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EXAMINATION OF THE PROPERTIES AND STRUCTURE OF TOOL STEEL EN 1.2379 DUE TO DIFFERENT HEAT TREATMENTS

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Abstract

The hardness, microstructure and wear behavior of EN 1.2379 cold work tool steel were investigated in different heat treatment condition. In metal forming industry tools can be exposed to very complex and surface demanding conditions, which are the result of different mechanical, thermal, chemical or tribological effects and require well defined properties. The aim of present work was to investigate the properties after conventional treatment, plasma nitriding and cryogenic treatment. The results show that it is an effective way to improve the properties of the tool steels modifying the microstructures and the surface through heat and chemical treatments. Using different heat treatment processes and parameters, the microstructure of a tool steel can be modified and optimized for a selected application.

Keywords*: tool steel, heat treatment, hardness, microstructure, wear behaviour.*

Introduction

Tool steels are used essential for the production of metal parts in various industries. For example, the automotive industry in 2015 had a share of nearly 44% of metal parts on a global scale. Increasing car production in countries such as the US, China, Japan and Germany meant an increased demand for tools of these types [1].

Along with the increase in demand from the automotive industry, the global market for stamping and punching metals is growing at a steady pace. It is expected that the global market for metal forming will grow with an annual growth rate of 3% until 2019. With the increase in the use of metals in various fields such as transport, aerospace, automotive and precision industries the demand for tools for cold forming also increases [2, 3].

Cold work tool steels area special set of steels used for fabricating stamping or forming dies, punches, forming rolls, knives, slitters, shear blades or any other component for shaping a material into a part or component adapted to a definite use. During service , this materials/components are subjected to severe loading conditions, as well as to sliding contact with the parts being shaped, which makes its useful life simultaneously dependent on bulk properties, such as strength and toughness, and surface properties, such as wear and fatigue resistance [4, 5]. By simply improving surfaces microstructure and/or chemical composition , i.e., by locally modifying surface properties, the abrasion wear resistance of steel tools can be improved without scarifying bulk toughness properties.

In order to simultaneously increase strength and toughness properties, cold work steel grades may be alloyed to improve the morphology, size and distribution of the strengthening carbides [6].

Cryogenic treatments were also already used in order to improve the wear resistance and toughness of these steels [7 - 9]. In addition to bulk properties optimization, surface enhancements were also already tested by using hard coatings [10, 11].

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Presence of high carbon and high alloying elements in tool steels lower their characteristic temperatures of martensite start and martensite finish [12]. Therefore conventional hardening treatment of these steels fails to convert considerable amount of austenite into martensite often leading to unacceptable level of retained austenite in the as quenched structure of these steels. The retained austenite is soft and thus adversely affects the desirable properties such as hardness and wear resistance [13]. Moreover, the retained austenite is unstable and transforms into martensite at the service conditions of tool steels. The freshly formed martensite being untampered is very brittle and hence undesirable. Furthermore, transformation of austenite to martensite is associated with approximately 4% volume expansion [14], which leads to dimensional changes and distortion of the components (Fig. 1), even failure in extreme cases [15].

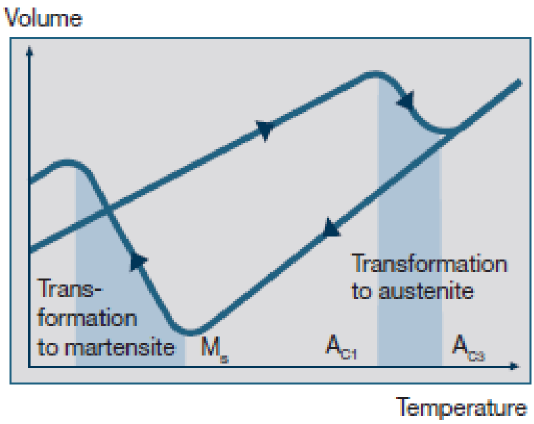


Fig. 1. Volume changes due to structural transformation

Therefore one of the major challenges in the heat treatment of tool steels is to minimize the amount of retained austenite or eliminate it.

In conventional heat treatment, the amount of retained austenite can be reduced by subjecting the hardened steel specimens to multiple tempering cycles at relatively higher temperature (Fig. 2).

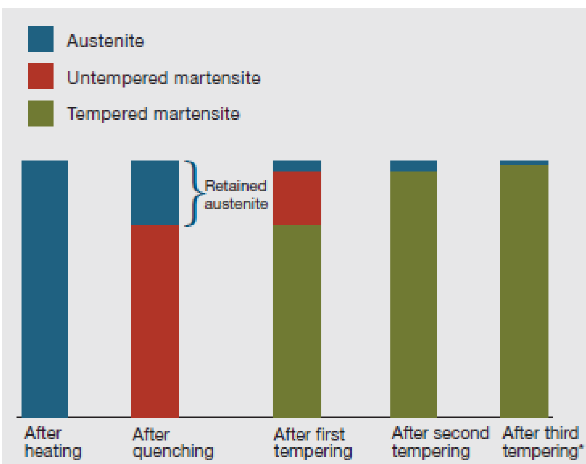


Fig. 2. Evolution on the phase content along the different step of the heat treatment

Alternatively, retained austenite content in tool steel can be reduced substantially by cryogenic treatment [16]. Multiple tempering treatments, cryogenic treatment improves the strength and hardness properties of tool steels.

This study presents the influence of different treatments on the variations of microstructure and hardness and the results regarding wear behaviour and its correlation with the pertinent microstructure and hardness.

Experiments

Materials and treatments

The chemical compositions of the specimens are indicated in Table 1. Each specimens were cut and machined from rolled and soft annealed bars, surface polished to Ra ≈ 0,1µm, and subsequently heat treated in a horizontal vacuum furnace with uniform high pressure gas quenching using N2 at a pressure of 5 bar.

Table 1. Chemical composition of the EN 1.2379 cold work tool steel (mass %)

C	Si	Mn	P	S	Cr	Mo	V
1,57	0,28	0,39	0,02	0,01	11,38	0,82	1,18

Austenizing temperatures and soaking times, cryogenic temperatures and immersion times, tempering temperatures and times, and plasma nitriding temperatures and times are given in Table 2.

Table 2. Vacuum heat treatment, cryogenic treatment tempering treatment and plasma nitriding parameters

Spec.	Austenizing		Cryogenic treatment		Tempering [°C/h]	Plasma nitriding [°C/h]
	Temp.[°C]	Time[min]	Temp.[°C]	Time[h]		
A1	1030	50	-	-	200/2	-
A2	1070	50	-	-	540/2	-
A3	1070	50	-	-	520/540/2	-
A4	1070	50	-	-	520/540/520/2	-
B1	1070	50	-	-	540/2	520/24
B2	1070	50	-	-	520/540/2	520/24
B3	1070	50	-	-	520/540/520/2	520/24
C1	1070	50	-80	2	520/2	-
C2	1070	50	-80	2	520/480/480/2	-

The samples were preheated at the rate of 30 °C/min up to 650 °C and kept at this temperature for 15 minutes, than were preheated with the same heating rate up to 900 °C and kept it for 15 minutes. Then for austenitizing, these samples were heated at the rate of 15 minutes and kept at austenitizing temperature for 50 minutes. After it the sample were quenched in inert gas to 80 °C, respectively (Table 2). After that, seven of the samples (A1, A2, A3, A4, B1, B2, B3) were immediately placed in the furnace under tempering treatment, one of them (A1) at 200 °C, four of them (A3, A4, B2, B3) at 520°C, and two of them (A2, B1) to 540 °C. Each sample was kept at the tempering temperature for 2 hours. The last two samples (C1, C2) were placed under cryogenic treatment at -80°C for two hours and after it were tempered (Table 2). Some of the samples were two (A3, B2) or three (A4, B3, C2) times tempered. Three of the samples after tempering were plasma nitrided (B1, B2, B3). For plasma nitriding the samples were preheated to 480 °C two hours in gas mixture (hydrogen 40 l/h, argon 5 l/h, nitrogen 1 l/h) and after nitriding was cooled to 180 °C 120 l/h hydrogen and 40 l/h nitrogen. Four samples (A1, A2, A3, A4) were conventionally treated. The A3 sample was two times tempered to transfer the untempered martensite into tempered martensite, and sample A4 was three times tempered to reduce the retained austenite (Fig. 2). In the samples treated cryogenically (C1, C2) all retained austenite were transformed into martensite.

Hardness measurement

Rockwell-C hardness (HRc) of differently treated samples was measured using a Rockwell hardness tester. The hardness of the matrix was measured with Vickers hardness HV1 using Buhler 1105 hardness machine. On each sample was determined the average hardness value after measuring at five different points across the surface.

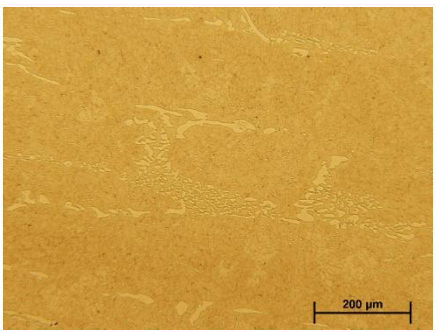
Wear experiment

To perform the wear resistance of de investigated samples ball-on-disc test device was used. The ball of 20 mm diameter was made of Al_2O_3 materials. The samples roughness was Ra ≈ 0,4 µm. All samples were cleaned with ethanol and dried with compressed air before testing. The tests were performed at room temperature (21 ± 1 °C) and relative humidity of 52%. After the wear test the worn surfaces were investigated by optical microscope and analyzed with software (Perthometer Concept Version 6.32-3).

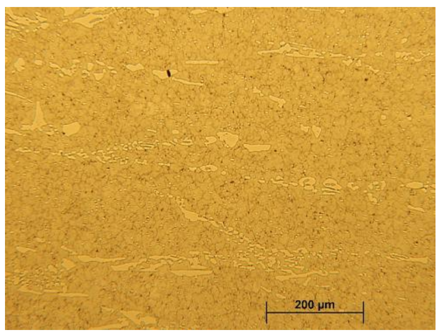
Results and discussion

Microstructure

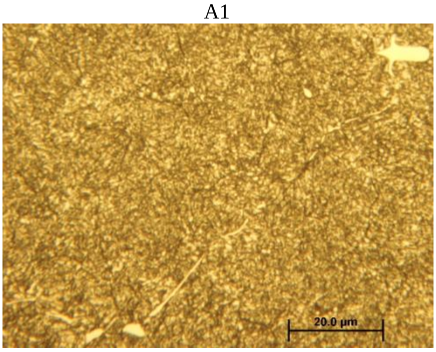
The microstructures of the conventional treated samples are shown in Fig. 3.



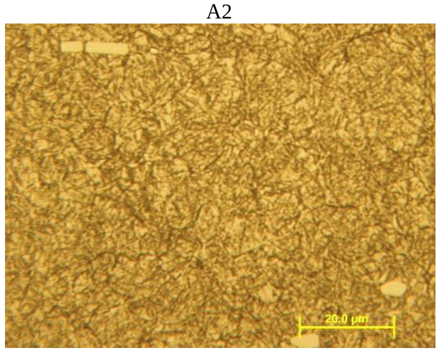
A1



A2



A3

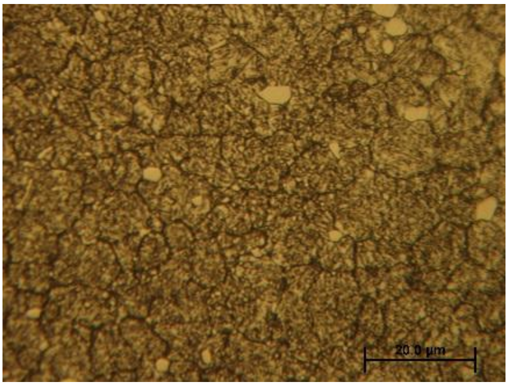


A4

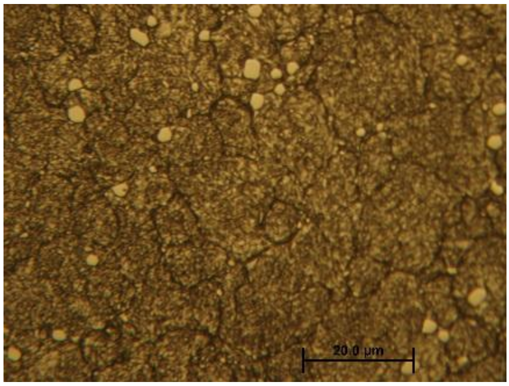
Fig. 3. Microstructures of samples conventional heat treated etched with Nital 2 %

The micrographs of samples A1 and A2 exhibit non-uniform distribution of primary carbides and undissolved carbide particles. Picture of samples A3 tempered two times present fine secondary carbides and retained austenite in tempered martensitic matrix. Picture of samples A4 (tempered three times) show the retained austenite transformed to martensite.

To perform the wear resistance of de investigated samples ball-on-disc test device was used.



C1



C2

Fig. 4. Microstructures of samples cryogenically treated, etched with Nital 2%

Micrographs on figure 4 represent samples treated cryogenically and tempered one (C1) and three (C2) times. The result is fine microstructure without retained austenite and increased hardness (Table 3).

Table 3. Surface hardness after different treatments

Specimen	A1	A2	A3	A4	B1	B2	C1	C2
HV1	670	732	685	734	993	1044	746	738

The results of hardness measuring are represented on Table 3. Plasma nitriding increased hardening with more than 40%.

Wear resistance

Wear test results for the investigated samples are shown in Table 4.

Table 4. Variations of the wear coefficient of the different heat treated samples

Specimen	A1	A2	A3	A4	B1	B2	C1	C2
K [m3/Nm]	$8,3*10^{-6}$	$6*10^{-6}$	$4,6*10^{-6}$	$9,8*10^{-6}$	$1,8*10^{-5}$	$2,6*10^{-5}$	$1,5*10^{-5}$	$1,2*10^{-5}$

The results of the wear resistance test show the correlation between the wear behavior and the hardness of the investigated samples.

Conclusions

It was observed that the cryogenic treatment and plasma nitrided surface treatment resulted in the increase of hardness and wear behaviour in comparison with conventional heat treatment of the EN 1.2379 cold work tool steel.

Acknowledgement

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