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The Effect of Tempering Temperature on Microstructure and the Mechanical Properties of Forged Steel Containing Chrome, Manganese and Molybdenum

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1. Introduction

Bearing steels cover a wide range of wear-resistance steels with high strength and they are widely used in variety of industries such as manufacturing of bearings, ball bearings, spare parts of vehicles and hot and cold rollers due to their unique properties such as formability, easy machining, fatigue resistance which stems from rolling and thermal stability. Heat treatment plays an important role in this part. Therefore, controlling heat treatment parameters like tempering temperature to obtain optimized microstructure and mechanical properties is of great importance [1]. In a study done by Gojic et al. [2], on tempering process of steels which contained chrome and chrome-molybdenum at 1246ºC, orthorhombic cementite and cementite contained hexagonal Mo_2C particles in the ferrite base were observed for chrome steels and chrome-molybdenum steels respectively. In another study done by Fang et al. [3] for the purpose of surveying the effect of tempering temperature on the yield and tensile strength of chrome-manganese steels, the tensile stress of the samples tempered at the temperature range of 150-450ºC, decreased due to increase of tempering temperature, however the yield strength did not show noticeable change. In a study done by Lee et al. [4] on high speed steels (HSS), the abrasive behavior of the tempered samplesat540ºC known to be caused by the deposition of M_2C, MC and M_7C_3carbide. The chemical composition of the mentioned steel in this research is similar to the steel of DIN 1.3359, but with an extra element of vanadium. Due to the high carbide content of this element, the wear resistance is higher. The effect of heat treatment on microstructure and mechanical properties is very important owing to the high utilization of this steel in the manufacture of cold rolling rollers and bearings. But there is no published research in this area. Therefore, in current study, the effect of tempering temperature on the microstructure, hardness, impact and wear resistance of the steels, have been examined using some testing methods such as impact test, hardness test and pin-on-disk wear test.

2. Material and research method

The chemical composition of the steel used in this study is shown in Table 1.

Table 1

Chemical composition of the studied steel (wt%)

Element	Si	Ni	V	Mo	Mn	Cr	C
wt%	0.6	0.4	0.2	0.5	0.9	1.9	1.2

The steel under test is made in an electric arc furnace and then forged at 1150 to 1180ºC followed by through annealing heat treatment at 750ºC for 4 hours. In heat treatment, the samples got austenized at 900ºC with heating rate of 8ºC/min in Nabertherm furnace and after being kept at this temperature for 30 minutes, quenched in oil. In order to study the effect of the tempering temperature on the microstructure and mechanical properties, the samples were tempered at different temperatures: 150, 250, 350, 450, 550 and 650ºC. For microstructural test the samples were etched in Vilella reagent (1 gr picric acid + 10 ml HCl 100 ml Ethanol). Finally, Olympus optical microscope was used to study the microstructure. For accurate examination of carbide, identifying the type of precipitated carbide in the martensitic base during the tempering process, EDS analysis was performed at 550ºC. This test was done by field emission scanning electron microscopy (TESCAN MIRA 3). The hardness test on the samples was conducted using EMCO (4U750) apparatus in Rockwell C scale. The hardness numbers were reported according to the DIN 6508 and by means of measuring the mean hardness number of three different points on the surface of samples. The Charpy Impact test was done on the tempered samples not etched based on DIN 10002 using ZWICK5111 apparatus at the ambient temperature. In each cycle, three strikes were chosen and the average was reported. Wear test was also conducted by Pin –on- disk method with the applied force of 130 N and the speed of 0.2 m/s. In this test, the pin was made of 100Cr6 steel with the hardness of 64 HRC.

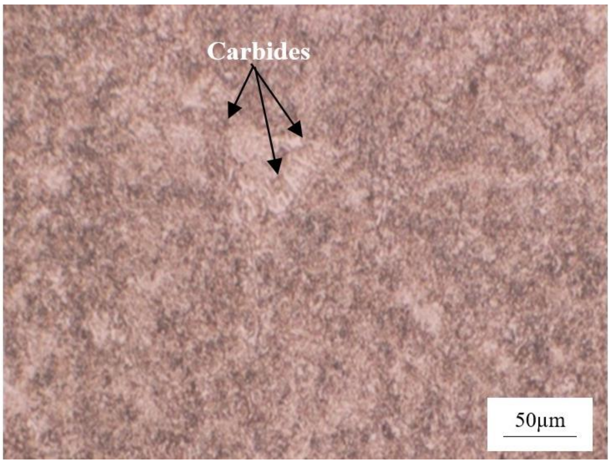
3. Results and discussion

In this section, the effect of tempering treatment on microstructure, hardness, impact and wear resistance is investigated.

3.1. The effect of tempering temperature on the microstructure

In Fig 1, the image taken by the optical microscope from two tempered samples at 350 and 550ºC can be seen.

As shown, the carbide is distributed in martensitic base. With an increase of tempering temperature from 350 to 550ºC, more carbide was formed in the structure and the morphology of carbide got bigger. Moreover, study done by Sehry et al [6] on high chromium martensitic medium carbon steel, the growth in carbide and the formation of new carbide with an increase in the tempering temperature were observed and documented.



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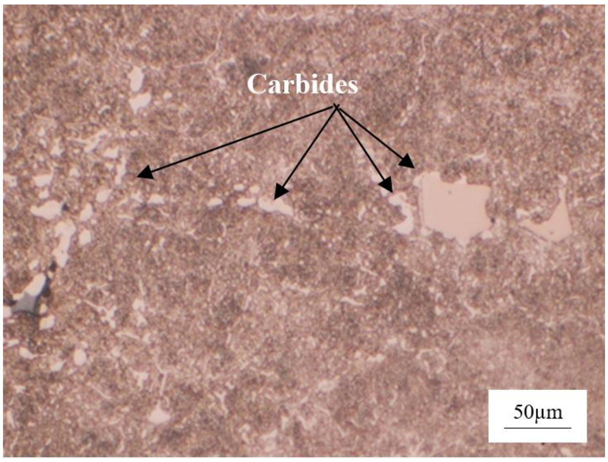


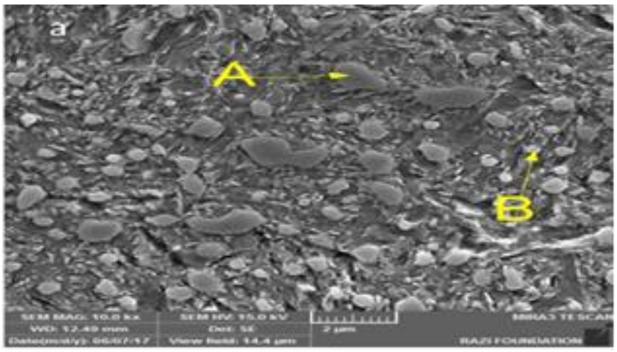
b

Fig. 1 The optical microscope image taken from samples after tempering for 60 minutes at a) 350ºC, b) 550ºC

In order to investigate the types of carbide, the tempered samples underwent EDS analysis at 550ºC and the results are shown in Fig. 2. Due to the chromium content in the EDS analysis and the type of carbides obtained, they can be made of chromium carbide or chromium carbide complex (Fig. 2, c).

3.2. The effect of tempering temperature on the hardness and impact energy

The influence of tempering temperature on hardness and impact energy are shown in Figs. 3 and 4. As shown in Fig. 3, the hardness is gradually decreasing at the temperature range of 150-250ºC. It is because of the formation of transition carbide which led to a delay in reducing the hardness [6]. At the temperature range of 250-650ºC, the hardness decreased. This reduction is the consequence of a decrease in the martensitic tetragonality, increment in carbide size and grain growth by an increase in the tempering temperature [7-9]. In a research done by



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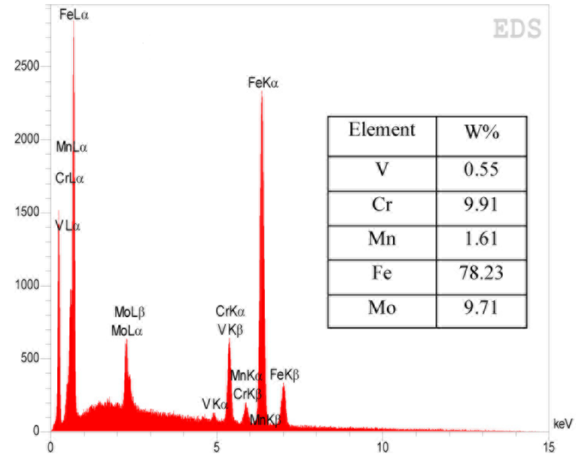

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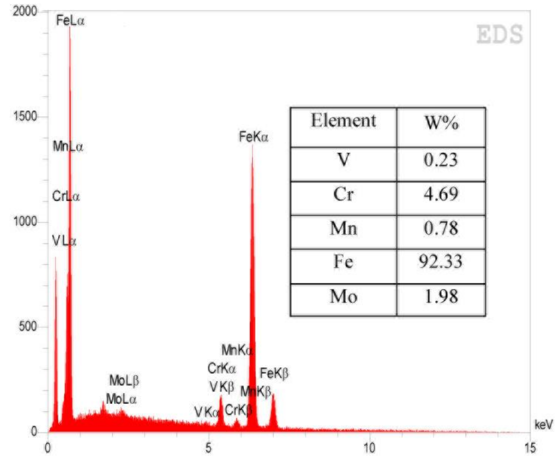

c

Fig. 2 SEM image of tempered sample at 550ºC – a; EDS analysis of the point A – b; EDS analysis of the point B – c

Babaei et al [10] on martensitic stainless steel (Grade 442), the hardness was constant at the temperature range of 300-400ºC (the first stage), at the temperature range of 400 - 500ºC increased (the second stage) and decreased at the temperature range of 500 -700ºC (the third stage). It was found that the formation of transition carbide (first stage), the secondary hardness and M_7C_3 formation (the second stage) and M_7C_3 transformation to $M_{23}C_6$ and carbide growth (the third stage) were the reasons for the change of properties.

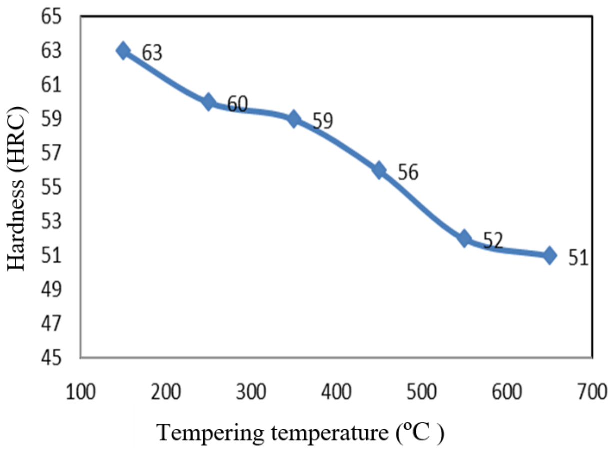

Fig. 3 The hardness changes in different tempering temperatures

It can be seen in Fig. 4 that the impact energy changes with tempering temperature. Impact energy variations have slowly increased to 250ºC, which is due to the slightly decrease in the hardness content. With increasing of tempering temperature from 250 to 650ºC, the impact energy would increase which is related to the reduction in hardness, martensitic transformation to tempered martensite and consequently ferrite and cementite formation [6, 7, 10]. In a study done by Amini et al [7] on martensitic stainless steel (Grade1.4057), the impact energy was almost constant till 350ºC and at the temperature range of 350-550ºC, the impact energy decreased owing to the secondary hardness and at temperatures above 550ºC. It decreased due to the elimination of internal stress stemmed from the recovery process.

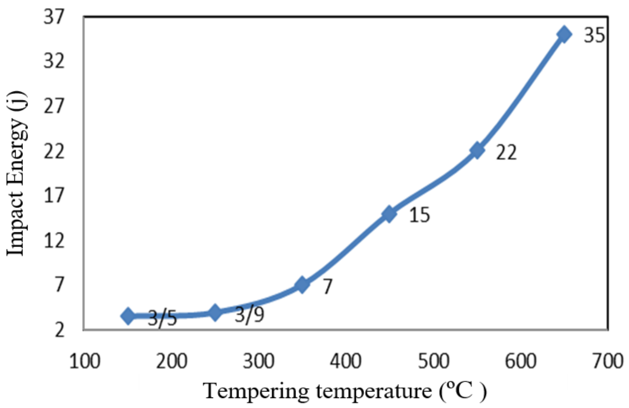

Fig. 4 Changes in impact energy at different tempering temperatures

In Fig. 5, fracture cross section of the impact samples underwent tempering process at 150 and 550ºC is shown. Smooth and flat surfaces are characterized by a fracture failure that is observed in a tempered sample at temperature of 150ºC. In the tempered sample at the 550ºC, the presence of micro voids is a result of ductile fracture. In a research done by Salami et al [11] for the purpose of surveying the tempering temperature on the fracture morphology of Ni-Cr-Mo steels, the presence of micro voids on the fracture surface at the temperature range of 300-600ºC was observed.

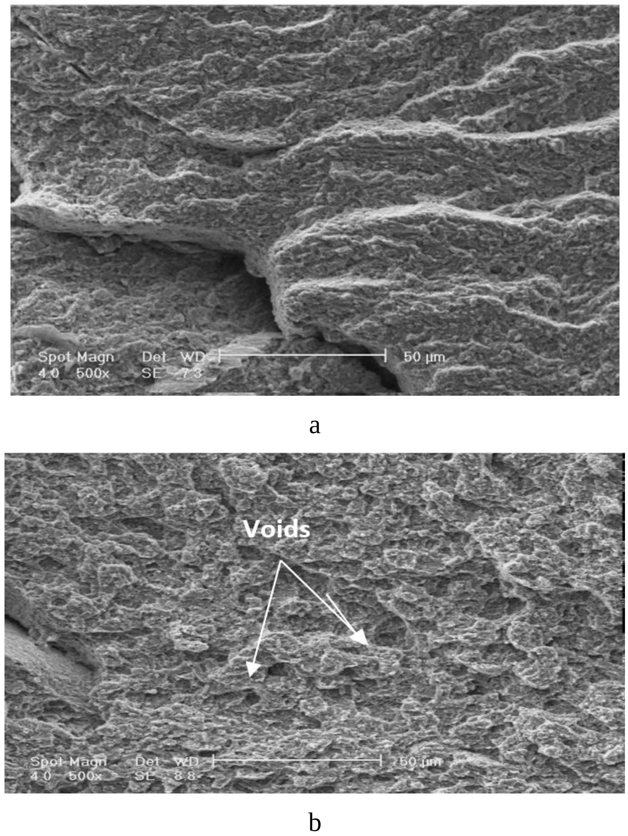

Fig. 5 Images taken from the fracture cross section of the tempered samples for 60 minutes at: a – 150ºC; b – 550ºC

3.3. The effect of tempering temperature on the wear resistance

As it is obvious in Fig. 6, the weight loss of the samples increases during the wear test with an increase in the tempering temperature. This issue is justified by the reduction in hardness and softening of the structure caused by the decreasing of the martensite tetragonality, the growth of the structure and the deformation of ferrite. SEM images from the wear surface of the samples are shown in Fig. 7. As can be seen, in lower temperatures of tempering, the wear mechanism is a combination of abrasive and adhesive wear. With an increase in the tempering temperature, abrasive wear mechanism was changed to the dominating adhesive mechanism which is justifiable according

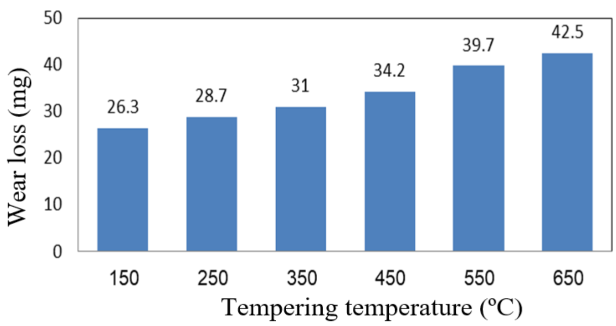

Fig. 6 The tempered samples weight loss at different temperatures after 1000 meters in wear test (with the applied force of 130 N and wear speed of 0.2 m/s)

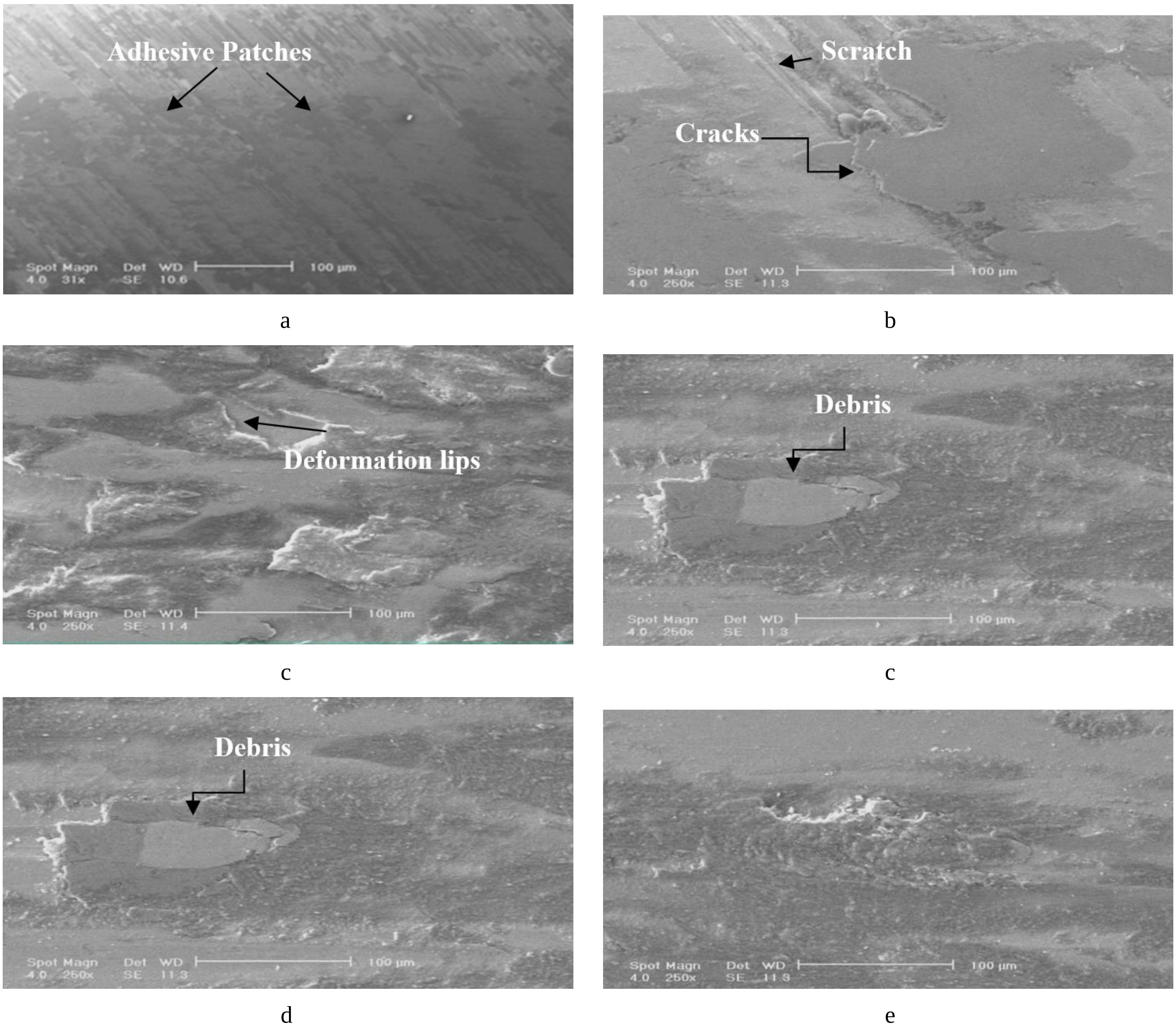

Fig. 7 SEM images from worn surface of tempered samples at a – 150ºC; b – 350ºC; c – 450ºC; d – 550ºC; e – 550ºC

to the softening in the structure and the reduction in the hardness. In addition, as seen, in lower temperatures, adhesive wear mechanism is weaker which is because of smaller size of carbide at lower tempering temperatures and carbide resistance against wear. In a study done by Yang et al [12], it is demonstrated that with an increase in the hardness, resistance to adhesive wear in steels increases which is in a good agreement with the current and other [13] studies.

4. Conclusion

1. The hardness was gradually decreased (impact energy gradually increased) at the temperature range of 150 - 250ºC but at 350 - 650ºC, with an increase in the tempering temperature, the hardness decreased and the impact energy increased which it was as a result of the structure softening, a decrease in martensitic tetragonality and the formation of ferrite phase.

2. With an increase in the tempering temperature, wear resistance decreased in a way the weight loss for the sample tempered at 150ºC increased from 26.30 mg to 42.50 mg for the sample tempered at 650ºC. It can be justifiable due to the structure softening with an increase in the tempering temperature and consequently a decrease in wear resistance.

3. The wear resistance mechanism at lower tempering temperature was a combination of adhesive and abrasive wear mechanisms and at higher temperatures it was just adhesive wear mechanism. Also, with an increase in the tempering temperature, there would be seen a dominant adhesive wear mechanism. It can be justified considering a reduction in the hardness with an increase in the tempering temperature.

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THE EFFECT OF TEMPERING TEMPERATURE ON MICROSTRUCTURE AND THE MECHANICAL PROPERTIES OF FORGED STEEL CONTAINING CHROME, MANGANESE AND MOLYBDENUM

S u m m a r y

Steel bearings have plenty of usages in manufacturing different kinds of ball bearings, bearings and cold rolling rollers. Heat treatment has an important role in the properties of this group of steels. Therefore, in current research the effect of tempering temperature on the microstructure, hardness, impact energy and wear resistance in forged steel containing Chrome, Manganese and Molybdenum will be studied. For this purpose, the samples were tempered after austenitizing at 900ºC and quenching in the oil at 6 temperatures of 150, 250, 350, 450, 550 and 650 ºC for an hour. Then microstructural studies and mechanical properties of the samples including hardness, impact energy and wear resistance were surveyed on the samples. The results showed that the hardness was gradually decreased (impact energy gradually increased) at the temperature range of 150 - 250 ˚C and at temperature range of 350 - 650ºC, the hardness would decrease and the impact energy would increase. Also, the wear resistance would decrease with an increase in the tempering temperature. The result should be justified considering the softening of the structure and the reduction in martensite tetragonality which stems from an increase in the tempering temperature. The study of the wear surface of the samples indicated that the dominant wear mechanism was adhesive wear in which with an increase the tempering temperature due to a reduction in the hardness of the samples, more sever adhesive wear was observed.

Keywords: wear resistance, hardness, tempering temperature, steel bearing.

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