IMPROVING THE CHARACTERISTICS OF THE HIGH SPEED STEEL WNR. 1.3243 BY VACUUM HEAT TREATMENT

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WNR. 1.3243 is defined as high speed steel that must provide high hardness, high red hardness, excellent cutting properties and good toughness for extreme demanding applications. Vacuum furnace heat treatment with controlled atmosphere ensures protection against decarburization and oxidation during heat treatment, simultaneous and perpetual control over all four heat treatment steps: preheating, austenitizing, quenching, and tempering in order to obtain the best properties and microstructure. By using vacuum furnaces with protective atmosphere, the WNR. 1.3243 high speed steel was heat treated by optimizing the process parameters. The entire process execution will be analyzed and described in this paper.

Keywords: high speed steel, vacuum heat treatment, austenitizing, high tempering

1. Introduction

According to the European Standard EN ISO 4957: 1999, high speed steels can be defined as: steels used mainly for machining and for forming processes and which, because of their chemical composition, have the highest high-temperature hardness and temper resistance up to about 600°C. If the alloying concept of a tool steel involves a mixture of more than 7% tungsten, molybdenum and vanadium combined with carbon content bigger than 0.6 %, that steel can be defined as high speed steel. Before the development of heat treating furnaces with controlled atmosphere, T-1 with 18% tungsten was the steel choice for machining. Afterwards molybdenum replaced a considerable percent of tungsten. If continuously exposed to high temperatures, the iron and chromium carbides grow fast and thus the steel becomes soft and brittle. For that reason molybdenum and vanadium are added so that the carbides can reform as secondary carbides, which prove a higher stability at high temperature. High speed steels contain enough carbon so that a hardness of at least 64 HRC can be

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achieved. Hardenability is excellent so that, after subjected to heat treatment, the steel presents uniform hardness from the surface to its center. High speed steels are used for manufacturing cutting tools such as drills, milling cutters, reamers, end mills, broaches taps, hobs and saws. For non-tooling applications such as cam rings and automobile valve inserts, a high speed steel containing molybdenum represents the right material choice because of wear resistance of the steel at high temperature [1].

High speed steel should simultaneously fulfill the demands in terms of red hardness, retention of hardness, compression strength, toughness and wear resistance. Due to the fact that there is a difference between the steel behavior at room temperature and its behavior at elevated temperatures caused by high friction, the high red hardness and the ability to retain this hardness at elevated temperatures are mandatory requirements for high speed steels. Cobalt additions significantly improve the hot hardness and compressive strength. The composition of the matrix and its hardness and also the precipitated M_2C and MC carbides that are responsible for secondary hardness, added to the carbides of the alloying elements, establish the level of the wear resistance proven by the high speed steel [2]. The wear resistance can be improved by increasing the carbon and vanadium content. The ductility and the elastic strength of the steel can be improved by selecting lower austenitizing temperatures [3].

2. The alloying concept of the WNR. 1.3243 steel

WNR 1.3243 represents a cobalt alloyed, tungsten-molybdenum high speed steel defined by high hardness, high red hardness, excellent cutting properties and good toughness. The chemical composition of the steel is presented in Table 1 (impurities as sulphur or phosphorus are not relevant to describe).

Table 1

Chemical composition [%] of WNR. 1.3243 high speed steel (Fe balanced)

C	Si	Mn	Cr	Mo	V	W	Co
0.92	0.38	0.29	4.15	5	1.89	6.38	5.02

In order to fulfill the required properties of a high speed steel, the WNR. 1.3243 steel has an alloying concept which includes different elements with specific properties and characteristics that determine the high quality of this material.

The most important element present in the WNR. 1.3243 steel is *carbon*. Carbon maximizes the hardenability, the wear resistance, the red hardness and the compressive strength and reduces the toughness of the steel. *Silicon* is not a decisive alloying element, but it has a minor influence on carbide morphology. It slightly decreases toughness while enhancing at a small extent the maximum possible tempered hardness. *Manganese* is present in small amount because it brittles the high speed steels structure and increases the risk of cracking during quenching, although it presents a favorable contribution on hardenability and it also has a deoxidizing effect. *Chromium* is one of the carbide forming alloying elements. It increases hardness and wear resistance. Chromium also lowers the critical cooling rate required for the formation of martensite, reduces scaling and oxidation during heat treatment, hence it facilitates this process, but at the same time it has an unfavorable effect on toughness level [4]. A chromium content of 4% is chosen because this value was empirically revealed as the right balance between hardness and toughness. *Molybdenum* forms double carbides with iron and carbon. It has an important positive effect on hardenability by lowering the critical cooling rate, by narrowing the γ-range and by its lower hardening temperature in comparison with tungsten which has a higher melting point, thus a higher hardening temperature is necessary. Molybdenum decreases the temper brittleness and it simultaneously increases the strength and the yield point, therefore the M-type high speed steels have a better toughness than the T-type high speed steels. Because of the slightly lower hot hardness level, the M-type high speed steels are additionally alloyed with tungsten or vanadium [5]. *Vanadium* narrows the γ-range, improves the retention of hardness and refines the primary grain. Due to the fact that vanadium is a strong carbide former, it appreciably increases the wear resistance [6-8]. It also improves the hot hardness, the high temperature strength and the weldability to a smaller extent. *Tungsten* increases the hot hardness and leads to secondary hardening. The wear resistance is significantly improved by the formation of complex carbides of iron, tungsten and carbon [9]. High-temperature strength, retention of hardness, cutting efficiency at high temperatures can be increased by tungsten additions. Tungsten inhibits grain growth and favors the toughness. *Cobalt* does not form carbides, yet it is added in high speed steels for its ability to increase the hot hardness and the compressive strength, although it enhances the brittleness of the steel in small extent [10].

The mixture between the alloying elements represents the right method to obtain the desired properties of the steel by combining the specific characteristics of each element, but the heat treatment process is the finishing step that determines the end properties, the "ready to use" properties. Without a proper heat treatment execution, the high speed steel may not reach its full potential. A "state-of-the-art" heat treatment execution is mandatory in order to reach the best properties of the high speed steel.

3. Heat treatment of WNR. 1.3243 steel in vacuum furnace with protected atmosphere

Incorrect heat treatment applied to the highest quality steel, to the highly alloyed and professionally machined one, can determine the tool or component manufactured by this material to underperform or to fail on accomplishing the required tasks [11].

The steel is supplied in annealed condition, which consists in a ferrite and carbides structure. Through heat treatment it is transformed into a martensitic structure with carbides and non-carbide-forming alloying elements, that should provide the highest level of hardness, hot hardness, compressive strength and wear resistance combined with adequate toughness [12-14].

WNR. 1.3243 steel was provided in annealed condition, having „ as supplied" hardness of 271 HB, after previously being heated through to 800°C, afterwards cooled in the furnace at a speed of 15°C per hour down to 600°C. From that point on the material was slowly air cooled.

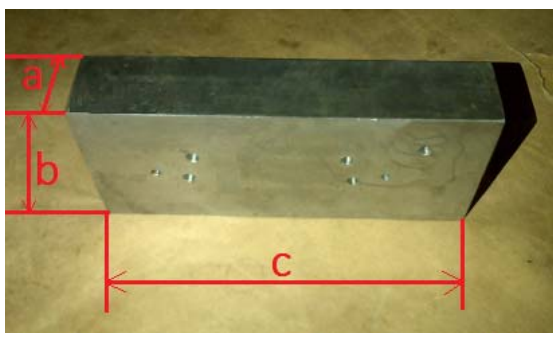

Fig. 1. The dimensions of the workpiece made out of WNR. 1.3243 steel : a – 30 mm, b – 90 mm, c – 170 mm.

The workpiece subjected to further heat treatment and the measured dimensions of this piece are presented in Fig. 1. The weight of the piece was 3.5 Kg after previously being milled, ground and drilled. The required hardness in order to achieve high toughness was selected at the value of 63±1 HRC.

The material was preheated in three prior steps before the final heating, until reaching the austenitizing temperature. The goal of the preheating steps was to reduce thermal shocks, which are created when a cold tool is introduced into a warm or hot furnace, by equalizing the temperature level at the surface of the piece with the temperature level at the center of the piece. Simultaneously the stresses developed during machining are considerably reduced. Reducing thermal shocks and stress relieving leads to fewer risks in terms of cracking or immoderate distortion.

The preheating, austenitizing and quenching steps were executed by using a Rübig® (type VH669 - 6 bar) vacuum furnace as presented in Fig. 2.

Fig. 2. Böhler Uddeholm Romania heat treatment department: Rübig® (type VH669-6 bar) vacuum furnace.

The WNR. 1.3243 steel was first heated until the temperature level of 650°C. At this point the nominal temperature was maintained constant for 45 minutes. The convection fan stopped and convection heating was replaced by radiation heating. After temperature equalization the temperature level was constantly increased up to 850°C where the heating process stopped again for 20 minutes.

When virtually uniform temperature level was reached, the high speed steel was heated up to 1030°C, where the heating was stopped for 15 minutes, so the same purpose as above to be achieved. The heating steps shown in Fig. 3 - curve 1, represent programmed parameters. The differences between the programmed temperature, the ambient temperature and steel temperature are determined by thermocouples located inside the furnace.

From the value of 1030°C the temperature was increased until the austenitizing temperature of 1150°C was reached. The soaking time was set for 10 minutes, but the thermocouple located in the center of the piece recorded a 5 minutes real soaking time, the time difference consisted on effective temperature equalization until the steel was fully heated through.

During austenitizing, the diverse complex carbides of the alloying elements are dissolved into the ferrous matrix. Usually the austenitizing temperature of high speed steel is between 1150°C - 1290°C. The low austenitizing temperature was selected in order to improve the impact toughness at the desired 63±1 HRC hardness. After soaking time, a rapid cooling under over pressurized nitrogen was performed as in Fig. 3. The aim of quenching is to transform the previously formed austenitic structure in to a hard martensitic one.

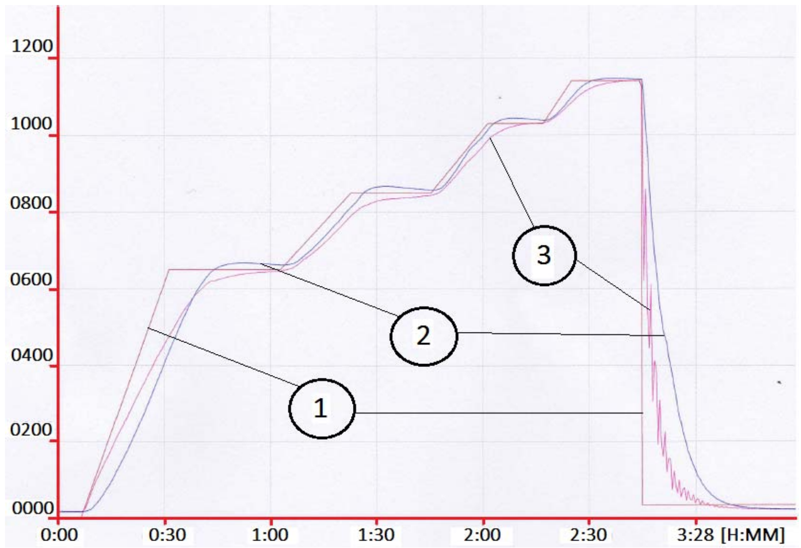

Fig. 3. The heating and quenching process diagram: 1- programmed process temperature [°C], 2- ambient thermocouple temperature [°C] and 3 – center thermocouple temperature [°C].

After austenitizing and quenching, the WNR. 1.3243 steel is in a highly stressed condition, under a lack of stable equilibrum, and it is very prone to cracking. By tempering the stresses are relieved and, additionally, the retained austenite is transformed into an additional amount of martensite. New precipitations of complex carbides take place and the secondary hardening phenomenon occurs, further improving steel properties. Concurrently a tempering process of martensite runs by heating to an intermediate temperature below the critical transformation temperature.

For the presented reasons the steel was relocated into a tempering vacuum furnace IVA Industrieöfen® (type VH669) as shown in Fig. 4. Three similar temperings were performed by heating for 2 hours until the temperature of 550°C, followed by a holding time of 2 hours. After the soaking step of each tempering, a cooling for 2 hours to room temperature was performed. During the execution of all three temperings, the temperature was recorded using three thermocouples positioned in different locations - in the furnace room and in or on the workpiece - as presented in Fig. 5.

Fig. 4. Böhler Uddeholm Romania heat treatment department: IVA Industrieöfen® (type VH669) vacuum furnace.

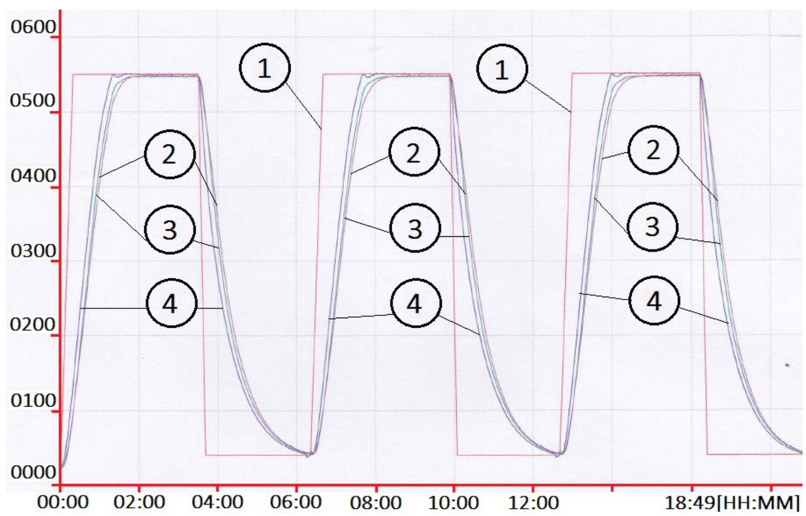

Fig. 5. The three temperings process diagram: 1- programmed process temperature [°C], 2- ambient thermocouple temperature [°C], 3- temperature of the thermocouple located at 1/4 the thickness of the workpiece [°C], 4 – temperature of the thermocouple located at 1/2 the thickness of the workpiece [°C].

A DEMIG® process supervisory technology accompanied the process parameters of the vacuum furnaces as shown in Fig. 6.

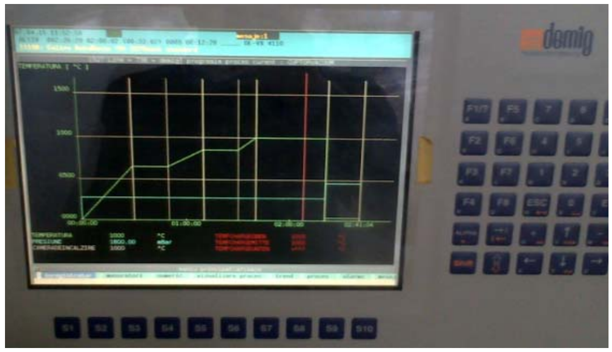

Fig. 6. DEMIG® process supervisory technology.

After the preheating, austenitizing, quenching and triple tempering processes, a hardness of 63±1 HRC could be measured on a Rockwell type hardness tester CV-600A, as presented in Fig. 7.

Fig. 7. Measured hardness on Rockwell type hardness tester CV-600A

The purpose of the execution of the heat treatment process was to obtain, besides the required hardness, the following minimum properties at the temperature of 20°C for a density of 8100 Kg/m^3: compressive strength of 2170 MPa and impact energy of 19 J, thermal conductivity of 19 W/m·K, modulus of elasticity of 217000 MPa, specific heat of 460 J/kg·K.

During the ferrite-to-austenite and austenite-to-martensite transformation, where the crystals shift from body-centered-cubic cells to face-centered-cubic cells and then to tetragonal cells, dimensional changes occur. The applied heat treatment parameters such as soaking time, cooling speed, heating speed, preheating speed or pressure also have an influence on the dimensional stability.

The internal stresses and the structural changes lead to the modified dimensions of the WNR. 1.3243 high speed steel, as presented in Table 2. From startup dimensions, recorded before the heat treatment process was executed, the length suffered a modification of +0.32 mm, the width recorded a shortage of 0.09 mm and the thickness shrunk about 0.05 mm.

Table 2

Dimensions before and after heat treatment process

WNR. 1.3243	Dimensions before heat treatment	Dimensions after heat treatment	Percentage changes
	mm	mm	%
Length (mm)	170	170.32	0.178
Width (mm)	90	89.81	-0.106
Thickness (mm)	30	29.89	-0.061

4. Conclusions

Red hardness, retention of hardness, compression strength, toughness and wear resistance represent critical properties that are mandatory for high speed steel. Alloying the iron matrix with the adequate elements that are responsible for enhancing each individual requested characteristic is the answer for achieving mixed properties. Heat treatment improves the properties of the material for the chosen applications by modifying the microstructure. The newly formed structure provides the technical answer for a specific application as against the annealed structure. For that reason, vacuum heat treatment, under controlled atmosphere, that provides protection against decarburization and oxidation, along with process surveillance and control system, represents the way for optimizing the material properties. WNR 1.3243 is a cobalt alloyed, tungsten-molybdenum high speed steel which needs proper selected heat treatment parameters because of its high alloying concept. In order to mix high wear resistance with the adequate toughness, the hardness of 63±1 HRC, obtained by soaking time at the lower limit of the austenitizing interval, was selected as the optimum solution. The proper method of heat treatment of obtaining these optimized characteristics was executed and described in this paper. Over pressurized nitrogen as quenching environment provided minimum distortion compared with conventional environments as oil or water.

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