ENHANCING THE WORKING PROPERTIES OF THE LEDEBURITIC STEEL AISI D2 BY PROTECTIVE ATMOSPHERE HEAT TREATMENTS IN VACUUM FURNACES

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Ledeburitic steel AISI D2 is frequently used for cold working applications. Different quenching environments may influence the quality of the heat treatment process, by too rapid cooling, too slow cooling or by improper technical means of controlling the actual process parameters. Controlled atmosphere heat treatments in vacuum furnaces represent the way to overpass these drawbacks and to protect the material against decarburization and oxidation during heat treatment. The heating and quenching parameters of this material applied in vacuum furnace with protection atmosphere, combined with high tempering for obtaining optimum properties will be presented in this paper.

Keywords: ledeburitic steel, heat treatment, vacuum, protective atmosphere, high temperature tempering

1. Introduction

Cold working tool steels represent high-quality steels with a specific chemical composition developed to meet the high requirements when working and shaping other materials at a temperature smaller than their recrystallization temperature.

Cold working application such as punching, blanking, cold forming, industrial cutting knives manufacturing and usage require materials with a high level of wear resistance, both adhesive and abrasive, toughness, compressive strength and retention of hardness.

In the case of AISI D2 steel, a high chromium content (more than 11%) along with a high carbon content (above 1.5%), leads to the shifting of the eutectic point to the left at a lower carbon content, phenomenon which determines the appearance of a ledeburitic component in the steel structure, although ledeburite represents a cast iron specific constituent. Ledeburite is a mechanical eutectic

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mixture of austenite and cementite. The main characteristics of this constituent are high hardness and brittleness.

Ledeburitic steels are mainly characterized by high working hardness and very good wear resistance, mainly abrasive (certified by ASTM G65-Rubber wheel test).

Table 1

Chemical composition of AISI D2 steel [%] – (Fe balanced)

C	Si	Mn	P	S	Cr	Mo	Ni	V	W
1.55	0.34	0.29	0.02	0.013	11.36	0.74	0.19	0.87	0.18

Carbon has the strongest influence on steel properties [1]. Hardenability and strength, especially wear resistance both abrasive and adhesive, increase with enlarging the carbon content, yet the forming and the welding properties, the machinability and elongation values are decreased.

Silicon has also a deoxidizing effect and narrows the γ-range. It increases wear resistance, strength and elastic limit.

Manganese has a deoxidizing effect and it lowers the A_{r3} and A_{r1} points while reducing significantly the critical cooling rate with a favorable impact on hardenability. It increases the yield point and strength.

Chromium represents a strong carbide former and its carbides are enhancing the wear resistance and the edge-holding property. Chromium lowers the critical cooling rate necessary for the martensitic formation process, therefore it intensifies the hardenability and it improves the heat treating properties. Simultaneously the impact strength is reduced. By providing a higher chromium content, the steel's high temperature strength is improved. The high pressure hydrogen resistance and the scale formation resistance are enhanced when increasing the chromium content. In order to obtain a corrosion resistant steel a minimum of about 13% chromium dissolved in the matrix is demanded [1].

Molybdenum increases the hardenability by reducing the critical cooling rate. It narrows considerably the γ-range, it reduces the scale formation resistance and it increases high-temperature strength. Molybdenum decreases the temper brittleness and it enhances the yield point and the strength. It is a strong carbide former and thus improves the cutting efficiency. Molybdenum is currently used as alloying element in austenitic CrNi steels and highly alloyed Cr steels for its resistance to corrosion. The susceptibility to pitting is lessened at a higher content of molybdenum [2].

Vanadium enhances the wear resistance, edge-holding property, high-temperature strength and resistance to high-pressure hydrogen, due to the fact that it represents a strong carbide former. It reduces the overheating sensitivity and improves the retention of hardness. Vanadium refines the primary grain and thereby the "as cast" structure. It shifts the Curie point to higher temperatures and narrows the γ-range. Vanadium is used as alloying constituent in high-speed steels, high-temperature steels and hot work tool steels. The welding properties of heat treatable steels are positively influenced by vanadium addition [3].

AISI D2 is characterized by high wear resistance, good through-hardening properties, high compressive strength, good resistance to tempering-back and high stability in hardening.

In order to achieve the best properties of this material, it should be heat treated from the soft annealing condition to hardened and tempered condition using vacuum technology [4]. Therefore the heating, the soaking and the cooling are subjected to continuous supervising and control [5]. Depending on the targeted application, the heat treatment process parameters are selected in order to obtain the main characteristics that should fulfill the required demands [6, 7]. In this case, after heat treatment, the semi-finished block from AISI D2 will be further subjected to electrical discharge machining (EDM) in order to develop a cutting die with a required hardness of 61 ± 1 HRC and improved toughness.

2. Heat treatment of AISI D2 in vacuum furnace with protected atmosphere

The selected AISI D2 material came in annealed condition with 210 HB hardness, after being heat treated at 850°C and then cooled with the furnace with a speed of 10°C per hour down to 650°C. Afterwards it was freely cooled in air.

The cutoff piece having the dimensions 120 x 150 x 180 mm (thickness-width-length) was heat treated as presented in Fig. 1 and Fig. 2, before being sent to the final electrical discharge machining process in order to develop the final design of the tool.

The AISI D2 was heated constantly up to 650°C where the heating process stopped and held at constant temperature for approximately 45 minutes in order for the temperature inside the working piece to equalize. Then the heating restarted up to 850°C, where it stopped again for approximately 30 minutes for the same purpose as above. After reaching 650°C, the convection heat transfer was replaced with radiation heat transfer, up to the end of the heating at 1030°C. The holding time at austenitizing temperature after the tool is fully heated through - the soaking time -, was programmed for approximately 45 minutes and then the workpiece was rapidly cooled by using over pressurized nitrogen as shown in Fig. 1 [8]. The pressure reached the value of 4 bars. The main goals are to avoid the perlitic nose by fast quenching, but also to maintain a certain level of cooling speed in order not to extend the thermal stresses and transformation stresses to a level that can cause the cracking of the workpiece. Dimensional changes are smaller if the cooling rate is not too high.

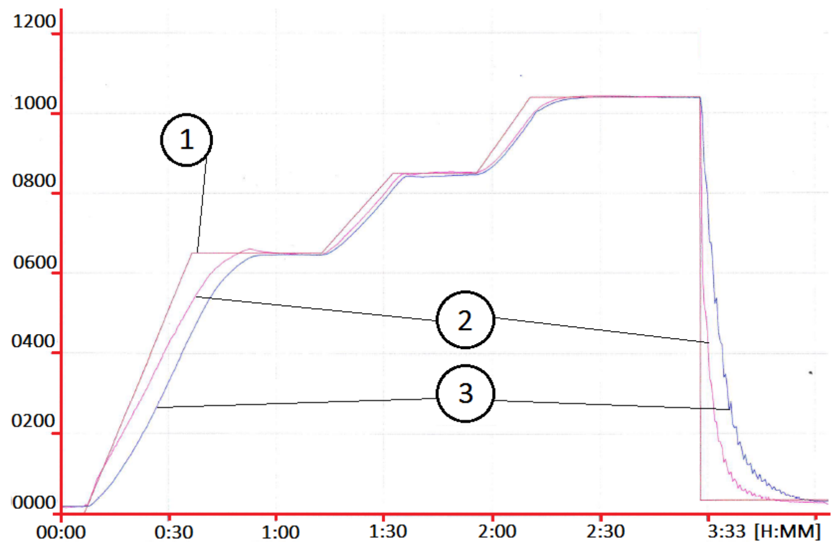

Fig. 1. The heating and quenching process diagram: 1- programmed process temperature [°C], 2- ambience thermocouple temperature [°C], 3 – center thermocouple temperature [°C]

The heating and quenching were executed in a Rübig® (type VH669-10 bar) vacuum furnace. In order to prevent the retained austenite from stabilizing, the AISI D2 was moved into a tempering vacuum furnace IVA Industrieöfen® (type VH669). The process parameters of both furnaces are accompanied by a DEMIG® process supervisory technology.

The first tempering was executed by heating for approximately 2 hours to the temperature of 500°C, followed by a holding time at that temperature of another approximately 2 hours and then by cooling to room temperature. The cooling period was also for 2 hours. The process was repeated again as presented in Fig. 2. Although the tempering could have been executed at a temperature of 180°C minimum, the high temperature tempering was chosen in order for the untempered martensite to transform into tempered martensite, in stress relieving conditions, and also to reduce significantly the retained austenite volume. Furthermore, during tempering the phenomenon of secondary hardness occurs because of newly formed precipitated complex carbides [9].

After heating, quenching and double tempering the hardness of 61 to 62 HRC was achieved and measured on a Rockwell type hardness tester CV-600A. Fig. 3 shows the total of 9 random points that were selected for measurement. The hardness is strictly related to impact strength and it is very important to reach equilibrium between these two properties. For that reason a lower austenitizing temperature was preferred in disfavor of the extreme austenitizing temperature specified in the time-temperature-transformation diagram of the ledeburitic steel AISI D2 [10].

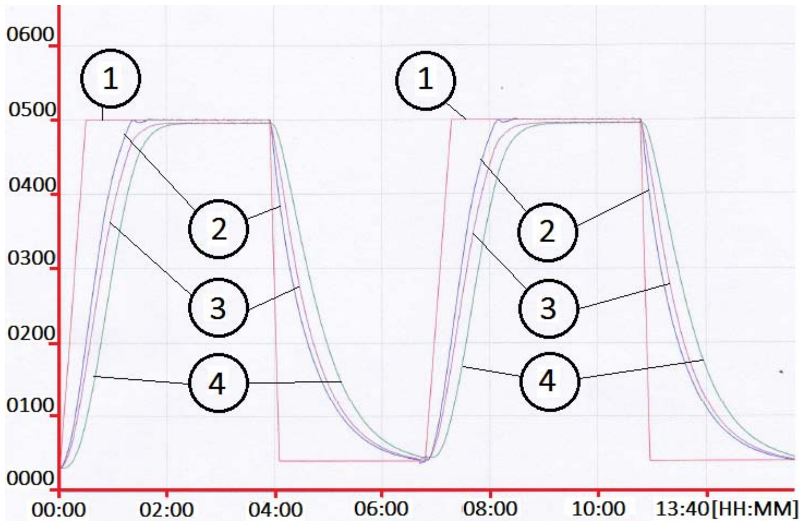

Fig. 2. The two temperings process diagram: 1- programmed process temperature [°C], 2- ambience thermocouple temperature [°C], 3- temperature of the thermocouple located at approximately 1/4 the thickness of the workpiece [°C], 4 – temperature of the thermocouple located at approximately 1/2 the thickness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

Fig. 3. Measured hardness on Rockwell type hardness tester CV-600A

The heat treatment process was executed in order to obtain the following properties at the temperature of 20°C: density = 7700 Kg/m^3, thermal conductivity

= 20 W/m·K, elasticity modulus = 210,000 MPa, specific heat = 460 J/kg·K, compressive strength = 2,100 MPa, and impact energy = 12 J.

The dimensional stability during heat treatment reaches different values in accordance to the applied heat treatment parameters, such as pressure, heating speed, cooling speed, soaking time, temperatures etc. [11, 12].

During heating, soaking and quenching processes, the transformation of ferrite to austenite and subsequently to martensite leads to significant microstructural changes. The first passage from a body centered cubic crystal structure to a face centered cubic one, followed by a second transformation from face centered cubic to body centered tetragonal crystal structure are resulting in dimensional changes.

During tempering, all the desired processes such as the modifications in residual austenite content, the precipitation of newly formed carbides, the martensite tempering represent important factors that also produce changes in the material's structure.

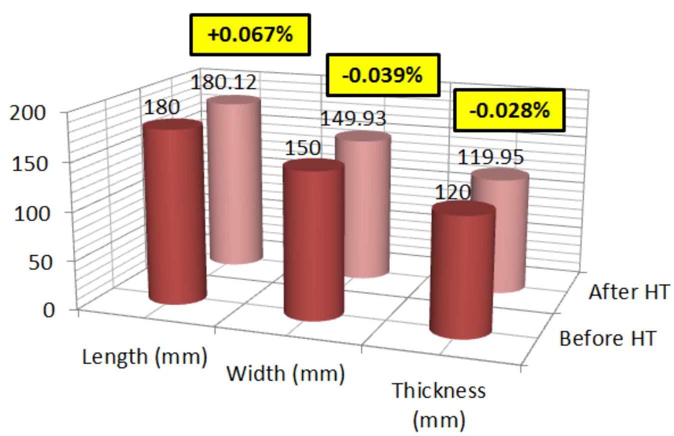

Fig. 4. Measured dimensional changes during the heat treatment process

After heat treatment, the dimensions of the AISI D2 ledeburitic steel were measured and compared to the startup dimensions, recorded before the heat treatment process was executed. The length suffered a modification of +0.12 mm, which represents a size increase to the value of 180.12 mm. The width recorded a shortage of 0.07 mm, reaching the value of 149.93 mm. The material also recorded a modification in thickness of -0.05 mm. The percentage changes are presented in Fig. 4.

The sum of all these dimensional changes that occur during a complete heat treatment cycle was taken into consideration by the presence of a material surplus of 2 mm on each side on the specimen, material that will be subjected to further grinding after completing the last tempering. After grinding the final dimensions were 118 x 148 x 178 mm.

4. Conclusions

Quality heat treatment delivers not only desired hardness but also enhances the properties of the material for chosen applications. By the assured protection against decarburization and oxidation during vacuum heat treatment under controlled atmosphere, together with process controlling and surveillance using protected thermocouples and advanced supervisory technology, there can be achieved a state-of-the-art material properties optimization. Using over - pressurized nitrogen as quenching environment ensures the reduction of distortions occurrence during fast cooling in comparison with conventional environments as oil or water. Less distortions lead to smaller grinding allowances, to smaller quantities of removed material after grinding and, of course, to a more cost efficient project, by saving resources.

Heat treating the ledeburitic cold work steel AISI D2 in vacuum furnace, with protective atmosphere, and using high tempering, ensures a viable alternative to conventional methods that involves water or oil quenching, by combining high hardness and abrasive wear resistance with toughness, a characteristic which usually is limited regarding ledeburitic cold work steels.

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R E F E R E N C E S

[1]. *BÖHLER Edelstahl Gmbh*, Alloying Elements of Special Steels, in: BÖHLER-Special Steel Manual, Kapfenberg, Jan. 2006, pp. 442-447.

[2]. *R. Narayanasamya, V. Anandakrishnana, K.S. Pandeyb*, “Effect of molybdenum addition on workability of powder metallurgy steels during cold upsetting”, in Materials Science and Engineering: A, **vol. 517**, Issues 1–2, Aug. 2009, pp. 30-36.

[3]. *T. Wen, X. Hu, Y. Song, D. Yan, L. Rong*, “Carbides and mechanical properties in a Fe–Cr–Ni–Mo high-strength steel with different V contents”, in Materials Science and Engineering: A, **vol. 588**, Dec. 2013, pp. 201-207.

[4] *A. Tiziani, A. Molinari*, “Improvement of AISI D2 steel properties by unconventional vacuum heat treatments”, in Materials Science and Engineering: A, **vol. 101**, May 1988, pp. 125-133.

[5] *B. Zieger*, “Vacuum heat treatment of hot work steel”, in 6th International Tooling Conference, Karlstad University, **vol. 1**, Sept. 2002, pp.643-655.

[6] *M. Pellizzari, A. Molinari*, The Application-Oriented Heat Treatment of Tool Steels, Materials and Manufacturing Process, **vol. 24**, n. 7-8, May 2009, pp. 723-728.
[7] *L. Bourithis, G.D. Papadimitriou, J. Sideris,* "Comparison of wear properties of tool steels AISI D2 and O1 with the same hardness", in Tribology International , **vol. 39** , Oct. 2006, pp 479-489.
[8] *T. Nykiel, T. Hryniewicz*, "Effect of Austenitizing Parameters on the Change of Concentration of Alloying Components and Phase Structure of Tool Steel of Type 2%C and 12%Cr with Additives of W, Mo, V", in Proceedings of the 11th Congress of the International Federation for Heat Treatment and Surface Engineering, **vol. 116**, Oct. 1998, , pp 87–96.
[9] *P. da Silva Farina, A. Farina; C. Barbosa, H. Goldenstein*, "Effects of cryogenic and stress relief treatments on temper carbide precipitation in AISI D2 tool steel", in International Heat Treatment and Surface Engineering, **vol. 7**, Issue 3, Sept 2013, pp. 120-124.
[10] Information on http://bohler-edelstahl.com/english/files/K110DE.pdf .
[11] *C. Surberg, P. Stratton, K. Lingenhöle*, "The effect of some heat treatment parameters on the dimensional stability of AISI D2", in Cryogenics, **vol. 48**, Issues 1–2, Feb. 2008, pp 42-47.
[12] *S. Al-Qawabah, K. Rababa, A. Awad*, "The Effect of Austenite Temperature on the Microstructure, Mechanical Behavior, Hardness, and Impact Toughness of AISI D2 Tool Steel", in International Journal of Engineering Research and Applications, **vol. 2**, May 2012, pp.2890-2896.