MICROSTRUCTURE CHANGES OF STEEL MATERIALS UNDER ISOTHERMAL HEAT TREATMENT IN SALT BATH*

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To improve the mechanical properties of steel materials such as Vanadis 4extra, Vanadis 10, Vancron 40, and Böhler S600, the isothermal heat treatment procedure using salt bath was used. Samples of the steels were processed at different time of austempering at various temperatures and compared to the samples processed by heat treatment (i.e. quenching in air or quenching in oil and tempering in air) which is most widely used in practice. Hardness properties are determined by the steel microstructure, the size and number of carbide particles in this microstructure. The suitability of heat treatment for improving mechanical properties of different steel materials is assessed.

steel, hardering, tempering, salts, bainite, martensite

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INTRODUCTION

The quality of machining steel materials should be monitored during processing. Machinability is determined by the mechanical properties of the steel tools such as hardness, wear resistance, and toughness. Tool steels are often used to protect parts of agriculture machines and agriculture tools, where the abrasive wear by abrasive particles affects the dimensions of engineering parts in the agriculture machines assembly. Protection by tool steels significantly decreases wear rate of engineering parts of agriculture machines or agriculture tools experimentally chisels (Smol'nikov et al., 1987; Li et al., 1997; Jacquet et al., 2011). The financial saving can be influenced by service life which is calculated as the time between replacement of old tools by new ones. Thus the target of tools producers is to keep long service time for most machining tools. Desirable mechanical properties can be improved by heat treatment of tool steels. The heat treatment should be selected and designed according to the requirements for the steel mechanical properties (Ozeryanaya, 1985; Devi, 2002).

Mechanical properties can be influenced by the microstructure transformation, namely refining of carbides in microstructure (Atamert, Bhadeshia, 1990; Li, Wells, 2005). Microstructure after heat treatment of steel tools affects the wear rate of steel (Dobrzański et al., 2004; Jurči, Dlouhý, 2011; Halfa, 2013).

Hardening with tempering is the conventional heat treatment method of the tool steels for the removal of brittleness (Salman et al., 2007; Kim et al., 2008). An isothermal technological process has been developed as the isothermal heat treatment of tool steels in salt bath to increase wear resistance, hardness, and corrosion resistance (Wang et al., 2012; Luo, Zhao 2013). The chemical composition of salt bath is chosen according to the requirement for mechanical properties of steels (Smol'nikov et al., 1976; Erdogan et al., 2007; Yeğen, Usta, 2010). The right choice of the salt bath chemical composition can increase corrosion resistance and can replace some processes as blackening, chrome plating, etc. (Yeung et al., 1997; Wang et al., 2011; Shaeri et al., 2012)

Heat treatment in salt bath reduces the size of carbide particles and increases the number of carbides by improving the mechanical properties of the tool steels. Finer carbides increase abrasion resistance with a higher volume of martensitic phase in the microstructure of tool steel (Fukaura et al., 2004; Wei et al., 2011).

Table 1. Chemical composition of the tested tool steels (wt. %)

	C	Si	Mn	Cr	Mo	V	W	N
Böhler S600	0.90	0.25	0.30	4.10	5.00	1.80	6.40	-
Vanadis 10	2.90	0.50	0.50	8.00	1.50	9.80	-	-
Vanadis 4 Extra	1.40	0.40	0.40	4.70	3.50	3.70	-	-
Vancron 40	1.10	0.50	0.40	4.50	3.20	8.50	3.70	1.80

A study by Rassizadehghani et al. (2006) shows that a specific cooling medium in comparison with other processes of heat treatment is created during the heat treatment of steel in salt bath. While the hot steel is being cooled in oil or water, vapour occurs on the interface of the material and the cooling medium. The cooling medium is not stable and thus significantly influences the process of heat treatment and consequently the tool steel microstructure (Prasanna Kumar, 2013; Bardelcik et al., 2014). The heat is dissipated evenly in salt bath by submersion of the material since no vapour blanket is produced on the interface (Cen, Fu, 2013; Torkamani et al., 2014).

The aim of this study is to compare hardness, structure, size, and volume of carbides in the microstructure of tool steels treated in salt bath and those processed by heat treatment (quenching and tempering).

MATERIAL AND METHODS

Alloying elements. The selected steels contain different alloying elements: steel Böhler S600 – high amount of tungsten, steel Vanadis 10 – vanadium and small amount of molybdenum, steel Vanadis 4extra – vanadium and molybdenum, and steel Vancron – molybdenum, vanadium, and tungsten (Table 1).

Experimental procedures. The procedure steps are as follows: preparation of steel samples sizing 7 × 7 × 40 mm; measurement of hardness according to Rockwell hardness tester C-type HP 2502 (Werkstoffprüfmaschinen-Leipzig GmbH, Leipzig, Germany); heat treatment of samples – heating in furnace and cooling in quenchant or salt bath 50 wt.% $NaNO_2$ + 50 wt.% $NaNO_3$. The chemical composition of this salt bath can be used at 250°C. A lower temperature than 250°C can be used for isothermal treatment in salt bath with the addition of $LiNO_3$ – where temperature and isothermal time were determined according to the TTT and CCT tranformation diagrams (Tizzoni et al., 2016).

The metallography process analyzes include the transverse sample cuts in half dimension, casting in acrylic resin, grinding by polycrystalline diamond suspension, and polishing with fine alumina oxide suspension. The polished surface was etched with a solution of 3.7 g NH4 FHF + 30.8 ml HCL + 61.5 ml H_2O + 0.08 g $K_2S_2O_5$, washed with water, and dried.

Metallography. A light optical microscope JENAVERT (Carl Zeiss, Jena, Germany) was used, with 15 images used for the image analysis from each specimen. The scanning electron microscope/energy dispersive X-ray spectroscope (SEM-EDS) system was used to determine the phases and chemical composition of carbides. The SEM-EDS analysis was carried out using a computer controlled field emission SEM Mira 3 GXM (TESCAN, Brno, Czech Republic) equipped with an EDS X-MaxN (Oxford Instruments, Abingdon, UK). All the samples were mounted on acrylic resin. The samples were placed in the corner of the SEM-EDS chamber. The working conditions were set at an accelerating voltage of 5–20 kV, a beam current of 40–50 μA, and a Si (Li) detector at a distance of 15 mm from the samples to be analyzed. The X-ray detection limit is ~0.1%. The EDS X-MaxN system (Oxford Instruments), resolution at 5.9 keV–124 eV, is capable of collecting spectrum from multiple points, lines across the interface, and elemental mapping.

For the measurement of hardness after heat treatment the samples were ground by abrasive cloth and Vickers hardness test was used (loading of 298 N). Indentation hardness was measured five times in different places of the sample.

Image analysis. The images from scanning electron microscopy were fitted by mask and transformed to binary code. The set of mask was the same for each of the analyzed images.

Data analysis. The area of carbides was determined from binary code and it was calculated for each image. Data of the carbide size and carbide ratio (the proportion between the area of carbides and the total area of carbides) were analyzed using the STATISTICA software (Version 12, StatSoft, Prague, Czech Republic). ANOVA analysis was used to determine the relationships between variables – heat treatment and responsible carbide size and carbide ratio.

RESULTS

Table 2 presents the heat treatment and hardness, carbide size and carbide ratio for each of the tested materials. The highest hardness (963HV) was achieved with the sample V40_4. The lowest hardness (628HV) was found in the material S600_5. In both cases, the materials were treated in salt bath, but at different

Table 2. Heat treatment conditions of the tested steels and the results for hardness, carbide size, and carbide ratio in microstructure

Sample	Heat treatment	Hardness [HV]	Carbide size [μm^2]	Carbide ratio [%]
S600_1	Heating at 1200°C; quenching 20°C/oil; tempering at 550°C/7200×7200s/air	834±18	0.473	0.947
S600_2	Heating at 1200°C; quenching 20°C/oil; tempering at 550°C/1×7200s/air	831±35	0.454	0.969
S600_3	Heating at 1200°C; quenching 1000°C/ air; quenching 660°C/salt/120s; quenching 258°C/ salt /1860s	798±45	0.280	1.72
S600_4	Heating at 1200°C; quenching 1000°C/ air; quenching 660°C/ salt /720s; quenching 258°C/ salt /1200s	863±41	0.337	2.23
S600_5	Heating at 1200°C; quenching 1000°C/ air; quenching 660°C/ salt / 120s; quenching 258°C/ salt / 21600s	628±29	0.312	1.77
S600_6	Heating at 1200°C; quenching 1000°C/ air; quenching 660°C/ salt /720s; quenching 258°C/ salt /21600s	664±24	0.368	2.11
V10_1	Heating at 1020°C; quenching 20°C/ air	845±34	0.889	24.4
V10_2	Heating at 1020°C; quenching 20°C/ air; tempering at 500°C/ air /2×7200s	860±21	0.943	22.7
V10_3	Heating at 1020°C; quenching 320°C/ salt /3600s; quenching 20°C/ air	887±90	0.829	25.9
V10_4	Heating at 1020°C; quenching 320°C/ salt /9000s; quenching 20°C/ air	822±47	0.801	6.89
V4E_1	Heating at 1020°C; quenching /20°C/ air; tempering at 525°C/ air /2×7200s	840±7	0.323	8.5
V4E_2	Heating at 1020°C; quenching 750°C/ air /600s; quenching 20°C/ air; tempering at 525°C/ air /2×7200s	797±28	0.255	9.8
V4E_3	Heating at 1020°C; quenching 300°C/ salt /9000s; quenching 20°C/ air	640±5	0.276	4.87
V4E_4	Heating at 1020°C; quenching 300°C/ salt /3600s; quenching 20°C/ air	713±17	0.278	6.89
V40_1	Heating at 1020°C; quenching 20°C/ air; tempering at 560°C/ air /3×3600s	724±15	0.547	28.3
V40_2	Heating at 1020°C; quenching 750°C/ air /600s; quenching 20°C/ air; tempering at 560°C/ air /3×1h	693±13	0.339	17.4
V40_3	Heating at 1020°C; quenching 300°C/ salt /9000s; quenching 20°C/ air; tempering at 560°C/ air /3900s	924±26	0.323	17.8
V40_4	Heating at 1020°C; quenching 300°C/ salt /3600s; quenching 20°C/ air; tempering at 560°C/ air /3600s	963±12	0.428	24.2

temperatures and times of heat treatment. The largest sizes of carbides were found in the sample V10_2. Sample V4E_2 showed the smallest size of carbides. The highest carbide ratio was found in the sample V40_1, the lowest carbide ratio was found in the sample S600_1.

The results of microstructure analyses (Figs. 1–4) showed that the heat treatments were correct according to the assumed microstructure of the TTT steel diagrams. The matrix consists of martensite (samples: S600_1, S600_2, S600_3, S600_4, V10_1, V10_2, V40_1, V40_2, V4E_1), martensite and bainite (samples: S600_5, S600_6, V10_3, V40_4, V40_3, V4E_3, V4E_4) or bainite and retained austenite (sample V10_4). The fundamental hard phases were analyzed by EDS, the chemical compositions of carbide and carbonitrides are presented in Table 3. The type of carbide was compared with the classification given in Sobotova et al. (2016). The EDS analysis has shown chemical homogeneity of the alloying elements in the steel samples (Fig. 5). The results showed that the alloying elements were in hard phases and the matrix contained a low amount of these elements.

Table 3. Chemical composition of carbides and carbonitrides in the tested steels (numbers of measuring are in accordance with Figs. 1–4, atm. %)

Mat	Co	**C**	**V**	**CR**	**Mo**	**W**	**N**	**Fe**	**type**
S600	1	13.84	5.44	42.41	-	-	-	rest.	M_7C_3
V40	1	40.81	3.09	3.61	8.26	5.9	-	rest.	M_6C
	2	24.45	12.56	2.53	0.51	0.21	28.05	rest.	M (N,C)
	3	26.08	14.62	3.46	0.67	0.44	27.04	rest.	M (N,C)
V10	1	29.97	5.54	5.54	0.46	-	-	rest.	MC
	2	23.89	4.11	5.22	0.38	-	-	rest.	MC
	3	31.35	21.84	6	1.21	-	-	rest.	M_6C_5
V4E	1	52.27	5.69	2.89	2.21	-	-	rest.	M_7C_3
	2	47.53	12.02	3.44	3.59	0.11	-	rest.	MC

Table 4. Results of one way ANOVA for the tested materials (variables carbide size and carbide ratio in microstructure)

	Variables	SS	DF	MS	Fk	P - value
Bohler S 600 (M1)	Carbide ratio	12.5	1	12.5	9.12	0.0166
	Error	11.0	8	1.37		
	Sum	23.5	9			
	Median	33.3	1	33.3	26.6	< 0.001
	All chosen	10.0	8	1.25		
	Total	43.3	9			
Vanadis 10 (M2)	Carbide ratio	360	1	360	6.89	0.0585
	Error	209	4	52.4		
	Sum	570	5			
	Median	6.88	1	6.88	13.7	0.0208
	All chosen	2.01	4	0.503		
	Total	8.90	5			
Vanadis 4 EXTRA (M2)	Carbide ratio	26.5	1	26.5	7.33	0.0537
	Error	14.5	4	3.61		
	Sum	40.9	5			
	Median	11.2	1	11.2	22.4	0.00911
	All chosen	2.00	4	0.500		
	Total	13.2	5			
Vancron 40 (M3)	Carbide ratio	425	1	425	55.5	0.00173
	Error	30.6	4	7.67		
	Sum	456	5			
	Median	10.4	1	10.4	20.8	0.0103
	All chosen	2.01	4	0.502		
	total	12.4	5			

The carbide size and carbide ratio were evaluated using one way ANOVA statistical analysis (Table 4). Table 4 shows that the heat treatment affected the carbide size in all materials. The carbide ratio, according to this analysis, was only influenced at some selected materials including Böhler S600 and Vancron 40. Heat treatment of the materials Vanadis 4extra and Vanadis 10 did not affect the carbide size and carbide ratio.

The effect of the heat treatment type on the hardness, carbide size, and carbide ratio was compared with the CCT diagrams. To arrange these diagrams, a different algorithm had to be developed for each type of heat treatment (Table 5). In the Materials (Mat) column the materials were divided into groups according to their chemical composition (co): mat 1 contains higher amount of W (hereinafter referred to as M1 – mate-

Table 5. Experimental design of the steel testing with variable levels of heat treatment

Material	Mat	1	2	3	4
S600_1	M1	N	N	N	Y
S600_2	M1	N	N	N	Y
S600_3	M1	Y	S	S	N
S600_4	M1	Y	L	S	N
S600_5	M1	Y	S	L	N
S600_6	M1	Y	L	L	N
V4E_1	M2	N	N	N	Y
V4E_2	M2	Y	L	N	Y
V4E_3	M2	N	N	L	N
V4E_4	M2	N	N	S	N
V10_1	M2	N	N	N	N
V10_2	M2	N	N	N	Y
V10_3	M2	N	N	S	N
V10_4	M2	N	N	L	N
V40_1	M3	N	N	N	Y
V40_2	M3	Y	L	N	Y
V40_3	M3	N	N	L	Y
V40_4	M3	N	N	S	Y

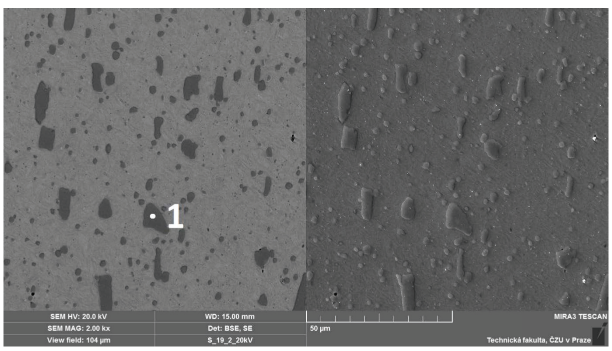

Fig. 1. Microstructure of S600 steel, SE and BSE mode of electron microscopy

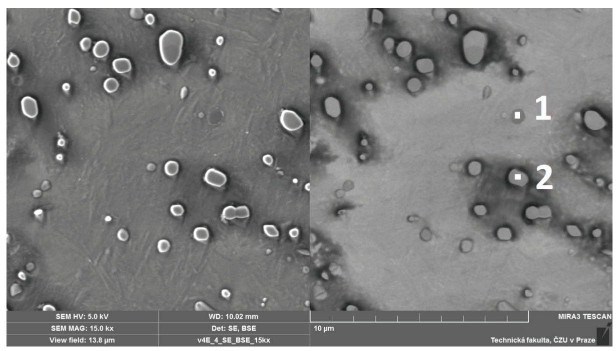

Fig. 2. Microstructure of V4E_4 sample, SE and BSE mode of electron microscopy, carbides in martensitic matrix

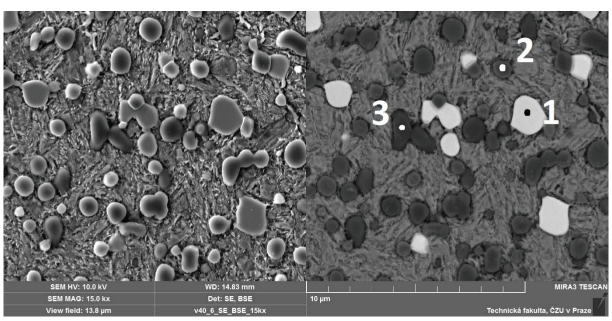

Fig. 3. Microstructure of V40_4 sample, SE and BSE mode of electron microscopy, carbides and carbonitrides in bainitic and martensitic matrix

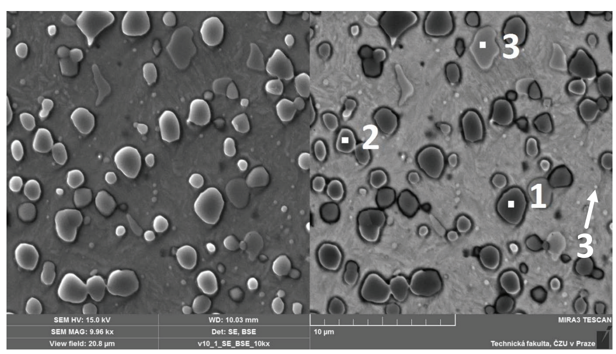

Fig. 4. Microstructure of V10_1 sample, SE and BSE mode of electron microscopy, carbides in martensitic matrix with a small amount of retained austenite around carbides (detected by EBSD)

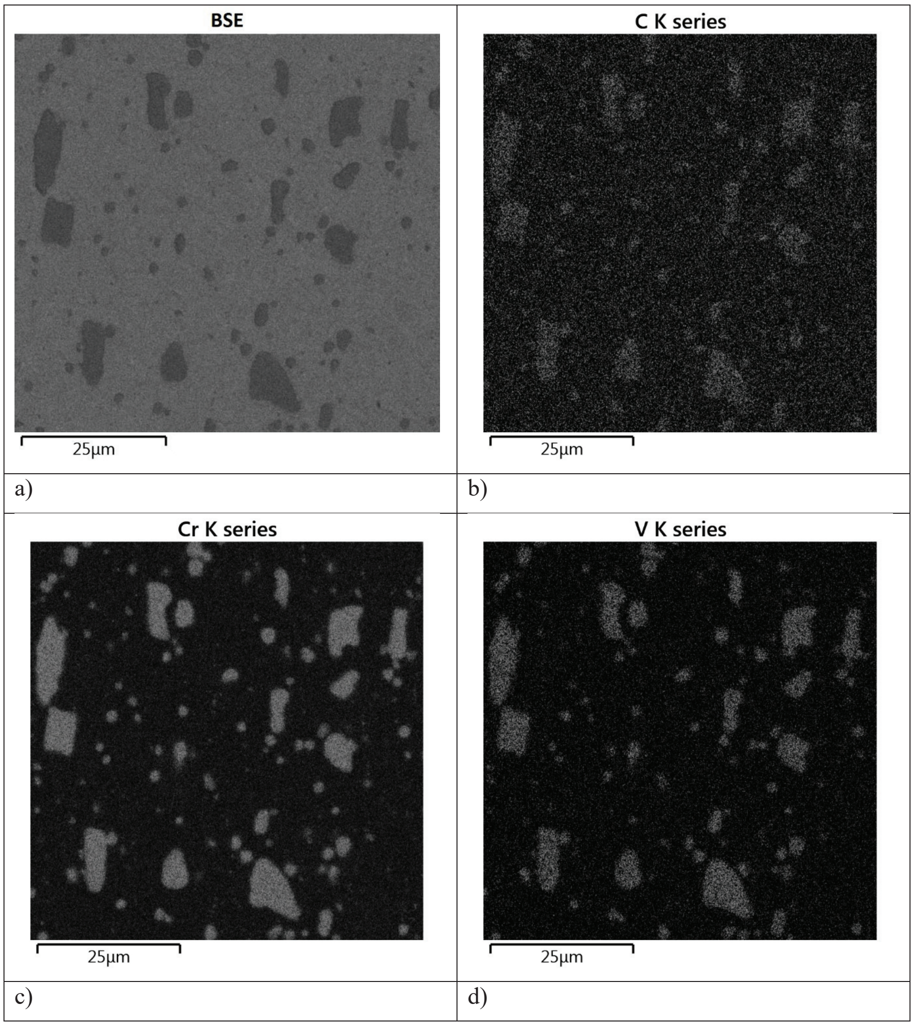

Fig. 5. Chemical homogenity of S600 steel (sample S600_3), a) BSE mode, b-d) true maps of EDS C, Cr and V element in microstructure

rial Böhler S600); mat 2 has a higher content of V (M2 – materials Vanadis 4extra and Vanadis 10); mat 3 has a higher content of V and W (M3 – material Vancron 40). In Table 5 the variables Yes (Y) and No (N) were assigned for each of the individual materials. In the cases when the material is processed it is assigned as (S) for short time or (L) for long time of the heat treatment in salt bath. These variables characterize the different types of heat treatment. Column 1 indicates whether the material was processed (Yes) or not (No) at a temperature of 750°C or 660°C. Column 2 indicates the material secondary treatment in salt bath 1, the column is assigned by No if the material was not secondarily treated, or S for a short-time or L for a long-time treatment. Column 3 (variable 3) indicates the material secondary treatment in salt bath 2 (Yes/No), S stands for a short-time or L for a long-time treatment. Column 4 indicates whether the material was tempered (Yes/No).

Diagrams created on the basis of Table 2 show the effect of heat treatment on hardness, carbide size, and carbide ratio. Samples heat-treated in salt bath at higher temperatures (750°C or 660°C) were compared to samples that were not heat-treated in salt bath, this treatment significantly influenced hardness of the material Vanadis V40, which showed a decreasing trend in hardness by 200HV (Fig. 6), reducing carbide ratio by about 5% (Fig. 7), and carbide size up to 0.1 μm^2 (Fig. 8). For the material Böhler S600, a lowering trend for hardness up to 180HV was measured and carbide size showed by approximately 0.1 μm^2 lower trend, but the carbide ratio increased by about 1%. Hardness at the Vanadis 4extra and Vanadis 10 was ambiguous – the difference in hardness was very small, the carbide ratio declined by 8%, and the measured carbide size was by ca. 0.4 μm^2 smaller.

The largest difference in hardness was measured by the material Vancron 40 which was heat-treated in salt bath at 300°C. Values of hardness were compared with the heat treatment without salt bath. Within a short time of heat treatment higher hardness (about 250HV) was obtained (Fig. 9). The ratio of carbides increased by about 1% (Fig. 10). The change of the carbide size has not been established (Fig. 11). Hardness was the highest (about 200HV) in the case of long-time heat treatment. The carbide ratio was lower by about 4%. The size of carbides decreased by about 0.1 μm^2. The materials Böhler

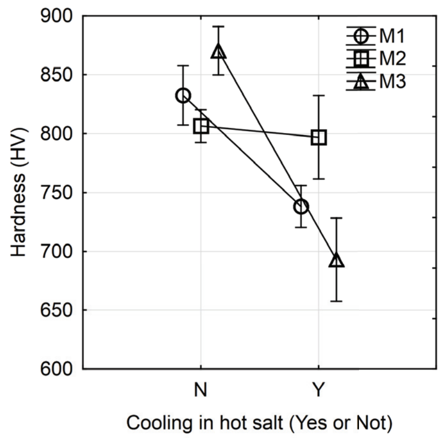

Fig. 6. Effect of hot salt bath (variable 1) on hardness of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

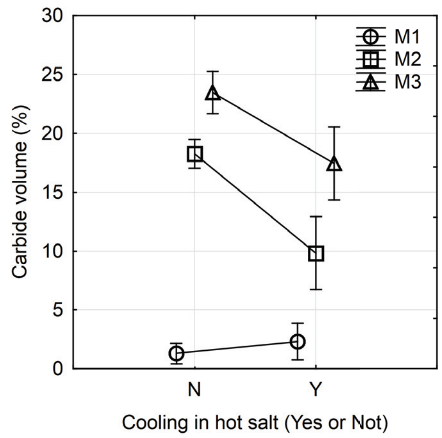

Fig. 7. Effect of hot salt bath (variable 1) on carbide volume of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

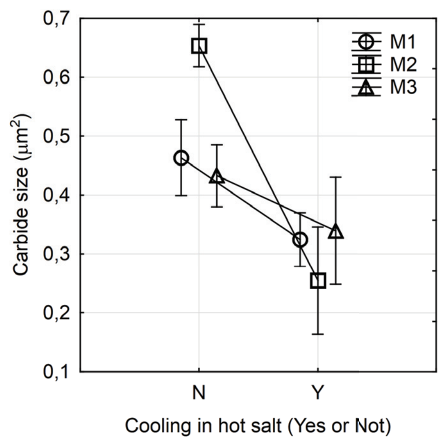

Fig. 8. Effect of hot salt bath (variable 1) on carbide size of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

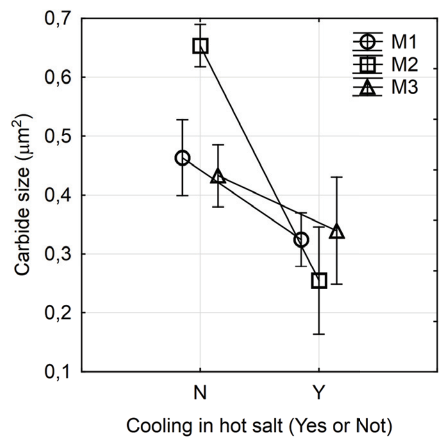

Fig. 9. Effect of cold salt (variable 2) on hardness of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

S600, Vanadis 4extra, and Vanadis 10 showed the same hardness despite they were heat-treated for a short time in salt bath or not. Hardness of the materials Böhler S600, Vanadis 4extra, and Vanadis 10 (830HV) decreased by about 120HV which was more than at the material Vancron 40 that was not heat-treated in salt bath (710HV). A short-time heat treatment of the material Böhler S600 in salt bath did not significantly affect the carbide ratio and carbide size decreased by about 0.1 μm^2. Long-time heat treatment significantly decreased hardness by about 150HV in salt bath, the carbide ratio was not significantly affected. The size of carbides dropped to about 0.1 μm^2. Material hardness of Vanadis 4extra and Vanadis 10 during the short-time heat treatment decreased by about 30HV in salt bath and during the long-time heat treatment by about 130HV in salt bath. The carbide ratio or carbide size were not significantly affected.

Hardness of materials Böhler S600, Vanadis 4extra, and Vanadis 10 was lower in comparison with the not tempered material. The material Böhler S600 showed up to 90HV lower hardness (Fig. 12). The carbide ratio increased by 6% (Fig. 13). The carbide size increased by about 0.2 μm^2 (Fig. 14). Hardness of the materials Vanadis 4extra and Vanadis 10 decreased by about 30HV, carbide size by about 0.1 μm^2. The carbide ratio was not significantly affected. The material Vancron 40 was always tempered. For this reason, in Figs. 7–9 its comparisons with non-tempered materials are omitted. Carbide sizes in the materials Böhler S600, Vanadis 4extra, and Vanadis 10 differred among the tempered and non-tempered samples. Tempering of the material Böhler S600 significantly increased

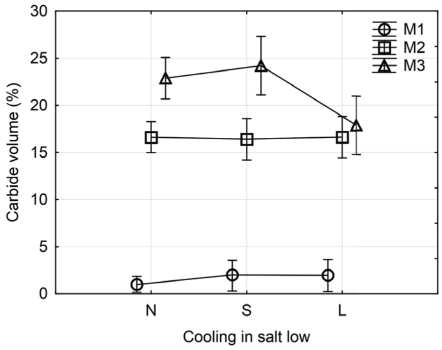

Fig. 10. Effect of cold salt (variable 2) on carbide volume of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

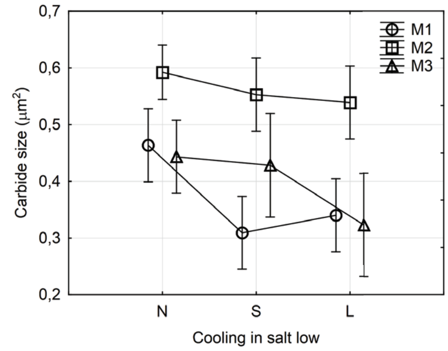

Fig.11. Effect of cold salt (variable 2) bath on carbide size of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

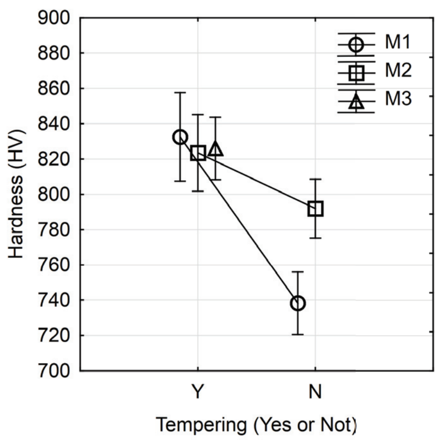

Fig. 12. Effect of temepering (variable 3) on hardness of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

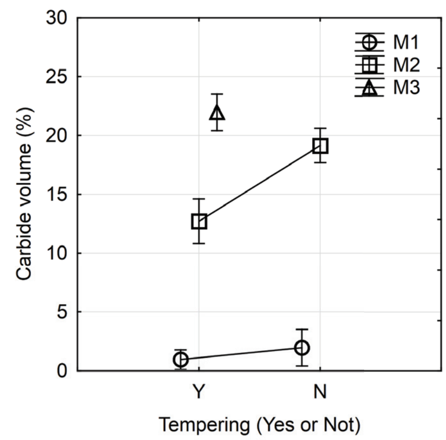

Fig. 13. Effect of tempering (variable 3) on hardness of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

the carbide ratio, while it decreased the carbide size in the materials Vanadis 4extra and Vanadis 10 despite the fact that the carbide ratio hardness was the same for those materials.

DISCUSSION

Torkamani et al. (2011) indicated two ways in which tempering affects hardness. The first is recovery (hardness reduction) and the second is the formation of secondary carbide phase (hardness increase).

In the present research tempering decreased hardness while the carbide ratio increased for Vanadis 4extra and Vanadis 10 but the difference of carbide ratio was ambiguous in Böhler S600 suggesting that during the tempering process the growth of carbides proceeded.

Yan et al. (2008) reported the results for hardness of Vanadis 4 by tempering in air at 500°C (789HV) and 550°C (567HV) for 2 × 2 h. The results showed that the difference of 50°C had a significant effect on hardness. Material Vanadis 4extra in this work was tempered in air at 525°C for 2 × 2 h and hardness was 797 ± 28HV. Hardness was the same during tempering at 500°C. It is necessary to respect the carbide size and carbide ratio and the alloying elements that can affect final hardness.

Arslan et al. (2011) studied the effect of supercooling of Vanadis 4PM, which has the same chemical composition as Vanadis 4extra. In his work, he compared two samples: the first sample was only hardened with heating 30 min at quenching temperature. The second sample was further cooled after hardening at –196°C for 30 min and then tempered at 525°C air for 30 min (Jurči et al., 2015a, b). After this, hardness of 785HV was measured. The results show hardness of 797 ± 28HV with samples austempered at 10 min at 750°C and subsequent double tempering at 525°C.

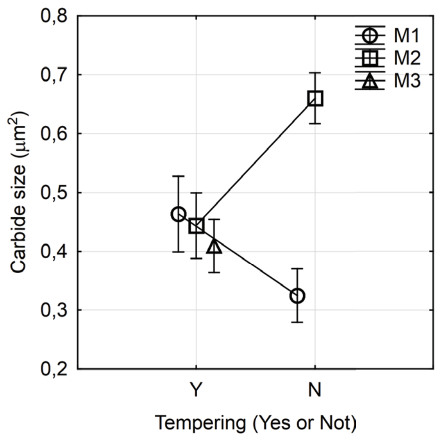

Fig. 14. Effect of tempering (variable 3) on carbide size of tested steels; M1 is Böhler S600, M2 are Vanadis 4extra and Vanadis 10, M3 is Vancron 40

Hardness in this case is identical, however, different resistance to wear can be expected; however, this is not within the scope of this study. The sample in this study was tempered in air at 525°C for 2 × 2 h, but was not sub-cooled, and the result showed hardness of 840 ± 7HV. The difference in hardness was more expressive; however it might be affected by different tempering durations.

The effects of heat treatment on the hardness of Vancron 40 and Vanadis 10 were presented by H a t a m i et al. (2010). Vancron 40 was thrice tempered in air for 1 h at 560°C. H a t a m i et al. (2010) presented hardness of 748HV but in this study hardness of 724 ± 15HV was measured. H a t a m i et al. (2010) measured hardness of Vanadis 10 tempered in air for 2 × 2 h at 525°C as 748HV. The value of hardness was similar to that for Vancron 40 which was determined as 860 ± 21HV in the present study. For both materials, the results are different. For the material Vancron 40 deviations at the upper limit up to 9HV were measured. This difference is not significant. However, a significant difference was found for the material Vanadis10 where the lower limit of measurement deviation was observed (91HV). Furthermore, H a t a m i et al. (2010) showed that during heat treatment different types of carbides are formed. For Vanadis 10 and Vanadis 4extra, two types of carbide are precipitated – vanadium carbide type M_6C_5 and manganese-chromium rich carbide type M_7C_3. For the material Vancron 40 also two types of carbide arise – carbonitride and carbonitrides VN which is rich in tungsten and molybdenum M_6C. The tungsten rich and molydenum rich carbides are formed in the material Böhler S600 during heat treatment along with the MC type carbides. After heat treatment each type of carbide reaches different hardness. From the viewpoint of heat treatment, it was found out that in the materials Böhler S600 and Vancron 40 during processing in hot salts hardness as well as carbides size and carbide ratio decrease, while untreating in hot salts leads to opposite results. The hardness decrease in the materials Vanadis 4extra and Vanadis 10 is not significant. Hardness, carbide ratio and carbide size increased slightly for Vancron 40, which heat treated in cold salt baths when compared to the untreated condition. However, these results were not significant. With the heat treatment duration, the hardness, carbide size, and carbide ratio decreased. In terms of hardness the material Vancron 40 acquires the best properties when it is treated in salt bath for a short period.

R i c h a r d s o n (1967) and B a d i s c h, M i t t e r e r (2003) investigated the influence of the size and carbide ratio of abrasives in three steel types of varying structures. Their results showed that the abrasive wear rate is dependent on the wear mechanism and on the particles that act on the material surface. According to the used abrasive the wear resistance is unchanged or increases with increasing carbide size. From this perspective, it is preferable when the size of the carbides remains the same during the heat treatment. Most preferred is isotempering of the materials Vanadis 4extra and Vanadis 10 in salt bath. During processing of the same material in the same way the material hardness significantly decreases. In this study the carbide ratio had no influence on the abrasive wear.

CONCLUSION

Heat treatment of the selected steel materials in salt bath showed different hardness, carbide ratio, and carbides sizes. Based on the present results and their comparison with the results of other studies it can be concluded that (1) in terms of hardness, the most suitable heat-treated material in salt bath for a short time is Vancron 40, over this period there was a slight decrease in hardness; (2) heat treatment of a material always influences the value of hardness. The highest hardness was measured at iso-tempering in salt bath with a short processing time for Vancron 40 material. Conversely, in the materials Böhler S600, Vanadis 4extra, and Vanadis 10 hardness was significantly reduced. Hardness decreased whenever the material was isothermally heat-treated in hot salts; (3) during heat treatment the size of carbides in hot salts decreased whenever the material was treated by iso-tempering in salt bath, the change of carbide ratio and carbide size was not significant. The largest size of carbides was observed in the materials Vanadis 4extra and Vanadis 10; (4) heat treatment of the materials Vanadis 4extra and Vanadis 10 did not affect the carbide ratio. Significant changes of the carbide ratio were only observed with heat treatment in hot salts; (5) temperature difference of 50°C during tempering has a significant impact on the resulting hardness value.

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