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EFFECT OF TEMPERING PARAMETERS ON MICROSTRUCTURE AND HARDNESS OF A LOW ALLOY ARMOR STEEL

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Abstract: *The final stage of heat treatment that gives high hardness to armor steels its final structure and characteristics is tempering after quenching. The precipitation of carbides from the supersaturated solution is influenced by the tempering regime selected. The steel used in this work was a low alloy quenched and tempered steel (commercial name "PROTAC"), with following chemical composition: 0.32 wt.% C, 0.44 wt.% Mn, 0.98 wt.% Cr, 3.09 wt.% Ni, 0.43 wt.% Mo, 0.019 wt.% Nb, 0.003 wt.% Ti, 0.035 wt.% V. The samples were tempered at various temperatures between 200 and 500°C for varying periods of time after being quenched in oil at 925°C. The samples were examined using hardness testing, scanning electron microscopy, and light microscopy. The highest value of hardness of 430 HV was obtained after tempering at 300°C for 15 min. Due to the comparatively short tempering duration, this result was attributed to the precipitation of coherent and semi-coherent ferrous carbide particles rather than alloying element carbides. After reaching the maximum value of 430 HV hardness drops with further increase of temperature. The increase of hardness by prolonged tempering time was higher at 300°C than at 200°C.*

Keywords: *Armor Steel, Quenching and Tempering, Kinetics of Tempering, Hardness*

1. INTRODUCTION

Due to the great diversity in alloyed steels and the inevitable overleap in chemical composition, there was a need to classify steels according to their heat treatment. Therefore, quenched and tempered steels (Q+T steels) are those that undergo these last steps in thermal processing after which they obtain final microstructure and properties [1,2]. When it comes to the best ratio of strength and toughness, microstructurally it comes to thermomechanically rolled fine-grain structural steels and quenched and tempered steels [3,4] The choice of tempering regime determines the process of precipitation of carbides from the supersaturated solution. The long duration and high temperatures of tempering (200-700°C) can provide huge variations in morphology of tempered martensite and mechanical properties [5]. Despite the fact that tempering increases strength at the expense of toughness Q+T steel are still unmatched when it comes to having increased toughness among high strength steels. Heat treatment regime controls the size and distribution of carbide particles in steels. This is of crucial importance for the dominant strengthening mechanism in quenched and tempered steels is precipitation hardening, followed by grain refinement [5].

The aim of this work was to examine different tempering regimes of quenched steel under commercial conditions and to determine the influence of heat treatment process parameters on microstructural changes and mechanical properties in terms of hardness.

2. MATERIALS AND METHODS

Low alloy high hardness armor steel (HHA) produced by Acroni d.o.o. Jesenice, Slovenia under commercial name Protac 500 was used in this investigation. Chemical composition of the steel is given in Table 1. As received 8 mm thick plates in quenched condition were soft annealed at 700°C for 4 hours in a protective argon atmosphere and furnace cooled, in order to prepare them for cutting and

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machining. In order to remove previous structure and prepare for further thermal treatment samples cut from the plates were homogenized at 1050°C for 5 min in a protective argon atmosphere and cooled in still air. Samples were afterwards austenitized at 925 °C for 5 min in a protective argon atmosphere and quenched in oil. Quenched samples were tempered at temperatures of 200, 300, 400 and 500 °C, at different times, as given in Table 2.

Table 1. Chemical composition of the Protac 500 steel.

Chemical Composition (%)						
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**
0,32	0,76	0,44	0,008	<0,001	0,98	3,09
Mo	**B**	**Cu**	**Al**	**V**	**Ti**	**Nb**
0,43	0,0009	0,16	0,033	0,035	0,003	0,019

Table 2. Tempering temperature and time.

200 ºC	300 ºC	400 ºC	500 ºC
15 min	5 min	15 min	15 min
30 min	15 min		
60 min			

Metallographic specimens of quenched and tempered samples were prepared by grinding, mechanical polishing and etching in 2% solution of HNO_3 in ethanol (2% nital). Microstructures were examined by light microscopy using Reichart-Jung MeF3 (Vienna, Austria) metallographic microscope, and by scanning electron microscopy JEOL JEOL JSM 6610LV equipped with EDS. Strength of the samples were evaluated by Vickers hardness test with a load of 30 kgf.

3. RESULTS AND DISCUSSION

The quenched microstructure is characterized by martensitic needles in the entire volume of the sample. The martensitic needles are of random orientation and it can be assumed that the previous austenite grain size is less than 20 µm. The impact of tempering temperature after 15 min is shown with light microscopy in Figure 1 and with SEM in Figure 2.

After tempering of 15 min at 200ºC microstructural changes are evident with light microscopy and with the increase of tempering time the previous austenite grain boundary becomes more pronounced. At the SEM level for tempering at 200ºC there are noticeable morphology in microstructure that do not correspond to martensite, which decrease with longer tempering times. At 300ºC after tempering for 15 min, the martensitic needles are much sharper and pronounced than after 5 min. Moreover, at the SEM the cementite plate can be noticed after 15 min at this temperature. For tempering temperature of 400ºC at the light microscopy level it is noticeable that the martensitic needles are blurry, unclear and dissolved, while at the SEM level the microstructure is interspersed with cementite plates. Finally for tempering at 500 ºC complete coarsening of the carbide can be observed at the light microscopy level, while at the SEM level the martensitic morphology is completely absent.

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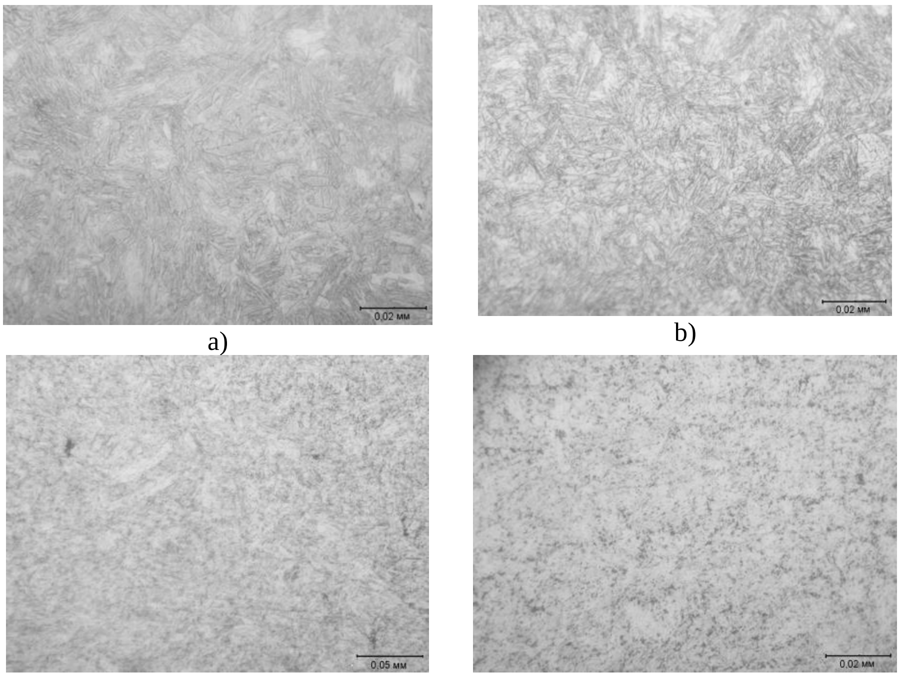

a) b) c) d)

Figure 1. Optical micrographs of the quenched and tempered samples microstructure at different temperatures: a) 200 °C/15 min, b) 300 °C/15 min, c) 400 °C/15 min, d) 500°C/15 min.

The general tempering of carbon steels is divided into four stages [6]: First stage (up to 250ºC), deposition of transitional ε-iron carbide, partial loss of tetragonality of the martensitic lattice; Second stage (200ºC - 300ºC), decomposition of residual austenite into ferrite and cementite; Third stage (200ºC - 350ºC), replacement of ε-iron carbide with cementite and complete loss of tetragonality of the martensitic lattice; Fourth stage (above 350ºC), coarsening and spheroidization of cementite, recrystallization of ferrite.

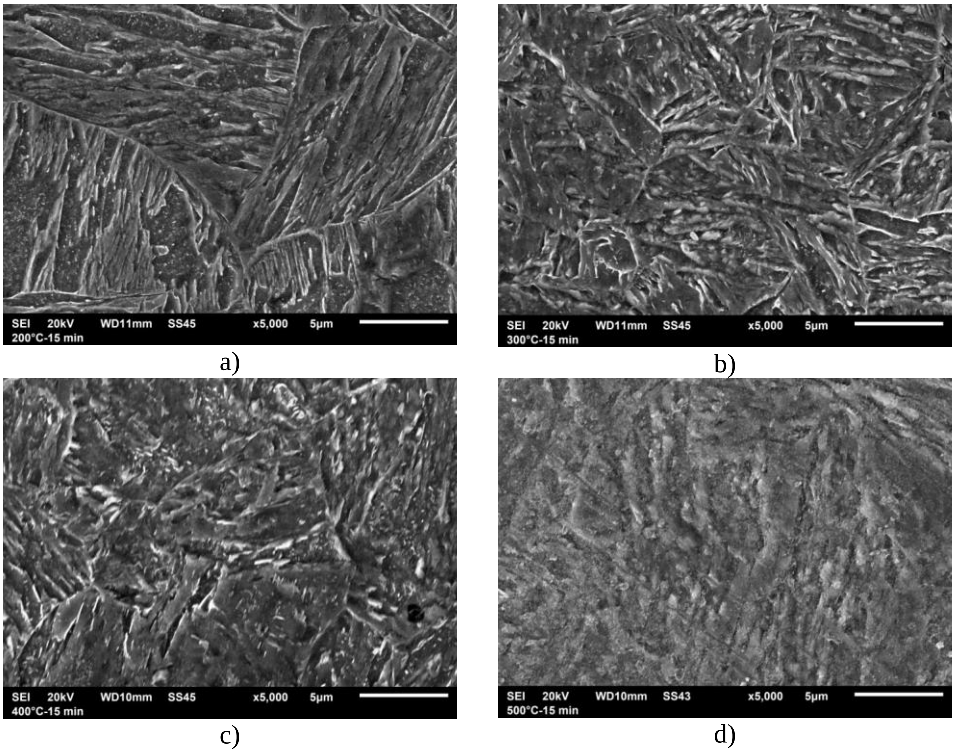

Figure 2. SEM micrographs of the quenched and tempered samples microstructure at different temperatures: a) 200 °C/15 min, b) 300 °C/15 min, c) 400 °C/15 min, d) 500°C/15 min.

At low temerature tempering at 200°C it is expected to see the efects of the first and second stage of tempering. This is reflected in fine carbide particles after noticed after 15 min, that loose the visibility as tempering time increaces. This lose in visibility can be attributed to the second interval and the retainted austenite dissolution [6-7]. The end of the second stage of tempering and the beginning of the third is noticed at 300 °C.

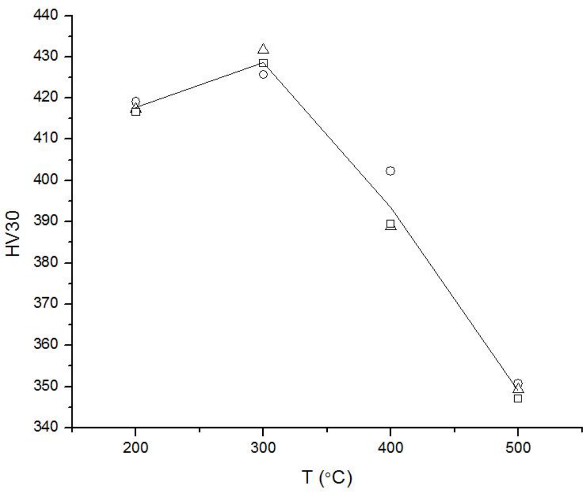

Figure 3. Vickers Hardness (HV30) dependence on tempering temperature (tempering time 15 min).

Additionally, some cementite plates can be seen after 60 min for tempering at 200°C so that can also mark the start of the third stage of tempering. The third interval is observed at 400ºC, the martensite matrix completely loses its tetragonality but retains a needle-like morphology permeated with cementite plates, while at 500ºC carbide coarsening is noticeable and ferrite (formerly martensite) takes the form of bainite. Figure 3 demonstrates the dependence hardness on tempering temperature after 15 minutes. As the temperature increases, the hardness increases, reaches a maximum value of 430 HV, and then decreases. Maximum hardness was obtained for firing at 300°C.

At high tempering temperature at 500ºC the loss of hardness is contributed to the absence of alloying element carbides due to their low content and an insufficient time for their formation. Therefore, during the forth tempering stage there was no participation hardening and only the effect of present carbide coarsening is noticed both in microstructure and hardness.

Figure 4 shows how measured hardness changes over time for tempering at temperatures of 200°C and 300°C. It was found that at 300°C, the increase in hardness with increasing tempering time is more intense than during tempering at 200°C.

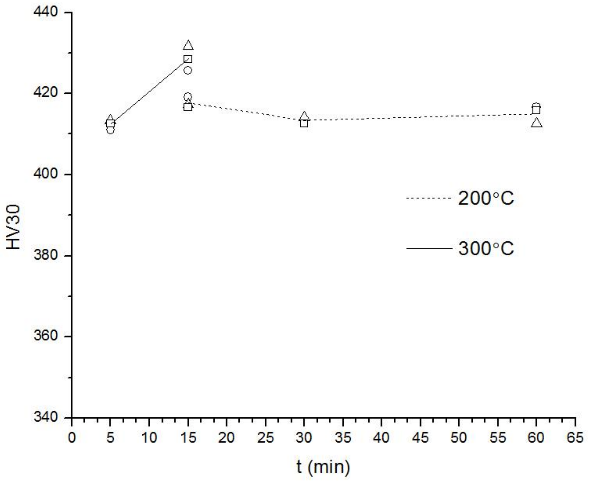

Figure 4. Vickers Hardness (HV30) dependence on tempering time (at 200 °C and 300 °C).

In terms of hardness as it does in microstructure tempering for 5 min at 300ºC shows similar effects as after 30 min at 200º. Since release is a diffusion-controlled process, at higher temperatures it takes a shorter time for certain changes to occur.

The highest hardness value for the sample tempered for 15 min at 300ºC can be attributed to the beginning of the third stage of tempering, the implementation of cementite plates inside the matrix that has not completely lost the tetragonality of the martensitic base. More precisely, diffusion in this stage enabled the kinetic conditions for the formation of finely dispersed coherent or semi-coherent particles, which in the mechanical sense have the strongest effect of increasing the hardness of the material [6-7].

4. CONCLUSION

According to the microstructural analysis and hardness measurements of a quenched and tempered low alloy high hardness armor steel the following conclusions are made:

• With increasing temperature, the hardness increases, reaching a maximum value of 430 HV, and then decreases with increasing temperature.

• The highest hardness is achieved after tempering at 300°C/15 min. The reason for this is the deposition of coherent and semi-coherent iron carbide particles and not carbides of alloying elements due to the short release time.

• The increase in hardness with increasing tempering time is more intense at 300°C than during tempering at 200°C.

• It is assumed that this behavior is due to kinetics of carbide precipitation and coarsening. Process seems to be most productive at 300°C.

Acknowledgement

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