



University of Zenica
FACULTY OF METALLURGY AND
TECHNOLOGY
Bosnia and Herzegovina



Univerzitet u Zenici
METALURŠKO-TEHNOLOŠKI FAKULTET
Bosna i Hercegovina

**14th Scientific - Research Symposium
with International Participation**

**METALLIC AND NONMETALLIC MATERIALS
production – properties – application**

**XIV Naučno - stručni simpozijum
sa međunarodnim učešćem**

**METALNI I NEMETALNI MATERIJALI
proizvodnja – osobine – primjena**

**BOOK OF ABSTRACTS with electronic edition of Proceedings
KNJIGA ABSTRAKTA sa elektronskim izdanjem Zbornika radova**



Zenica, Bosnia and Herzegovina, 27th-28th April 2023
Zenica, Bosna i Hercegovina, 27-28. april 2023.

EDITOR/UREDNIK

Dr Farzet Bikić

PUBLISHER/IZDAVAČ

Univerzitet u Zenici

Organizaciona jedinica Metalurško-tehnološki fakultet

Travnička cesta 1, 72000 Zenica

Tel: ++

387 401 831, 402 832, Fax: ++ 387 406 903

TECHNICAL ASSISTANCE AND DTP

KOMPJUTERSKA OBRADA TEKSTA

Amila Krnjić

Zahida Begović

Dejana Kasapović

Lamija Sušić

PRINTED BY/ŠTAMPA

ŠTAMPARIJA FOJNICA D.D.

ISSUE/TIRAŽ: 100 copies/primjeraka

ORGANIZING COMMITTEE/ORGANIZACIONI ODBOR

Dr Farzet Bikić, president

Dr Jusuf Duraković
Dr Ilhan Bušatlić
Dr Adnan Mujkanović
Dr Hasan Avdušinović
Mr Dejana Kasapović
Mr Amna Karić, secretary
Lamija Sušić, dipl. Ing.

INTERNATIONAL SCIENTIFIC/RESEARCH COMMITTEE/NAUČNI ODBOR

Dr Anžel Ivan, SI	Dr Jovanović Marina, BA
Dr Avdušinović Hasan, BA	Dr Komatina Mirko, RS
Dr Balanović Ljubiša, RS	Dr Kosec Borut, SI
Dr Begić-Hajdarević Đerzija, BA	Dr Korać Fehim, BA
Dr Berberović Edin, BA	Dr Krolo Petar, RH
Dr Bikić Farzet, BA	Dr Lamut Jakob, SI
Dr Bizjak Milan, SI	Dr Lazić Dragica, BA
Dr Bogdanović Grozdanka, RS	Dr Lemeš Samir, BA
Dr Burzić Zijah, RS	Dr Mamuzić Ilija, HR
Dr Bušatlić Ilhan, BA	Dr Medved Jožef, SI
Dr Bušatlić Nadira BA	Dr Merdić Nevzet, BA
Dr Chumbley Scott, US	Dr Mirjanić Dragoljub, BA
Dr Ćubela Diana, BA	Dr Mujkanović Adnan, BA
Dr Ćatić Sead, BA	Dr Nagode Aleš, SI
Dr Dabić Pero, HR	Dr Oruč Mirsada, BA
Dr Delijić Kemal, CG	Dr Pašić Sead, BA
Dr Dolić Natalija, HR	Dr Perušić Mitar, BA
Dr Dolinžek Slavko, SI	Dr Ranogajec Jonjaua, RS
Dr Duraković Jusuf, BA	Dr Rustempašić Neriman, BA
Dr Džubur Žana, BA	Dr Salihović Senaid, BA
Dr Džonlagić Nusreta, BA	Dr Senk Dieter, DE
Dr Ekinović Sabahudin, BA	Dr Spužić Sead, AU
Dr Fidančevska Emilija, MK	Dr Srbić Vladimir, RS
Dr Gigović-Gekić Almaida, BA	Dr Stanojlović Rodoljub, RS
Dr Gojić Mirko, HR	Dr Stuhli Vedran, BA
Dr Grubešić Ivana, BA	Dr Suljagić Jasmin, BA
Dr Hadžikadunić Fuad, BA	Dr Sunulahpašić Raza, BA
Dr Halilović Azra, BA	Dr Štrajčić Jovan, BA
Dr Hamedović Safet, BA	Dr Štrbac Nada, RS
Dr Haračić Nedžad, BA	Dr Volkov-Husović Tatjana, RS
Dr Hessling Goetz, DE	Dr Vučenović Siniša, BA
Dr Herenda Safija, BA	Dr Vukojević Nedeljko, BA
Dr Holger Frenz, DE	Dr Vukojević-Medvidović Nediljka, HR
Dr Imamović Aida, BA	Dr Zelić Jelica, HR
Dr Imamović Nusret, BA	Dr Zlokolica Miodrag, RS
Dr Ivanković Hrvoje, HR	Dr Zovko-Brodarac Zdenka, HR
Dr Iličković Zoran, BA	Dr Žero Sabina, BA
Dr Janačković Đorđe, RS	Dr Živković Živan, RS

14(2023), No.14
ISSN2566-4344

14th Scientific – Research Symposium
with International Participation

METALLIC AND NONMETALLIC MATERIALS
production – properties – application

PROCEEDINGS

Zenica, B&H, April 27th 2023

CONTENTS

page

KEYNOTES PAPERS

1. **PYROPHYLLITE-MODIFIED CARBON PASTE ELECTRODE FOR CARBENDAZIM DETECTION IN WATER AND FOOD**
J. Grbović Novaković, A. Mitrović Rajić, K. Tošić, S. Mijaković,
S. Milošević Govedarević, A. Vujačić Nikezić, B. Paskaš Mamula, J. Kustura,
E. Kurtanović, B. Halilhodžić 1
2. **FERTILIZER BASED ON PYROPHYLLITE IN ACCORDANCE WITH THE REGULATION EU 2019/1009**
M. J. Adamović, J. Kustura, E. Kurtanović, B. Halilhodžić, A. Hodžić,
M. Harbinja, M. D. Stojanović..... 10
3. **REMOVAL OF POTENTIALLY TOXIC METAL IONS FROM AQUEOUS SOLUTION BY ADSORPTION ON MECHANOCHEMICALLY ACTIVATED PYROPHYLLITE**
T. M. Trtić-Petrović, D. Lazarević, I. Pušica, J. Kustura, B. Halilhodžić,
E. Kurtanović, A. Teletović, A. Hodžić, M. Harbinja..... 17
4. **CHALLENGES IN THE APPLICATION OF THE LAW ON SAFETY AT WORK IN FBiH**
M. Todorović, A. Helvida, S. Živković 25

METALLIC MATERIALS

1. **Analysis of production method and stabilizing agent on structure of aluminum metal foams**
K. Grgić, I. Čulum, B. Lela, J. Krolo, S. Jozić..... 37
2. **Manufacturing and characterization of Ti6Al4V alloy by selective laser melting**
M. Zorc, A. Nagode, M. Pogačar, B. Karpe, B. Kosec, M. Bizjak..... 43
3. **Adsorption of Cu(II) ions by means of foundry waste**
A. Štrkalj, Z. Glavaš 51
4. **Hydrogenation process of titanium alloy for biomedical purposes**
A. Imamović, Š. Žuna, M. Oruč, E. Hadžibulić 58
5. **Effect of particle shape and size of copper powders on the properties of sintered parts**
I. Marković, D. Manasijević, Lj. Balanović, M. Mitrović, U. Stamenković,
S. Trujić 64
6. **Thermal and microstructural analysis of the low-melting Bi–In–Sn ternary alloys**
Lj. Balanović, D. Manasijević, I. Marković, M. Gorgievski,
U. Stamenković, D. Milkić..... 73

7. Relationship of microstructural transformations in austempered nodular cast with microhardness values <i>A. Burić, B. Fakić, E. Horoz, H. Avdušinović, R. Sunulahpašić</i>	83
8. Effect of mixing of cooling media on microstructure and hardness of steel 23MnB4 <i>A. Gigović-Gekić, H. Avdušinović, B. Muminović, A. Hodžić</i>	91
9. The influence of alloying elements to cast iron microstructure <i>A. Henjaković, H. Avdušinović, A. Muslić</i>	98
10. Characteristics of the microstructure and grain size of S690QL steel in the hardened and tempered state <i>M. Oruč, M. Rimac, A. Imamović, A. Gigović-Gekić</i>	105
11. Properties of austenite stainless steel X8CrNiS18-9 microalloyed with tellurium <i>D. Mujagić, A. Imamović, M. Hadžalić</i>	111
12. Microstructural degradation of boiler headers steels under long term exposure to high temperature <i>A. Husika, B. Fakić, M. Rimac</i>	116
13. The influence of heat treatment on microstructure and thermal properties of C45 tool steel <i>U. Stamenković, I. Marković, S. Mladenović, D. Manasijević, Lj. Balanović, M. Nedeljković, J. Božinović, A. Kovačević</i>	125
14. Thermal properties of copper base shape memory alloy <i>B. Kosec, B. Karpe, A. Nagode, M. Bizjak, L. Vrsalović, D. Čubela, M. Gojić, I. Ivanić, S. Kožuh</i>	133
15. Effect grain size of S690QL steel on impact fracture at low temperature <i>M. Oruč, G. Kosec, A. Imamović, R. Sunulahpašić</i>	139
16. Application of the BAS EN ISO 1463:2022 standard in the characterization of pipe materials for thermal energy plants <i>B. Fakić, A. Burić, E. Horoz</i>	145
17. Contribution to mechanical properties assessment of spherical cylindrical head shells made by the incremental sheet forming <i>M. Hadžalić, R. Sunulahpašić, Z. Ištvanić</i>	149
18. NDT testing and determination of the state of the materials of the headers of the boiler unit 5 in the Thermal Power Plant Kakanj <i>A. Husika, B. Fakić, M. Rimac</i>	158
19. The effect of cysteine on the corrosion characteristics of bioalloy <i>S. Herenda, M. Begović, E. Hasković, V. Asanović</i>	167

20. Electrical properties of granular metals <i>M. Đekić, A. Karić, A. Salčinović Fetić, M. Baždar, B. Husković, D. Dujak, D. Čubela</i>	172
21. Investigation of cutting conditions influence on surface roughness during MQL machining of steel <i>T. Gazić, S. Ekinović, E. Begović, I. Plančić</i>	179
22. Some aspects of a metallurgy consulting in the industrial transition of B&H <i>F. Uzunović</i>	186

NONMETALLIC MATERIALS

1. Partial replacement of cement with calcined clays from central Bosnia <i>M. Jovanović, A. Mujkanović, N. Bušatlić, N. Haračić, A. Čaušević</i>	199
2. Possibility of production of metallurgical cement type CEM III/A 42.5N in Cement plant Kakanj <i>N. Merdić, N. Haračić, I. Bušatlić, N. Bušatlić, A. Mujkanović</i>	209
3. Development of new cement type CEM II/C-M according to EN 197-5 <i>N. Haračić, N. Merdić, I. Bušatlić, N. Bušatlić</i>	214
4. Strength development of concrete containing ground granulated blast furnace slag from ArcelorMittal Zenica as a partial cement replacement <i>A. Mujkanović, A. Bitić, M. Jovanović, N. Bušatlić, N. Merdić, A. Zahirović</i>	218
5. Calculation of thermal conductivity for crystalline nanostructures <i>S. M. Vučenović, J. P. Šetrajčić</i>	226
6. Charge carriers states in a model of CuO superconductive ceramics <i>J. P. Šetrajčić, S. M. Vučenović</i>	233
7. Catecholase activity and substituent effect of new homoleptic copper(II) chalcone complexes <i>S. Hadžalić, I. Osmanković, A. Zahirović</i>	241

ENVIRONMENT PROTECTION AND SUSTAINABLE DEVELOPMENT

1. Pyrophyllite as an ecological mineral of the future <i>J. Kustura, B. Halilhodžić, E. Kurtanović, K. Kozlo, A. Čizmić, A. Teletović, A. Hodžić, M. Harbinja</i>	253
2. Removal of heavy metals from landfill leach water using pyrophyllite as adsorbent <i>J. Kustura, B. Halilhodžić, E. Kurtanović, A. Čizmić, K. Kozlo, A. Teletović, A. Hodžić, M. Harbinja</i>	264
3. Heavy metal concentrations in surface water and sediment from Drina river, B&H <i>A. Bilajac, S. Žero, A. Karadža</i>	274

4. The long-term impact of heavy metals from Bosna river to human health <i>A. Šapčanin, F. Bikić.....</i>	<i>280</i>
5. Influence of current density on leachate treatment efficiency by electrocoagulation with zeolite addition <i>N. Vukojević Medvidović, L. Vrsalović, S. Svilović, M. Cestarić.</i>	<i>286</i>
6. Study of interactions between metal ions and crown ethers in liquid organic membrane systems <i>E. Bjelić, J. Suljagić, M. Suljkanović.....</i>	<i>293</i>
7. Rutin analysis by high-resolution liquid chromatography on reverse phases in raspberry flower extract (<i>Rubus idaeus L.</i>) <i>D. Kasapović, F. Bikić.....</i>	<i>299</i>
8. Characteristics of vacuum distillation fractions depending on the characteristics of the input hydrocracked base oil raw material of the Modriča Oil Refinery <i>A. Halilović, I. Bušatlić, Š. Botonjić, N. Bušatlić, E. Zolotić.....</i>	<i>304</i>
9. The influence of the heating value of coals from Coal Mine „Gračanica“ d.o.o. Gornji Vakuf on quality of coal as energy source in energy production <i>A. Halilović, Š. Botonjić, A. Krnjić, L. Sušić.</i>	<i>312</i>
10. The measures of energy efficiency in Natron-Hayat Maglaj <i>N. Imamović, A. Čamić, H. Lepić.</i>	<i>320</i>
11. Screening of particulate matter in urban area of Sarajevo <i>A. Šapčanin, A. Hasanović, F. Bikić.....</i>	<i>326</i>
12. Analysis of the origin of air pollution in the area Zenica-Doboj canton <i>V. Birdahić, M. Šišić, N. Imamović, H. Prčanović, M. Duraković.....</i>	<i>335</i>
13. Research of the possibility of using the heat generated in the aerobic biodegradation procedure <i>M. Šišić, F. Bikić, V. Birdahić, S. Beganović, M. Duraković.....</i>	<i>342</i>
14. The role of wood-based products in sustainable development <i>P. Čurić, J. Obranković, A. Pirc Barčić.....</i>	<i>349</i>

THE INFLUENCE OF HEAT TREATMENT ON MICROSTRUCTURE AND THERMAL PROPERTIES OF C45 TOOL STEEL

**Uroš Stamenković, Ivana Marković, Srba Mladenović, Dragan Manasijević, Ljubiša
Balanović, Avram Kovačević, Milan Nedeljković, Jovana Božinović**
University of Belgrade, Technical Faculty in Bor
Bor, Serbia

Keywords: C45 steel, Microstructure, Martensite, Thermal properties, Tempering

ABSTRACT

In this paper, C45 medium carbon tool steel was investigated after various heat treatments. The thermal properties, specifically thermal diffusivity and thermal conductivity, were measured and also the microstructure analysis was done on a light microscope. Heat treatment of the samples included: 1) the normalization heat treatment at 900°C for one hour and cooling in the air; 2) quenching the samples in water and in oil separately after reheating them at 880°C for one hour and; 3) tempering the quenched samples at 200°C-350°C for 2 hours. The results show the highest values of thermal properties for the normalized sample. Also, the lowest values were recorded for the quenched samples, and the values of thermal properties for the tempered samples are between the values of the quenched and normalized samples. Microstructure analysis shows a typical ferrite-pearlite structure after normalization. Martensite appeared in the water-quenched sample. However, the microstructure of the oil-hardened sample predominately consists of ferrite and pearlite because the critical cooling rate was not reached. Tempered samples quenched in the water had the microstructure of tempered martensite.

1. INTRODUCTION

Steels with a carbon content between 0.3-0.5% are often called medium carbon steels. These steels are used in many applications. Because of their mechanical, physical, and other properties, many of them are essentials for building parts in many industries. Those industries are automotive, naval, civil, military, electrical, etc. [1]. Medium carbon steels can exhibit different properties when subjected to various heat treatments [2]. The most common heat treatment for these steels includes quenching and tempering at high temperatures in order to achieve highly tempered martensitic microstructure which would provide the highest values of toughness and high wear resistivity [3]. In addition, medium carbon steels are considered to be a type of tool steel. For tool steels, besides good mechanical properties, several thermophysical properties are very relevant for tool design [4]. Two of those thermophysical properties are thermal diffusivity and thermal conductivity. These properties sometimes dictate the lifespan of the tool. For example, higher thermal conductivities in steels can reduce temperature gradients that appear in tools during their application [5,6]. Thermophysical properties are greatly influenced by different heat treatments, especially given the fact that a large number of these tools are used in applications at elevated temperatures. Medium carbon steel research is usually based on investigating the mechanical properties after various heat treatments. Some heat treatments have already been investigated by other researchers. In most cases, the authors dealt with how quenching in water, aqueous polymer solutions, or aqueous salt solutions as well as subsequent tempering affects the mechanical properties of C45 steel [3,7].

Groom et al. monitored the change in mechanical properties after oil quenching and tempering [8]. A. Laouissi et al. colleagues made their contribution by optimizing the heat treatment process, investigating the influence of annealing temperature as well as the influence of different types of quenching (in air, in water, and in hydrochloric acid solution) on mechanical properties [1]. Some authors examined the thermal properties of different steels after various heat treatments, including C45 steel. Wilzer et al. investigated the influence of heat treatment on the thermophysical properties of martensitic steels. They showed that tempering increases the values of thermal conductivity and thermal diffusivity, but with a decrease in hardness values [4,9].

The primary aim of this paper is the investigation of thermal properties of C45 medium carbon tool steel after normalization, and subsequently after quenching and low to medium temperature tempering (200°C-350°C). The secondary aim is to investigate the microstructures that appear after various heat treatments and see if those structures are in agreement with the obtained results for thermal properties.

2. EXPERIMENTAL PROCEDURE

Experiments were performed on C45 medium carbon tool steel with the defined chemical composition given in Table 1. Steel was received in the form of hot extruded bars with a diameter of 20 mm. The samples were firstly normalized at 900°C for one hour in an electric resistance furnace in order to normalize and eliminate the structure after the manufacturing process, and then cooled in still air. Normalized samples were then annealed at 880°C, for one hour and quenched separately in oil and in cold water. Quenched samples were tempered at different temperatures (200°C-350°C) for 2 hours. Samples were separated for further analysis after normalization, quenching, and tempering. Characterization of the samples included measuring the thermal properties and microstructural analysis on a light microscope. The Xenon flash method was applied to determine the thermal diffusivity of the investigated samples after different heat treatments by irradiating the disc-shaped specimens with a diameter of 12.7 mm with the xenon lamp in a nitrogen atmosphere. The thermal conductivity as a function of temperature was calculated according to the equation:

$$\lambda(T) = \rho(T) \times c_p(T) \times \alpha(T) \quad (1)$$

where, λ - thermal conductivity; (W/m*K), ρ - density; (kg/m³), c_p - specific heat capacity; (J/kg*K), α - thermal diffusivity; (cm²/s), T - temperature; (°C).

Light microscopy was used for the investigation of the microstructure. Preparation of the samples included wet grinding on a series of SiC papers, and polishing with alumina suspension with two different granulations of Al₂O₃: particle sizes of 0.3 μ m and 0.05 μ m. 4% Nital solution was used for the etching of the samples by immersion to reveal the microstructure. The microstructures were examined on two light microscopes CarlZeiss Jena Epytip 2 and Reichert MeF2. Also, the equipment used and various steps in the heat treatment process can be seen in Figure 1a-d.

Table 1. Chemical composition of investigated steel (mass. %)

C45 medium carbon steel				
Fe	C	Mn	S	P
98.51-98.98	0.42-0.5	0.6-0.9	≤0.05	≤0.04



Figure 1. Equipment and different steps in the heat treatment process: a) electric resistance furnace; b) sample heating; c) and d) samples after tempering for 2 hours at different temperatures

3. RESULTS AND DISCUSSION

3.1. The properties of investigated samples after normalizing

After normalization heat treatment, the fabricated structure was removed and the structure of investigated samples was normalized. Obtained results show relatively high values of thermal diffusivity and thermal conductivity, $16.97 \text{ mm}^2/\text{s}$, and $60.9 \text{ W/m}\cdot\text{K}$, respectively. The relatively high values for thermal properties were obtained due to the normalization heat treatment which involved high-temperature heating and slow cooling leading to an equilibrium state at room temperature. The equilibrium state caused by slow cooling has a low density of dislocation and vacancies, so the movement of electrons (as thermal energy carriers) is facilitated. In this state, samples had a microstructure that consisted of a fine mixture of ferrite and pearlite, shown in Figure 2a-b. Duka et al. stated that the microstructure of C45 steel is composed of 66% pearlite and 34% ferrite [10].

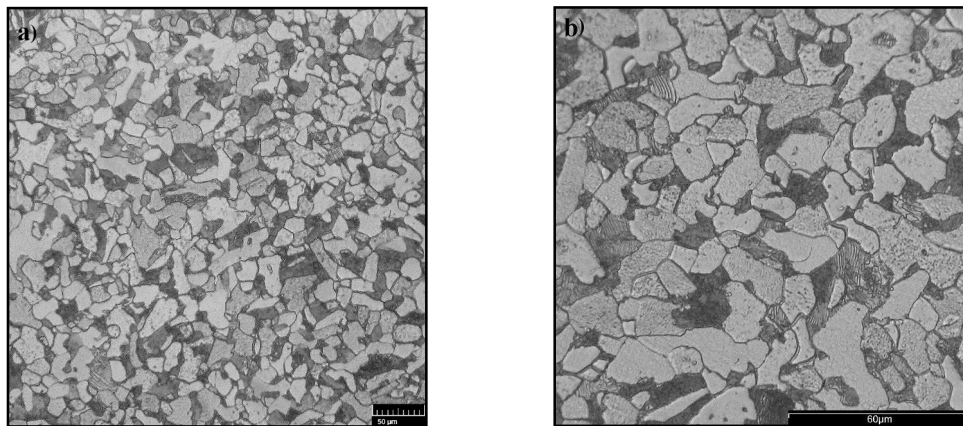


Figure 2. Microstructure of the investigated C45 steel after the normalization heat treatment; a) magnification is x500; b) magnification is x1000

3.2. The properties of investigated samples after quenching

After the normalizing heat treatment, samples were austenitized and quenched to room temperature using two different quenchants. Table 2 shows the results after quenching separately in oil and in water.

Table 2. Thermal properties of the investigated steel after quenching

Type of quenchant	Thermal diffusivity (mm^2/s)	Thermal conductivity ($\text{W/m}\cdot\text{K}$)
Water	11.41	43.76
Oil	11.88	46.49

The values of thermal diffusivity and thermal conductivity decreased after quenching in water and oil when compared to the values obtained after normalization. The absolute decrease in thermal diffusivity and thermal conductivity after quenching in water is 5.56 mm²/s and 17.14 W/m*K, respectively. After quenching in oil, the results are somewhat different and an absolute decrease of 5.09 mm²/s and 14.41 W/m*K was recorded for thermal diffusivity and thermal conductivity, respectively. After quenching in water, the formation of martensite led to the formation of a supersaturated solid solution of carbon in the iron matrix. According to Wilzner, all other elements that enter into the composition of steel are trapped in addition to carbon during tempering. In this regard, martensite is characterized by high supersaturation as well as a high density of dislocations and vacancies. This type of structure hinders the movement of electrons, as carriers of thermal energy, lowering the values of thermal properties [4,9].

These characterizations are less pronounced in the samples that were quenched in oil, because, due to the insufficient cooling rate, a mixed microstructure is expected. This can be concluded by comparing the results obtained after quenching in water with those obtained after quenching in oil. The comparison of those results shows that higher values of thermal properties are obtained after quenching in oil.

The microstructural analysis confirmed the statements above to some extent. After quenching in water, finely distributed martensite needles can be observed in the microstructure. For the oil-quenched sample, the critical cooling rate was not reached, therefore no martensite was formed. The microstructure of the oil-hardened sample is of a mixed type, which predominately consists of ferrite and pearlite. Microstructures can be seen in Figure 3a-d.

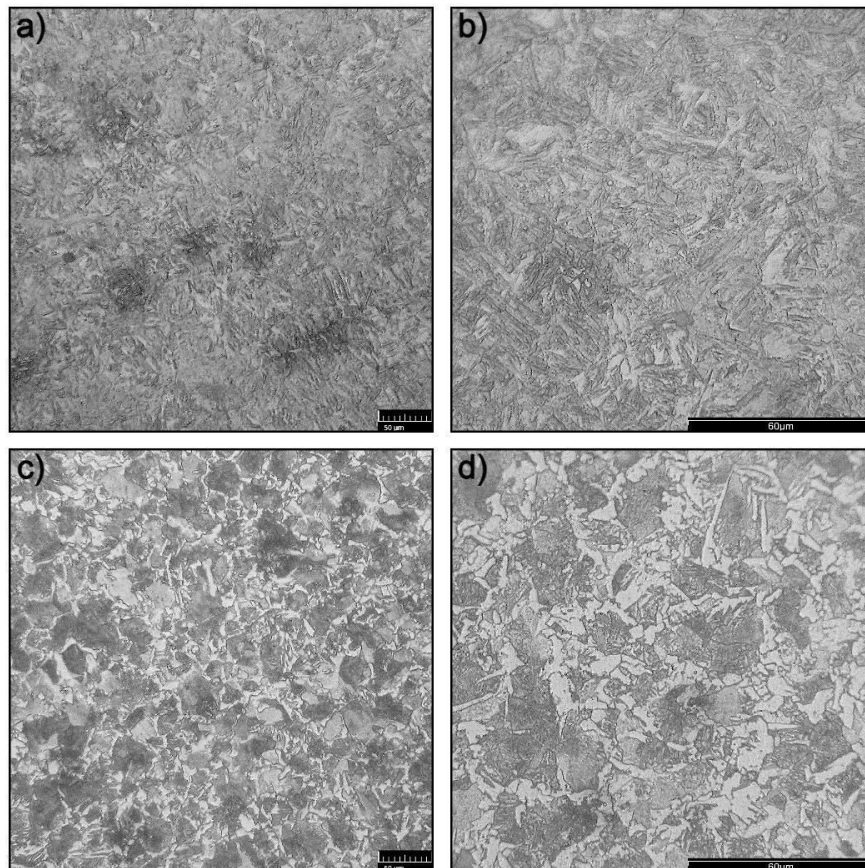


Figure 3. Microstructure of the investigated C45 steel after quenching; a) in water, magnification is x500; b) in water, magnification is x1000; c) in oil, magnification is x500; d) in oil, magnification is x1000

3.3. The properties of investigated samples after tempering

After quenching in water and oil separately, samples were subjected to tempering at different temperatures for 2 hours. During tempering, changes in the thermal properties were observed and investigated. Figure 4 shows the obtained values for thermal diffusivity and thermal conductivity after tempering at 200°C-350°C for 2 hours. Analysis of the obtained results shows that the values of thermal diffusivity and thermal conductivity gradually increase with the increase of tempering temperature.

The reason for the increase in values of thermal properties lies in the tempering of hardened samples. Winczek et al. stated that steels with a carbon content > 0.2 wt.% starts tempering even at room temperature [11]. During tempering, there is a reduction in stress and the transformation of martensite that was formed by quenching into tempered martensite. After tempering in this temperature range there are a couple of processes that occur simultaneously: the diffusion of carbon atoms; the loss of tetragonality of martensite; the formation of cubic ferrite; the formation of cementite; the decomposition of residual austenite; whereby lower hardness values are recorded [4,7,8,11].

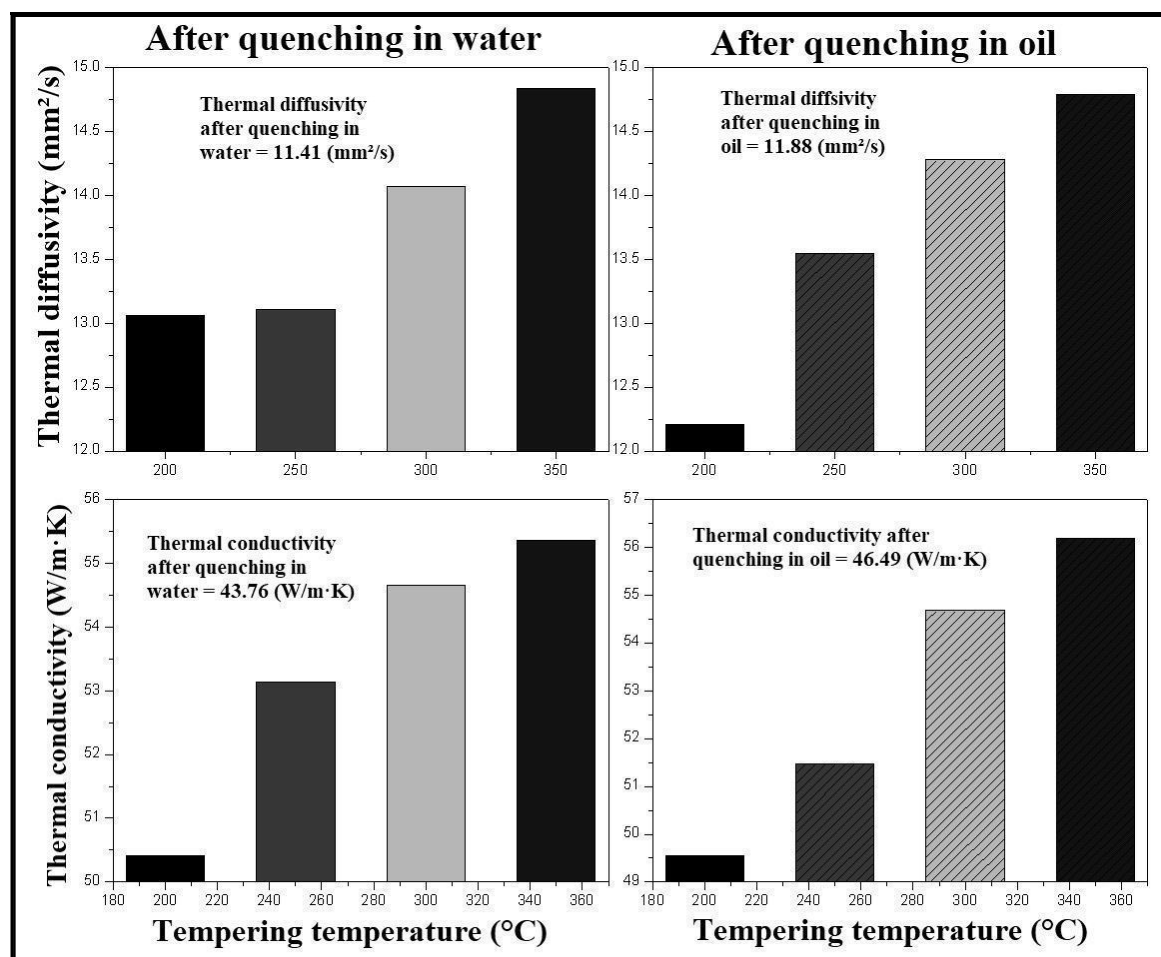


Figure 4. Change in thermal properties after tempering quenched samples at different temperatures for 2 hours

During tempering, with the increase in tempering temperature, a slight rearrangement in the structure occurs. Change in thermal properties depends on two mutual processes, namely: 1) thermal vibrations in the lattice caused by the increase in temperature and 2) precipitation of carbon atoms from the supersaturated martensitic lattice. Consequently, these two processes are at odds. So essentially, one process (1) hinders the movement of

electrons and causes the values of thermal properties to decrease and one process (2) facilitated the movement of electrons and causes the increase of values for investigated thermal properties. Depending on which of the processes is more active at a given moment, values of thermal properties will be defined accordingly. Given that, the measurements of the thermal properties in this part of the experiment were made at room temperature, the thermal vibrations were significantly reduced, so in this case, the process of precipitation from the supersaturated martensite prevailed [4,9,12].

As for the samples that were tempered after quenching in oil, obtained values for those samples show a similar trend to the water-quenched samples, which is interesting considering that no martensitic microstructure was obtained in these samples. It can be assumed that due to the heating of those samples, the acceleration of diffusion and the removal of possible residual stresses occurred causing the values of thermal properties to increase in comparison to the quenched sample.

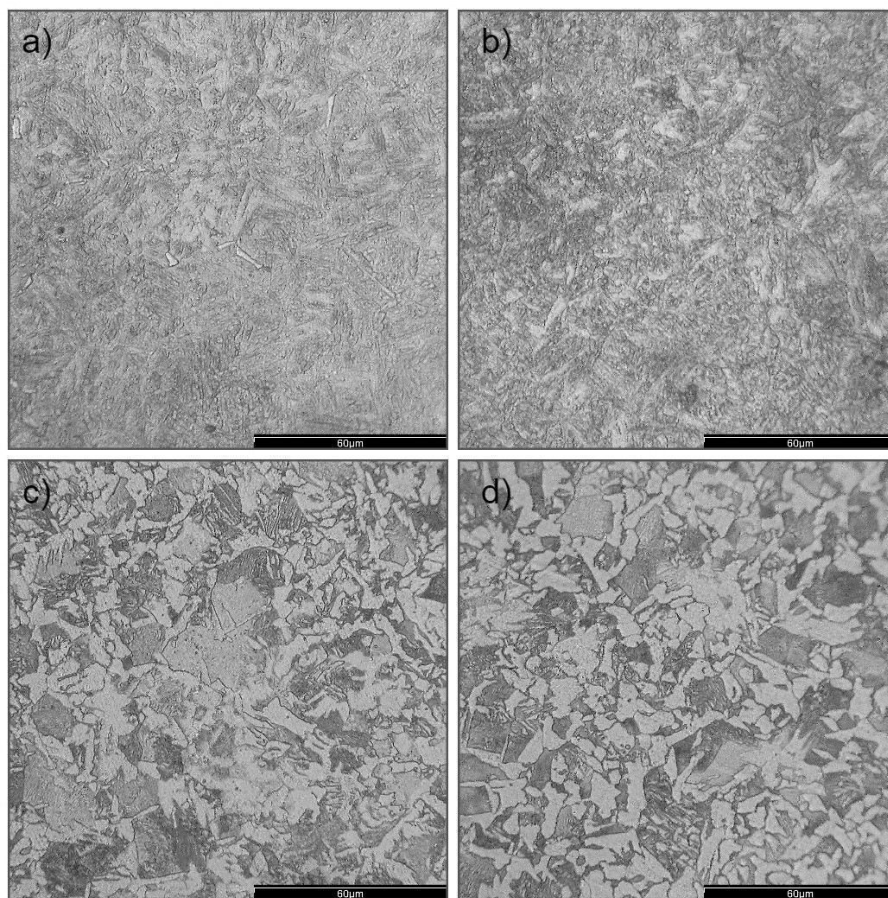


Figure 5. Microstructures after: a) quenching in water and tempering at 200°C, 2h; b) quenching in water and tempering at 350°C, 2h; c) quenching in oil and tempering at 200°C, 2h; d) quenching in oil and tempering at 350°C, 2h;

Analysis of the microstructures after tempering is in agreement with the given statements about the influence of tempering on thermal properties. Figure 5a-d shows the microstructures after quenching and tempering at 200°C and 350°C for 2 hours. After quenching in water and tempering, microstructures are well homogenized and they consist of tempered martensite where martensitic needles are less pronounced. Due to the low tempering temperatures, microstructures do not differ as much as those obtained after quenching. As for the microstructures obtained after quenching in oil and tempering, considering that the critical cooling rate was not achieved by quenching in oil, and that

martensite was not formed, concrete changes in the microstructure cannot be expected. The grains are somewhat larger due to exposure to slightly higher temperatures.

4. CONCLUSIONS

The influence of different heat treatments on the microstructure and thermal properties of C45 medium carbon tool steel was investigated. Some conclusions can be outlined:

- After normalization heat treatment, values of thermal properties are the highest of all investigated states. Microstructure consists of a fine mixture of ferrite and pearlite.
- Quenching in water caused the formation of martensite in the structure. The values of thermal diffusivity and thermal conductivity decreased in comparison to the values obtained for the normalized sample. The relative decrease in values of thermal diffusivity and thermal conductivity were, 33% and 28%, respectively.
- The critical cooling rate was not achieved by quenching in oil, so martensite was not present in the microstructure. Nevertheless, the values of thermal diffusivity and thermal conductivity decreased in comparison to the values obtained for the normalized sample. The relative decrease in values of thermal diffusivity and thermal conductivity were, 30% and 24%, respectively.
- After tempering the quenched samples, the values of the thermal properties gradually increase with the increase of the tempering temperature. The values of thermal diffusivity and thermal conductivity had the lowest increase at the tempering temperature of 200°C and the highest increase at the tempering temperature of 350°C. The relative increase in values of thermal properties was in the range of 20-30%.
- Microstructural analysis after quenching in water and tempering showed typical microstructure of tempered martensite.

5. ACKNOWLEDGEMENT

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, with the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-47/2023-01/200131.

6. REFERENCES

- [1] Laouissi A., Blaoui M.M., Abderazek H., Nouioua M., Bouchoucha A.: Heat Treatment Process Study and ANN-GA Based Multi-Response Optimization of C45 Steel Mechanical Properties, *Metals and Materials International*, 28 3087-3105, 2022
- [2] Davanageri M.B., Narendranath S., Kadoli R.: Influence of Heat Treatment on Microstructure, Hardness and Wear Behavior of Super Duplex Stainless Steel AISI 2507, *American Journal of Materials Science*, 5(3C) 48-52, 2015
- [3] Wozniak W., Sasiadek M., Jachowicz T., Edl M., Zajac P.: Studies on the Mechanical Properties of C45 Steel with Martensitic Structure after a High Tempering Process, *Advances in Science and Technology Research Journal*, 16(3) 306-315, 2022
- [4] Wilzer J., Ludtke F., Weber S., Theisen W.: The influence of heat treatment and resulting microstructures on the thermophysical properties of martensitic steels, *Journal of Material Science*, 48 8483-8492, 2013
- [5] Valls I., Casas B., Rodriguez N.: Importance of tool material thermal conductivity in the die longevity and product quality in HPDC, *Tool steels—deciding factor in worldwide production*, 8th international tooling conference, Mainz, Aachen, Germany, 2009
- [6] Hamasaiid, A., Valls, I., Heid, R., Eibisch, H.: A comparative experimental study on the use of two hot work tool steels for high pressure die casting of aluminum alloys: high thermal

- conductivity HTCS® and conventional 1.2343 (AISI H11), 9th international tooling conference: developing the world of tooling, Leoben, Austria, 2012
- [7] Haiko O., Kaijalainen A., Pallaspuuro S., Hannula J., Porter D., Liimatainen T., Komi J.: The Effect of Tempering on the Microstructure and Mechanical Properties of a Novel 0.4C Press-Hardening Steel, *Applied Science*, 9 4231, 2019
- [8] Grum J., Žerovnik P.: Statistical Processing Of A Voltage Signal Of The Magnetic Barkhausen-Noise Emitted By Quenched And Tempered Specimens of C45 Steel, 16th World Conference on NDT, Montreal, Canada, 2004
- [9] Wilzer J., Kupferle J., Weber S., Theisen W.: Temperature-dependent thermal conductivities of nonalloyed and high-alloyed heat-treatable steels in the temperature range between 20 and 500 °C, *Journal of Material Science*, 49 4833-4843, 2014
- [10] Duka E., Oettel H., Dilo T.: Connection between micro and macro hardness pearlitic-ferritic steel, 2nd International Advances in Applied Physics and Materials Science Congress, Antalya, Turkey, 2012
- [11] Winczek J., Kulawik A.: Dilatometric and hardness analysis of C45 steel tempering with different heating-up rates, *Metalurgija*, 51(1) 9-12, 2012
- [12] Tritt T.M.: *Thermal Conductivity: Theory, Properties and Applications*, Kluwer Academic/Plenum Publisher, New York, 2004