University of Belgrade, Technical Faculty in Bor

29th International Conference Ecological Truth
& Environmental Research

EcoTER'22

Proceedings

Editor
Prof. Dr Snežana Šerbula

21-24 June 2022, Hotel Sunce, Sokobanja, Serbia

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PREFACE

In today's world, the environment has been endangered by the use of outdated technology, fossil fuels and environmental law violations. Therefore, environmental and many other scientists all over the world have been concerned about finding sustainable technology in resolving these issues. That is why environmental research and ecological truth are at the focus of the 29th International Conference Ecological Truth & Environmental Research 2022 (EcoTER'22), which will be held in Sokobanja, Serbia, 21–24 June 2022. On behalf of the Organizing Committee, it is a great honor and pleasure to wish all the participants a warm welcome to the Conference.

We hope to convey the message of the conference, which is that a transformation of attitudes and behavior would bring the necessary changes. This is also an opportunity for the participants who are experts in this field to exchange their experiences, expertise and ideas, and also to consider the possibilities for their collaborative research.

The 29th International Conference Ecological Truth & Environmental Research 2022 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology, the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica, the University of Zagreb, Faculty of Metallurgy – Sisak, the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Association of Young Researchers, Bor.

These proceedings include 85 papers from the authors coming from the universities, research institutes and industries in 6 countries: Bulgaria, Italia, Albania, Bosnia and Herzegovina, Montenegro and Serbia.

As a part of this year's conference, the 4th Student section – EcoTERS'22 is being held. We appreciate the contribution of the students and their mentors who have also participated in the Conference.

Financial assistance provided by the Ministry of Education, Science and Technological Development of the Republic of Serbia is gratefully acknowledged by the Organizing Committee of the EcoTER'22 conference.

The support of the Platinum donor and their willingness and ability to cooperate have been of great importance for the success of EcoTER'22. The Organizing Committee would like to extend their appreciation and gratitude to the Platinum donor of the Conference for their donation and support.

We appreciate the effort of all the authors who have contributed to these Proceedings. We would also like to express our gratitude to the members of the scientific and organizing committees, reviewers, speakers, chairpersons and all the Conference participants for their support to EcoTER'22. Sincere thanks go to all the people who have contributed to the successful organization of EcoTER'22.

Prof. Snežana Šerbula,

President of the Organizing Committee

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CHARACTERIZATION OF CARBON AND LOW-ALLOY STEEL AFTER DIFFERENT HEAT TREATMENTS

Uroš Stamenković[1*], Svetlana Ivanov[1], Ivana Marković[1]
[1]University of Belgrade, Technical Faculty in Bor, V.J. 12, 19210 Bor, SERBIA
ustamenkovic@tfbor.bg.ac.rs

Abstract

The aim of this paper was the characterization of carbon and low-alloy steel after different heat treatments. Two steels were investigated, medium carbon C45 steel and low-alloy chrome-vanadium 51CrV4 steel. Two steels were also compared based on their chemical composition. Heat treatment of both steels included: normalizing at 880°C for 1 hour and cooled in air after which the samples were separated and investigated, second assortment of samples were again heated at 850°C for 1 hour and then quenched in water. Investigation was conducted after every step in heat treatment process. After every step, hardness was measured, tensile strength was calculated from hardness values, and thermal properties were also investigated. Metallographic studies were performed on every sample and analyzed. Results show increase in hardness and tensile strength values in quenched samples in comparison to the normalized samples. Also, thermal properties had lower values after quenching which is in accordance with the literature data. Metallographic investigation shows the typical ferrite-pearlite microstructure after normalizing and martensitic microstructure after quenching.

Keywords: C45 steel, 51CrV4 steel, heat treatment, hardness, thermal properties

INTRODUCTION

Steels, as one of the most used materials, can be very versatile based on the microstructure obtained by different heat treatments. One of the most important characteristics of steel is that it can be recycled continuously without any major changes in its properties. Carbon steels, besides tool steels, stainless steels and cast irons are one of the most used materials in the world. Medium-carbon steels are used for different applications where good combination of ductility and strength are required i.e. for various heavy-duty machinery, tractors and mining equipment [1,2]. Chrome-vanadium steels are often used for making different parts which can withstand high stresses. 51CrV4 steel is one of them, and it is used for making springs, small tools and auxiliary parts due to its elasticity, high tolerance for dynamic loads and sufficient wear resistance [3,4]. Both of these steels are very susceptible to heat treatment. Most common heat treatments of steel include: normalizing heat treatment in order to obtain fine pearlite, and quenching for obtaining martensite [1,5]. In order to improve performance and applicability of steels quenching must be done [6]. To achieve this, steels are heated to γ area in order to austenitize them after heating steels are rapidly cooled (quenched) in different mediums depending on the type of steel and other applications [7]. The aim of this paper is to expand the knowledge related to medium carbon steels and low-alloyed chrome-vanadium steels and how mechanical, thermal and microstructural properties change with different heat treatments. Also, since the carbon content in the investigated steels is almost equal, our secondary goal was to investigate the influence of alloying elements (chromium and vanadium) on investigated properties of steel after different heat treatments.

MATERIALS AND METHODS

Experimental investigation was performed on two different types of steels, medium-carbon (C45) and chrome-vanadium steel (51CrV4). Both steels were received in the form of hot rolled bars with the diameter of 20 mm. The Table 1 represents the chemical composition of the investigated steels.

Table 1 *Chemical compositions of investigated steels (mass. %)*

C45 medium-carbon steel					*51CrV4 low-alloyed steel*					
Fe	**C**	**Mn**	**S**	**P**	**C**	**Mn**	**Si**	**Cr**	**V**	**Fe**
98.51–98.98	0.42–0.5	0.6–0.9	≤0.05	≤0.04	0.51	0.9	≤0.4	1.05	0.18	Rem.

Firstly, all the samples were normalized at 880°C for 1 hour in an electric resistance furnace Vims elektrik LPŽ-7,5 S in order to remove as fabricated structure and then cooled in air. Normalized samples were heated up again at 850°C for 1 hour and quenched in water. After each heat treatment sample were separated and investigated. The heat treatment process can be seen on Figure 1.

Figure 1 *Heat treatment of steel samples in an electric resistance furnace*

Hardness was measured on the VEB Leipzig Vickers hardness tester using a 20 kg load and a 15 s dwelling time. Tensile strength was calculated using the hardness value and a conversion chart which gives tensile strength values based on the measured hardness values according to ISO 18265:2013 standard [8,9]. 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 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/mK), ρ – density; (kg/m^3), c_p – specific heat capacity; (J/kgK), α – thermal diffusivity; (cm^2/s), T – temperature; (°C).

For investigation of the microstructure optical microscopy was used. Preparation of the samples included wet grinding on a series of SiC papers, polishing with alumina suspension with two different granulation of Al_2O_3: particle sizes of 0.3 μm and 0.05 μm. 4% Nital solution was used for etching of the samples by immersion to reveal the microstructure. The microstructures were examined on the optical microscope Carl Zeiss Jena “Epytip 2”

RESULTS AND DISCUSSION

The properties of investigated samples after normalizing

After normalizing, as fabricated structure has been removed, thus structure has been normalized. Table 2 shows the results after normalization heat treatment of the investigated steel samples.

***Table 2** Different properties of the investigated steels after normalizing*

Type of steel	**Hardness (HV_{20})**	**Calculated tensile strength (MPa)**	**Thermal diffusivity (cm^2/s)**	**Thermal conductivity (W/mK)**
C45	232	748	0.1697	60.9
51CrV4	300	965	0.124	43.3

Table 2 shows typical values for these types of steel after normalizing. Hardness values are low due to normalization of the structure and slow cooling which provided formation of the fine ferrite-pearlite microstructure. By comparing two steels, the influence of chromium and vanadium can be clearly seen. Values of hardness and tensile strength are higher for the low-alloyed steel due to formation of fine chromium and vanadium carbides which have extremely high values of hardness. Consequently, values of thermal properties are lower than those measured for C45 steel. This is due to the fact that any presence of alloying elements causes the scattering of electrons which are primary carriers of heat in this case [10,11].

Figures 2a and 2b show the microstructure of the C45 and 51CrV4 steel after normalizing, respectively.

From the presented Figure it can be seen typical ferrite-pearlite microstructure. According to Duka *et al.* [12] C45 steel has around 66% pearlite and 34% ferrite. Microstructures given in Figures 2a-b are somewhat similar, which is to be expected due to similar carbon content. Chromium and vanadium carbides have influence on mechanical properties but have not so much influence on the microstructure.

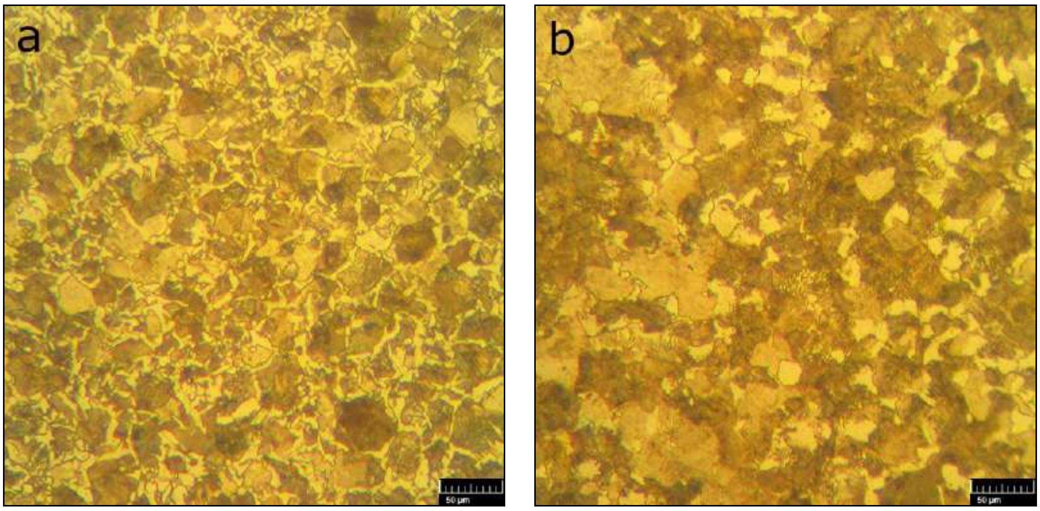

Figure 2 *Microstructure of the investigated steels after the normalization heat treatment a) C45; b) 51CrV4 magnification is x500*

The properties of investigated samples after quenching

Following the normalizing heat treatment, samples were again heated to temperature in austenite region and quenched to room temperature. Table 3 shows the results after quenching of the investigated steel samples.

Table 3 *Different properties of the investigated steels after quenching in water*

Type of steel	Hardness (HV$_{20}$)	Calculated tensile strength (MPa)	Thermal diffusivity (cm^2/s)	Thermal conductivity (W/mK)
C45	550	1810	0.1367	45.5
51CrV4	661	2220	0.09	32.9

Comparison of the results given in Table 2 and Table 3 shows that hardness values are twice as high as the values obtained for samples after normalizing. Tensile strength, due to direct proportionality, shows roughly the same trend. Somewhat similar results were obtained by other authors [13–15]. For both steels, thermal diffusivity and thermal conductivity had lower values after quenching, as seen in Table 2 and 3.

The reason for obtaining higher values for investigated mechanical properties, as well as for the decrease in values for the thermal properties lies in the formation of martensite during quenching. Quenching of steel creates a supersaturated solid solution in the structure, carbon atoms are being retained in the newly formed crystal lattice, as well as atoms of other alloying elements. During the formation of martensite, dislocation and twin density increases. In addition, the number of sliding systems decreases in the newly formed tetragonal lattice, which leads to intense hardening due to dislocation hindering [4,16,17]. All of these processes caused by quenching lead to a weaker flow of electrons due to their scattering in the lattice, which causes an increase in electrical resistance in hardened steels [4]. Besides that, any presence of alloying elements in the lattice causes the scattering of electrons, and with that values of electrical and thermal properties decline [10,11]. Also, as well as after the normalizing, the influence of chemical composition is evident after quenching. 51CrV4 steel has higher values of hardness and tensile strength in comparison to the C45 steel. In addition, values of thermal properties are lower than those measured for C45 steel after the same heat treatment.

Figures 3a and 3b show the microstructure of the C45 and 51CrV4 steel after quenching, respectively. From presented figure it can be concluded that martensitic structure has been obtained in both of investigated steels. There is not as much difference in the microstructures. In the case of the 51CrV4 steel, the microstructure appears somewhat denser and finer. The cause of that can be found in the fact that alloyed steel are much easier to quench, i.e. martensite can be easier to obtain. Higher values of hardness obtained for the 51CrV4 steel in comparison to the C45 steel can be ascribed to that and to the formation of the chrome and vanadium carbides, which are likely to be present after applied heat treatments.

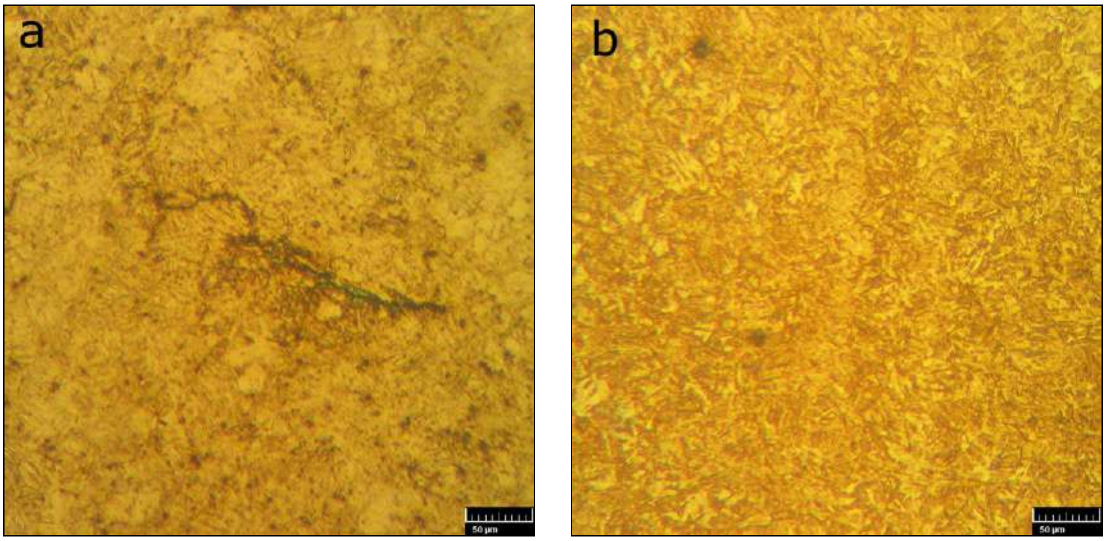

Figure 3 Microstructure of the investigated steels after quenching
a) C45; b) 51CrV4 magnification is x500

CONCLUSION

The conclusion in this paper can be summarized as:

1. After normalizing at 880°C for 1 hour and cooling in air
    - Steel had the lowest values of hardness and tensile strength in relation to other investigated states, as well as the highest values of thermal properties;
    - Optical microscopy showed a relatively small-grained ferrite-perlite microstructure.
2. After heating at 850 °C for 1 hour and quenching in water:
    - The highest hardness values of all investigated states were obtained. The relative increase in hardness values in relation to the normalized sample is 137% for C45 steel and 120% for 51CrV4 steel. The relative increase in tensile strength for the

C45 steel is 142%, while for the sample of 51CrV4 steel this value is 130%, compared to the normalized sample;

- The values of thermal diffusivity and thermal conductivity decreased in relation to the values obtained for the normalized samples. The relative decrease in the value of thermal diffusivity is 19% for C45 steel, and 30% for the 51CrV4 steel. The value of thermal conductivity for the C45 steel sample decreased by 25%, while for the 51CrV4 steel sample it decreased by 24% compared to the normalized sample;
- The strengthening of steel as well as the decrease in thermal properties lies in the formation of martensite during hardening.

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