EFFECT OF QUENCHING OIL ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF HEAT TREATED 34CrMo4 STEEL

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Abstract. *Aim of this research was assessment of quenching oil influence on microstructure and mechanical properties of 34CrMo4 quenched and tempered steel. Conducted work includes analysis of microstructure and examining mechanical properties of heat treated steel quenched in Hartex70S and OH120M oils with following tempering. Fracture surfaces of specimens used in impact test were subject to microfractographic research. Comparative simulation for quench hardening processes in two quenching oils was carried out using computer program.*

Key words: *quenching oil, heat treatment, mechanical properties, 34CrMo4 steel.*

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Introduction. Steel designed for machine parts, mechanisms and steel frameworks is required to exhibit required mechanical properties. These properties can be achieved using heat treatment processes. Proper heat treatment enables to obtain the microstructure providing demanded mechanical properties. The most common type of heat treatment, which improves mechanical properties, is quench hardening followed by tempering.

Quench hardening is one kind of heat treatment, whose purpose is to increase hardness of steel as the effect of martensitic transformation of undercooled austenite. During quench hardening steel is heated to austenitization temperature, withstand in this temperature and quenched at rates above critical values allowing martensitic transformation of undercooled austenite to occur. Quenching may be carried out in several cooling media, like: liquid, gas, solid and fluidic [1]. Nonalloy steels are quenched in liquid media, usually in water and – in case of low alloy steels with higher hardenability – in quenching oils. Oils have lower cooling ability in comparison to water and her solutions, and are used to quench hardening of steel with higher hardenability. During cooling of austenitized steel in quenching oils, materials are subjected to smaller stresses and risk of hardening crack is lower [2].

Materials and methods of investigations. Laboratory cast of low alloy steel 34CrMo4 was used in research [3]. Chemical composition of this steel is presented in Table 1.

Table № 1

Chemical composition of investigated steel [in % wt]

C	Si	Mn	Mo	Cr	P	S	N
0,29	0,15	0,35	0,17	1,09	0,015	0,015	0,011

Hardenability of investigated steel was estimated using Jominy test. Hardenability curve of investigated steel is presented in Figure 1. Ideal critical diameter, D_i, estimated using hardenability curve was 74 mm [4].

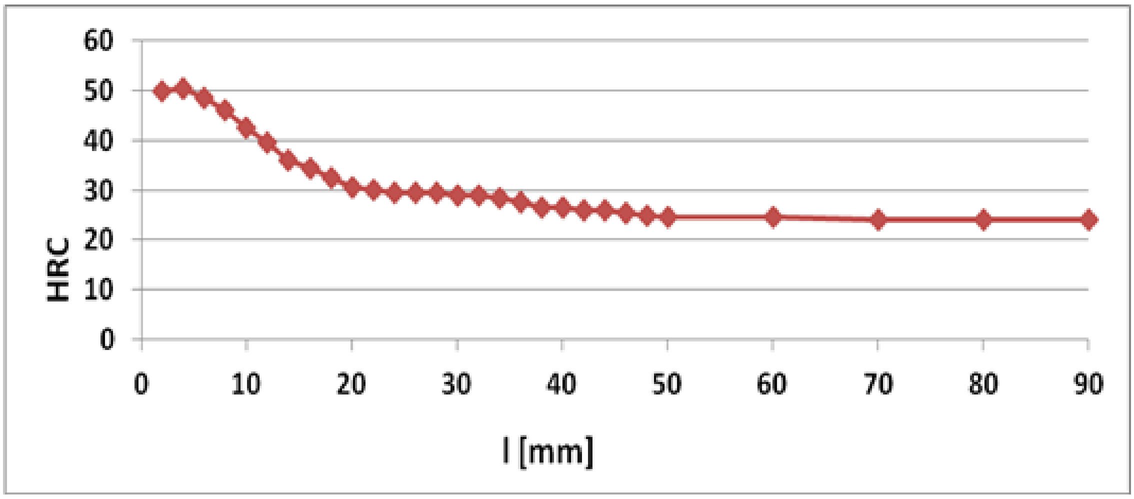


Figure 1. Hardenability curve of investigated 34CrMo4 [3]

In specific research two cuboids with size of 40x40x80 mm were heat treated in protective argon environment using electrical chamber furnace. Heat treatment was conducted in two stages, which include austenitizing cuboids in temperature of 870 °C and hardening them in quenching oils: sample 1 – HARTEX 70S, sample 2 – OH-120M. These oils differ in cooling abilities described by the relationship between heat transfer coefficient, α, and temperature of surface, T.as it is shown in Fig. 2. compartment, HARTEX 70S allows for quicker cooling in comparison to OH120M. Quenched samples were divided into two parts as it is shown in Fig.3. Part A was tempered for one hour in electrical chamber furnace at 650°C and was used for investigation of impact strength.

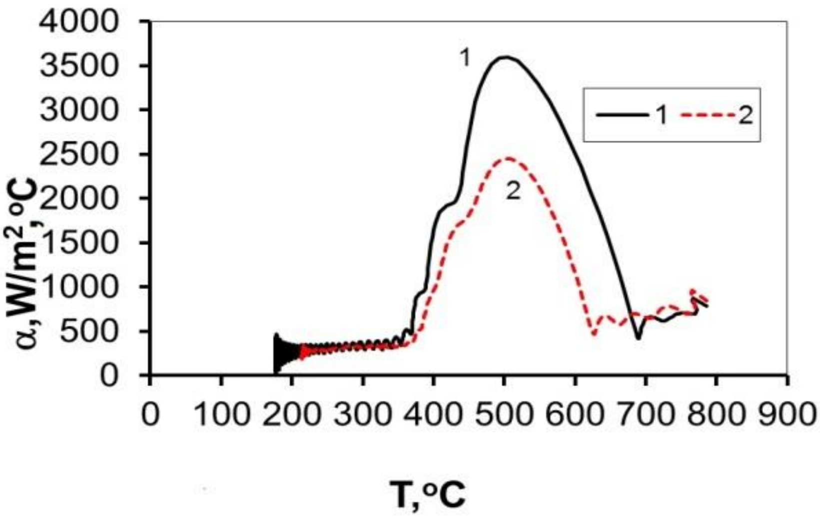


Figure 2. Heat capture coefficient v_s surface temperature graph 1 – HARTEX 70S, 2 – OH-120M [3]

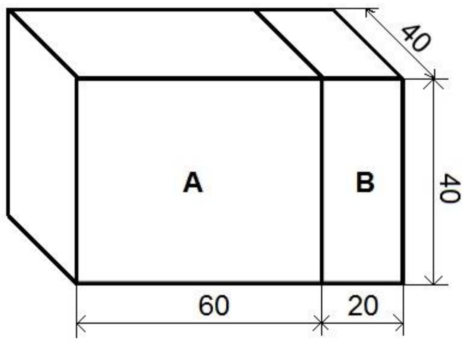


Figure 3. Cuboid division in two parts

Part B was used hardness measurements and then in research of microstructures obtained after quench hardening.

Standardized samples were prepared for impact strength studies after tempering. From each part A of heat treated samples four Charpy-V specimens were prepared. Impact strength tests were performed with usage of Charpy impact hammer with cracking energy of 15 kGm. Impact strength is determined as the ratio of measured crack energy, L, and cross-section surface, S_o, at notch position.

Specimens B were subjected to grinding of surfaces perpendicular to axis of specimens and hadness distibution on cross sections was measured, according to scheme, shown in Fig. 4. Hardness distribution was therefore examined in two directions, perpendicular to cross-section sides and along two cross-section diagonals. In total, 312 measurements were conducted.

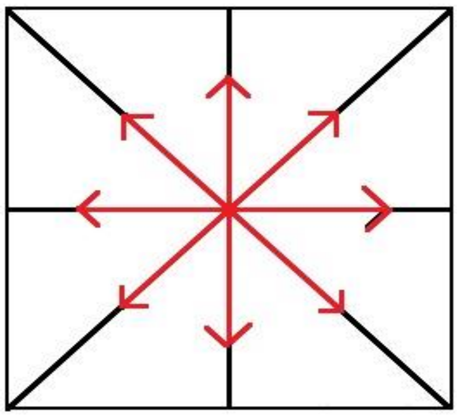
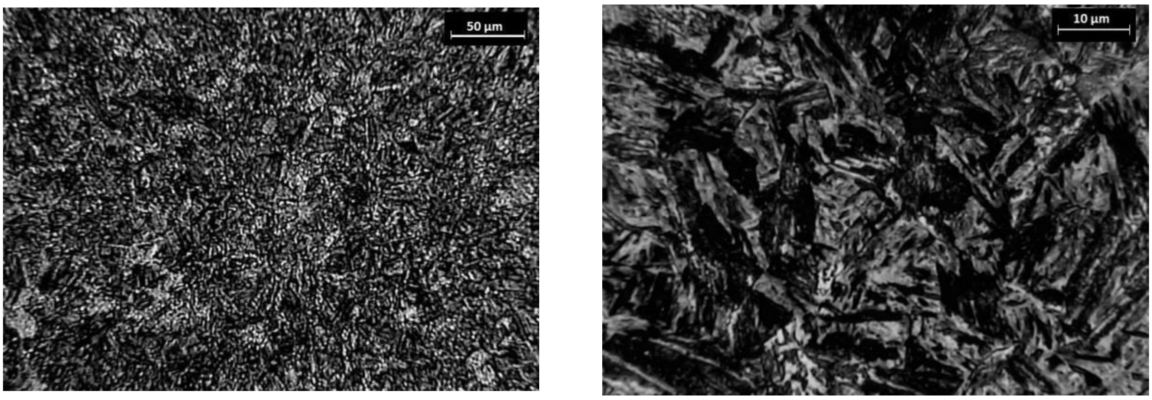


Figure 4. Hardness measurement scheme on specimen B

Fractographic investigations of fracture surfaces of selected samples used for impact test measurement were carried out using SEM microscope Hitachi 3500.

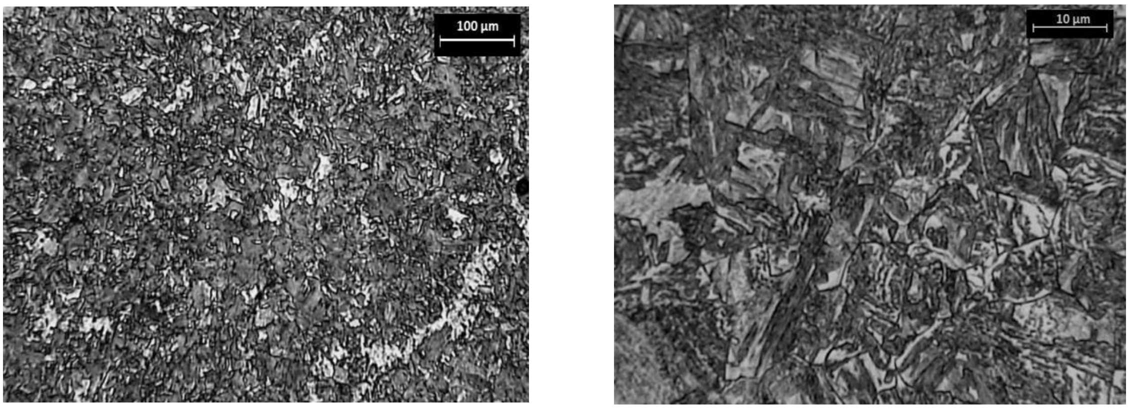
In order to simulate hardening processes, Heat_CTP software [4] was used. It allows to compute temperature field, T(x,y,z,time) on the cross section of heat treated steel component using steel chemical composition and heat treatment conditions [5]. Also qualitative analysis of microstructure developed during quenching of austenite is available.

Results. ***Microstructure analysis.*** Microstructure analysis was performed on samples cut from heat treated B part, which were marked as 1B and 2B. 34CrMo4 steel quenched from 870^{o}C temperature in HARTEX 70S oil had microstructure containing mixture of bainite and martensite, as is shown in Figure 5.



a) **b)**

Figure 5. 1B sample microstructures



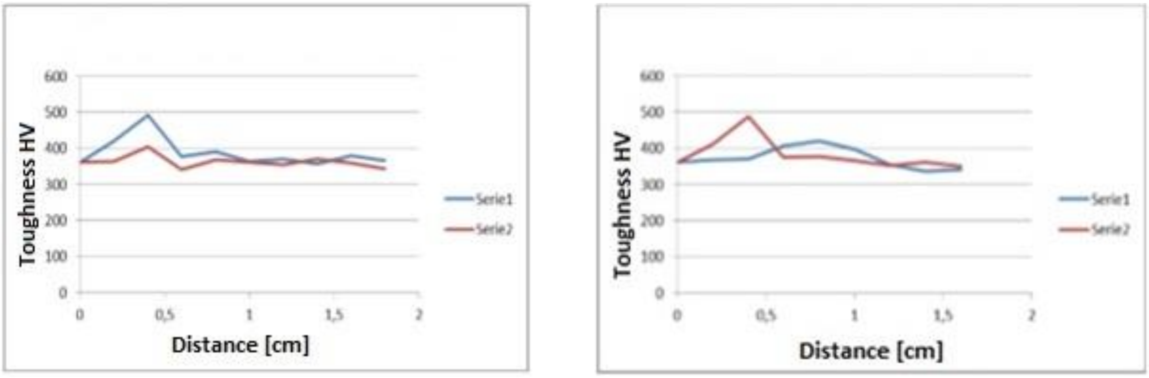
a) **b)**

Figure 6. 2B sample microstructures

Examples of microstructure of specimen quenched in OH-120M oil (with lower cooling ability), are shown in Fig. 6. Except of martensite and bainite low amount of pearlite is present.

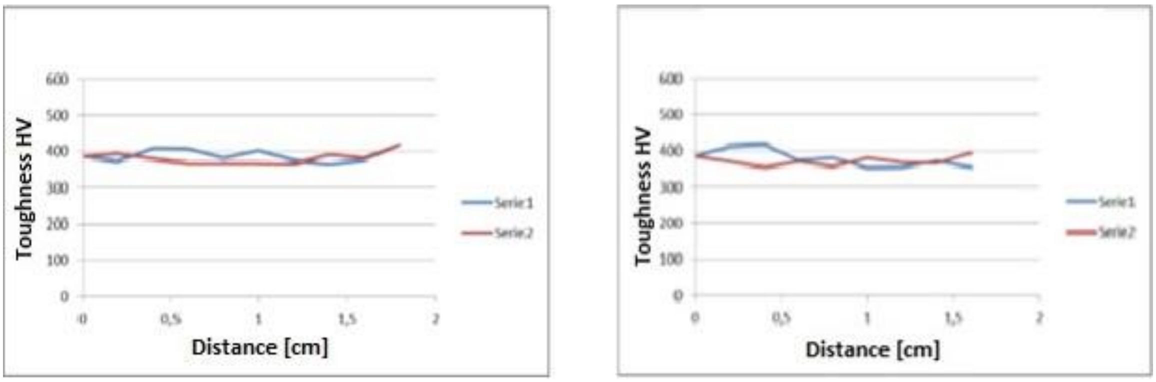
Hardness measurement. Surface hardness distributions were performed via samples contour diagonals and are presented in 7a and 8a figures. Figures 7b and 8b show hardness values, which were measured along lines perpendicular to samples outline side.

Hardness distributions for sample 1B, quenched in HARTEX 70S oil, indicate that the microstructure is heterogeneous. Near surface, approximately 5mm from the top, hardness values increase noticeably to 500 HV10, and gradually decrease do 350 – 380 HV10 at approx. 15 – 17 mm. Observed hardness gradients are an effect of heterogeneous structure and creation of martensite in certain areas.



a) b)

Figure 7. Hardness distribution in cross-section of 1B sample, hardened in HARTEX 70S oil;
a) Hardness measured in direction 1 and 3 (diagonal lines),
b) hardness measured in directions 2 and 4 (lines perpendicular to sample surface)



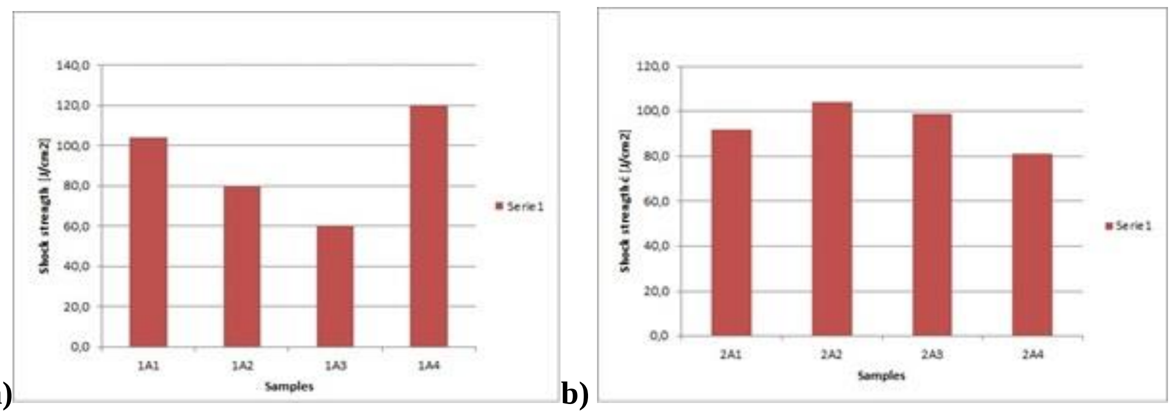
a) b)

Figure 8. Hardness distribution in cross-section of 2B sample, hardened in OH120M oil;
a) hardness measured in direction 1 and 3 (diagonal lines),
b) hardness measured in directions 2 and 4 (lines perpendicular to sample surface)

Hardness distributions for samples hardened in OH120M oil have lower hardness values in samples axis and higher near surface and corners (Figure 8). Mean values of hardness were calculated as 376,6 HV10 and 383,4 HV10 for samples hardened in HARTEX 70S and OH120M accordingly.

Impact strength measurement. Figure 9 presents impact strength measurements results for samples 1 (quenched in HARTEX 70S oil) and 2 (quenched in OH120M oil) in parallel. Mean values were 91 J/cm^2 and 93,5 J/cm^2 respectively.

a)



b)

Figure 9. 34CrMo4 steel impact strength measurement results for quenched in: a) HARTEX 70S oil,
b) OH120M oil and tempered 650ºC

Makro observations of fracture surfaces revealed that sample fractures after impact strength tests had mixed nature. Both bright (fragile fracture) and mat (plastic fracture) areas were observed. Figures 10 show examples of fractures surface areas using SEM microscope.

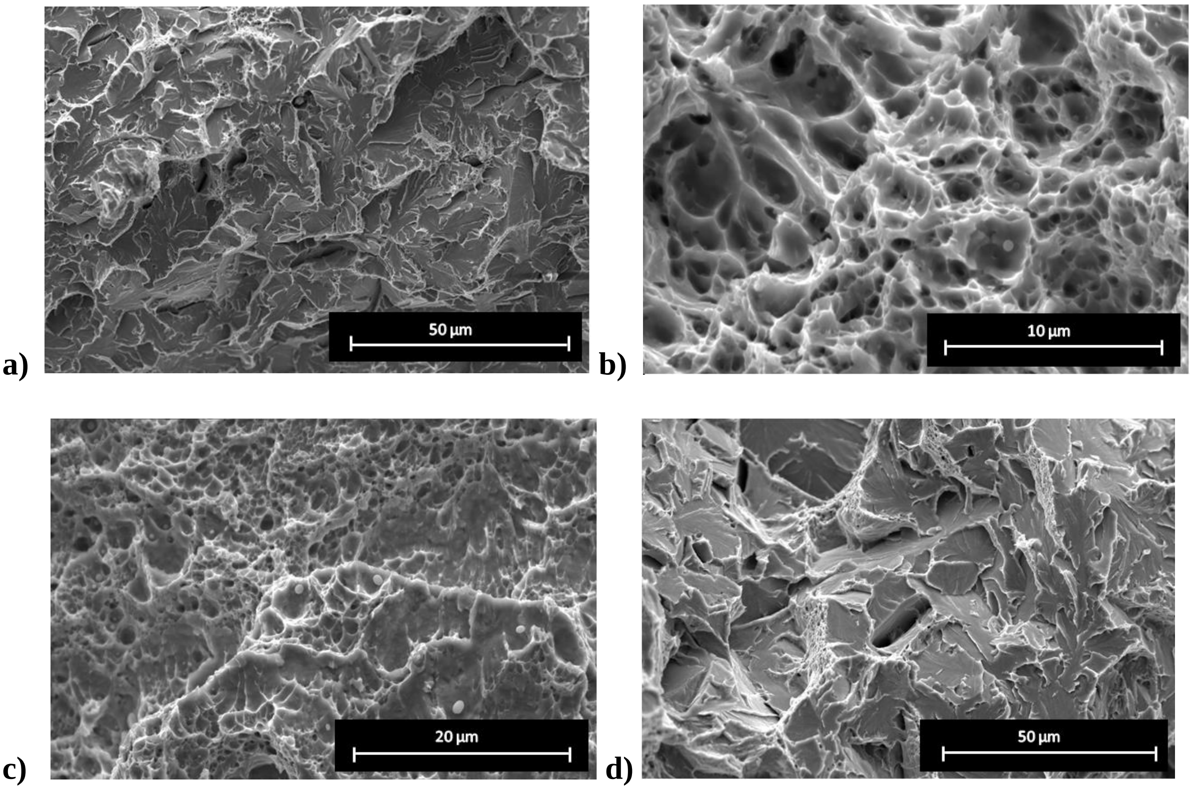
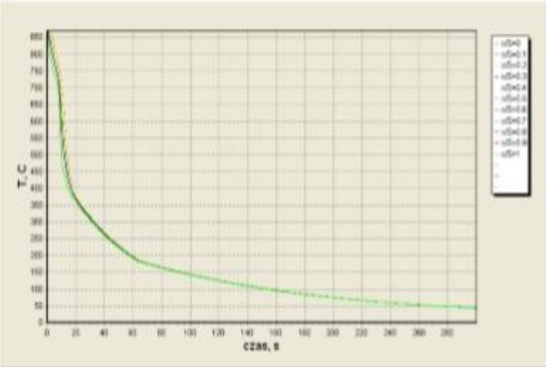


Figure 10. Examples of fracture surfaces of 34CrMo4 steel after heat treatment

Transcrystalic cracking is associated with fragile zones. This cracking developed itself along cleavage planes for particular grains. Fracture sections with poorly developed morphology and characteristic "basin lines" were observed (Figure 11, 12b). Plastic areas exhibit extended surface, which has singular "cavities" with non-metallic and nitrocarbides inclusions visible inside them (Figure 11, 12a, b).

Computer simulation results. Figures 11 and 12 present results of process simulation of quench hardening from austenisation temperature of cuboid with 40x40x80 mm dimensions in HARTEX 70S and OH120M oils. These results are presented in form of cooling curve in selected points on cross section of heat treated element. Cooling curves in various points of cuboid cross-section, given by ratio x/s, where x – distance to cuboid axis, s – half thickness of cuboid, was shown in Figures 11a and 12a. Calculations were made for 0 and 1 of x/s value (center and surface of specimen). In higher temperatures, above 350°C, differences between surface and center temperatures are bigger. At lower temperatures, these differences are significantly smaller [6,7]. Cooling curves at two extreme points of cross-section (x/s = 0 and x/s = 1) for samples cooled in HARTEX 70S and OH120M oils were printed on to CTP_c graph for 34Cr4 steel in order to verify simulation results.

Calculation results indicate that steel should exhibit martensitic structure in both cases, and therefore there should be no difference in hardness in cross-sections of hardened samples. Differences noticed in cooling curves for HARTEX 70S and OH120M oils point towards reaching M_s temperature faster for samples cooled in HARTEX 70S.

a)


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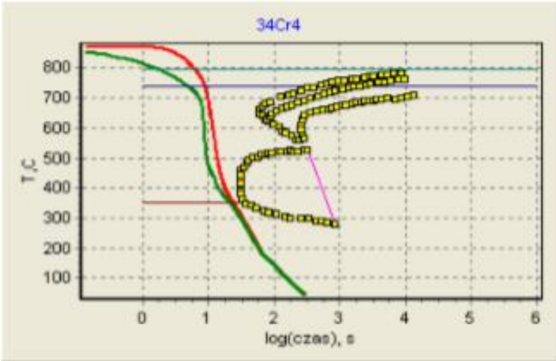
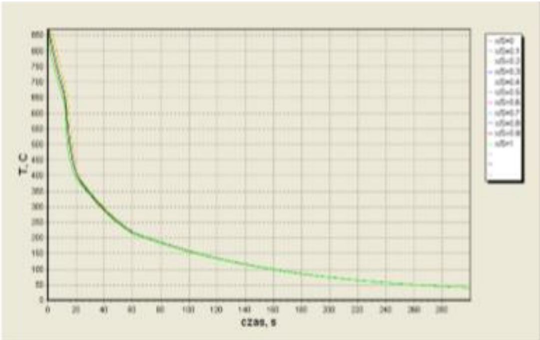


Figure 13. Simulation results for 34CrMo4 steel hardened in HARTEX 70S oil
a) Relationship between temperature, T and time of quenching,
b) Center and surface cooling curves on CCT diagram of 34Cr4 steel

a)


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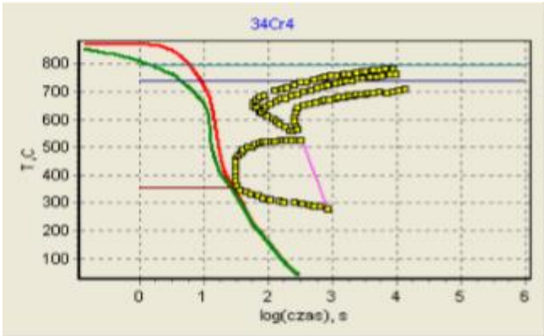

Figure 14. Simulation results for 34CrMo4 steel hardened in OH120M oil
a) Relationship between temperature, T and time of quenching,
b) Center and surface cooling curves on CCT diagram of 34Cr4 steel

Figures 15 and 16 present simulation results for quench hardening a massive item, namely cylinder with R = 50 mm and H = 100 mm dimensions. Temperature and cooling curves indicate that oil type has stronger influence on microstructure in this case in comparison to cuboid elements after steel quench hardening, especially in areas close to surface.

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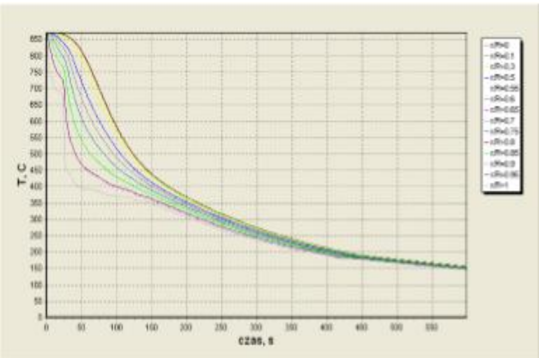

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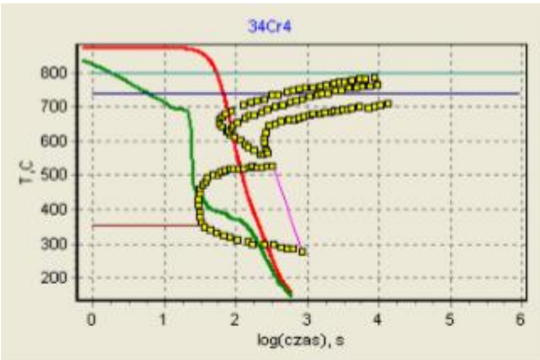
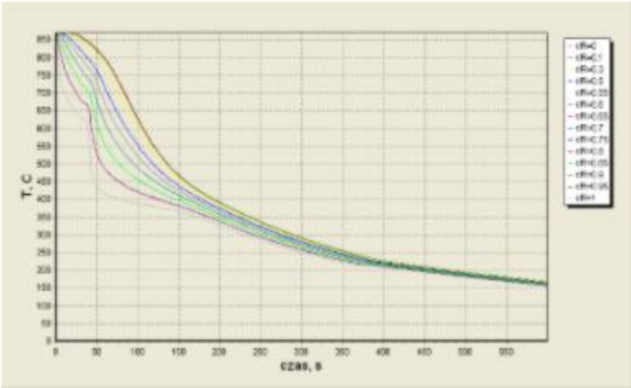


Figure 15. Simulation results for cylinder with R = 50 mm, H = 100 mm dimensions hardened in HARTEX 70S oil a) Relationship between temperature, T and time of quenching,
b) Center and surface cooling curves on CCT diagram of 34Cr4 steel



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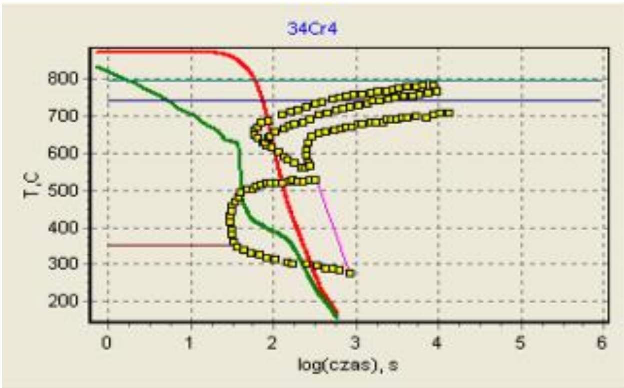

b)

Figure 16. Simulation results for cylinder with R = 50 mm, H = 100 mm dimensions hardened in OH120M oil a) Relationship between temperature, T and time of quenching, b) Center and surface cooling curves on CCT diagram of 34Cr4 steel

Discussion. This work presents results of investigating of quenching oil type effect on microstructure and mechanical properties of heat treated 34CrMo4 steel. Microstructure and hardness distribution in cross-section were examined after hardening samples in HARTEX 70S and OH120M tempering oils.

There were no significant differences between hardness of samples hardened in quenching oils. There was also no remarkable influence of hardness measurement point location on results. It means that temperature in cuboid cross-section was congenial in temperature range of overcooled austenite conversions and therefore similar microstructure was developed.

Difference in cooling ability of chosen oils were proven to be irrelevant for 40x40x 80 mm steel samples. Bigger differences in microstructure and mechanical properties of steel hardened in both tempering oils are to be expected during heat treatment of bigger samples. This was confirmed by simulating hardening of cylinder elements with d = 100 mm and h = 500 mm dimensions. In that case, oil cooling ability has stronger effect on microstructure formed during phase transformation of undercooled austenite.

To anticipate microstructure obtained during hardening, CCT graph of 30Cr4 steel was applied. Comparison of simulation results and microstructure analysis results suggests that, hardness of examined steel is lower than the one pointed by graph.

Microstructure investigation results let us conclude that samples cross-section is dominated by bainitic structure with fractional perlite contribution. Some areas of cross-sections were observed to have martensitic structure, which comes from heterogeneous chemical composition in tested steel. Areas with higher alloy elements concentration were subjects to martensitic transformation.

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УДК

ДОСЛІДЖЕННЯ ВПЛИВУ ГАРТУВАЛЬНОГО МАСЛА НА МІКРОСТРУКТУРУ І МЕХАНІЧНІ ВЛАСТИВОСТІ ТЕРМООБРОБЛЮВАЛЬНОЇ СТАЛІ 34 CrMo 4

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Резюме. *Мета даного дослідження – оцінювання впливу гартувального масла на мікроструктуру і механічні властивості загартованої і відпущеної сталі 34CrMo4. Представлена робота містить аналіз мікроструктури і дослідження механічних властивостей термічно оброблювальної сталі загартованої в гартувальних маслах Hartex70S і OH120M. Представлено результати мікрофрактографічних досліджень поверхні зламу зразків, випробуваних на ударну міцність. Порівняно результати комп'ютерного моделювання процесів гартувального зміцнення в середовищі двох гартувальних масел.*

Ключові слова: *гартувальне масло, термообробка, механічні властивості, сталь 34 CrMo 4.*

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