UDK 669.14.018.252:621.785
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 45(5)489(2011)

EVALUATION OF THE MICROSTRUCTURAL CHANGES IN Cr-V LEDEBURITIC TOOL STEELS DEPENDING ON THE AUSTENITIZATION TEMPERATURE

OCENA SPREMEMB MIKROSTRUKTURE V LEDEBURITNEMN ORODNEM JEKLU Cr-V V ODVISNOSTI OD TEMPERATURE AVSTENITIZACIJE

Pavel Bílek, Jana Sobotová, Peter Jurči

Czech Technical University in Prague, Faculty of Mechanical Engineering, Karlovo nám. 13, Prague 2, CZ 121 35, Czech Republic
pavel.bilek@fs.cvut.cz

Prejem rokopisa – received: 2010-11-29; sprejem za objavo – accepted for publication: 2011-04-14

Samples of Vanadis 6 PM Cr-V ledeburitic steel were austenitized at temperatures in the range 1000–1200 °C and oil-quenched. The structural changes were investigated by scanning electron microscope and evaluated using NIS Elements software. The obtained results indicated that the M_7C_3-carbides underwent intensive dissolution in austenite and were not detected above a temperature of 1100 °C. On the other hand, the MC-carbides remained almost completely unaffected and symptoms of dissolution were found only at a temperature of 1200 °C. The saturation of austenite by carbon, chromium and partly vanadium increased the hardness of the as-quenched material, with the maximum at an austenitizing temperature of 1025 °C.

Key words: Cr-V ledeburitic steels, Vanadis 6, MC carbides, M_7C_3 carbides, temperature of austenitization.

Vzorci ledeburitnega jekla Cr-V Vanadis 6 PM so bili avstenitizirani v temperaturnem območju 1000–1200 °C in kaljeni v olju. Spremembe mikrostrukture so bile raziskane z vrstičnim elektronskim mikroskopom in ocenjene z uporabo NIS-elementnega softvera. Rezultati kažejo, da so se karbidni M7C3 hitro raztapljali v avstenitu in jih ni bilo opaziti nad temperaturo 1100 °C. Po drugi strani so VC-karbidi ostali nespremenjeni, a simptome raztapljanja smo opazili le pri temperaturi 1200 °C. Nasičenje avstenita z ogljikom, kromom in delno vanadijem je povečalo trdoto kaljenega materiala z maksimumom pri temperaturi 1025 °C.

Ključne besede: ledeburitno jeklo Cr-V, Vanadis 6, MC-karbidi, M7C3-karbidi, temperatura avstenitizacije

1 INTRODUCTION

The group of Cr-V ledeburitic steels is widely used in various industrial processes and operations. To meet the industrial requirements for high production stability and reliability, they have to withstand wear and plastic deformation. On the other hand, the steels should be resistant to micro- and macro-cracking, e.g., their toughness and fracture toughness must be as high as possible.[1,2]

The main alloying element of Cr-V ledeburitic steel is chromium. It forms various types of more or less stable carbides. These carbides are well soluble in austenite, which saturates the solid solution with carbon and the alloying elements. A large amount of alloying elements in austenite makes good though-hardenability of the material.[3]

Vanadium is the second typical element of Cr-V ledeburitic steel. Vanadium has a high affinity for the carbon and forms very stable MC-carbides.[4] Vanadium deteriorates the machinability (as a result of very hard carbides) and the grindability of steels. In tool steels, vanadium is used for the following reasons: improvements of hardenability, formation of very hard carbides, increase of the wear resistance and hot hardness. Due to the small size of the carbide particles and their high thermal stability, the steels containing vanadium are resistant to grain coarsening during austenitizing. It preserves the relatively favourable mechanical properties after the heat treatment.[3]

The structure and properties of ledeburitic steels are determined by the character of the matrix and the type, quantity, size and distribution of the carbides. The properties of tool steels are given by the superposition of the matrix and the carbides. The hardness in the soft-annealed state, for instance, is closely related to the quality and amount of carbides. The matrix composition is not as important, since it consists in any case of ferrite. On the other hand, after austenitizing and quenching, the matrix hardness is the most important factor influencing the hardness of the steels. But, it is impossible to get a sufficient as-quenched matrix hardness without the presence of carbides in the material. During austenitizing, as is well known, some of them undergo dissolution in the austenite, which results in a high hardness of the material after heat treatment. The other part of the carbides, which does not undergo the dissolution, hinders the austenite grains coarsening and makes the steels wear resistant.[1]

Carbide phases have different thermal stability and, while some of them are dissolved during austenitizing in the solid solution at relatively low temperatures, others remain stable up to the solidus temperature.[3]

The standard heat treatment of Cr-V ledeburitic steels consists of the following steps: austenitizing, holding at temperature to dissolve a certain amount of carbides and to homogenize the austenite, quenching to room (or sub-zero) temperature and several times tempering, usually to the secondary hardness peak. After these procedures, the hardness reaches more than 60 HRC.[5]

The paper is focused on an investigation of what happens with the carbides and the matrix of the Cr-V ledeburitic steels, when heated up to different austenitizing temperatures. The PM made Vanadis 6 steel is used as an example.

2 EXPERIMENTAL

2.1 Material and processing

The experimental substrate material was the ledeburitic steel Vanadis 6 with nominally 2.1 % C, 1.0 % Si, 0.4 % Mn, 6.8 % Cr, 1.5 % Mo, 5.4 % V and Fe as balance, made by PM.[6]

Round-shaped samples from the steel were austenitized at the temperatures (1000, 1025, 1050, 1075, 1100, 1150 and 1200) °C and oil-quenched. From the heat-processed material, metallographic specimens were prepared, ground, polished and etched with 2 % Nital solution.

2.2 Characterization

The microstructure was investigated using SEM. EDS mapping was done on the same device at an accelerating voltage of 15 kV and a standard working distance of 15 mm. For the quantification of the structural changes, for each specimen 10 micrographs were taken at a standard magnification of 5000-times.

To quantify the amount of M_7C_3- and MC-carbides, each carbide particle was identified using the corresponding EDS mapping of chromium and vanadium. Afterwards, the volume fraction, size and density (number of particles per mm^2 on a metallographic sample) of particles were determined for the specimens processed at all the austenitizing temperatures, as well as for the as-delivered material, using the NIS-elements® software. From the obtained results, the mean value and the standard deviation were calculated. The size of the carbides, as a function of austenitizing temperature, was evaluated as follows: the size classes of the particles were chosen first. Then, the particles were classified according to their dimensions.

The hardness was measured using the Rockwell C method (HRC). Five measurements were made on each specimen and the mean value was calculated.

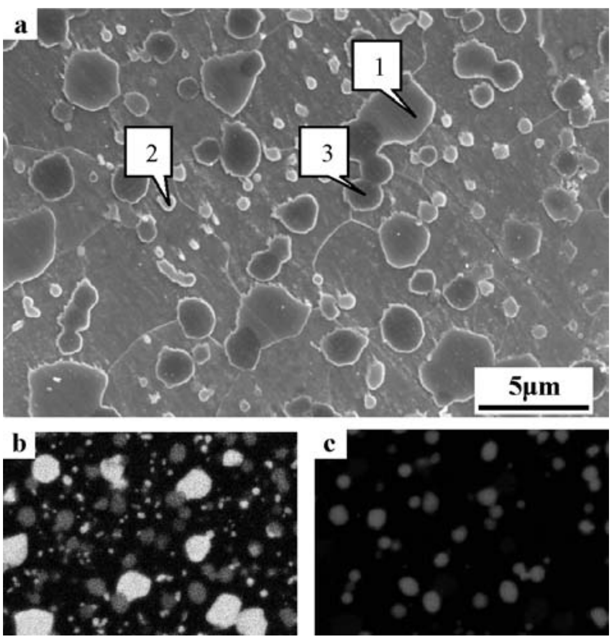

Figure 1: Microstructure of PM ledeburitic steel Vanadis 6 in soft-annealed state: a – overview (SEM), b – EDS-map of chromium from the Figure 1a, c – EDS-map of vanadium from the Figure 1a

Slika 1: Mikrostruktura PM-ledeburitnega jekla Vanadis 6 v mehko žarjenem stanju: a – pregled (SEM), b – EDS-posnetek kroma s slike 1a, c – EDS-posnetek vanadija s slike 1a

3 RESULTS AND DISCUSSION

The as-received Vanadis 6 steel contains a matrix together with fine and uniformly distributed carbides (**Figure 1a**). The particles are of two types. Large particles (1) as well as those of sub-micron size (2) are chromium-based carbides (**Figure 1b**). Smaller particles (3) are the vanadium-rich phases (**Figure 1c**). A previous investigation has shown that the chromium-based particles are M_7C_3 and the vanadium-rich particles are MC.[7]

The hardness of the as-received material was 21.3 HRC.

The as-quenched structure consists of martensite, retained austenite and two types of undissolved carbides (**Figure 2**). In previous investigations, the larger and

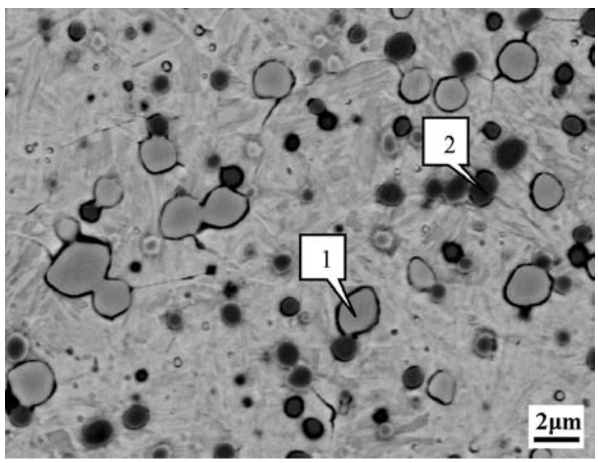

Figure 2: Microstructure of PM ledeburitic steel Vanadis 6 after heat treatment (SEM)

Slika 2: Mikrostruktura PM-ledeburitnega jekla Vanadis 6 po toplotni obdelavi (SEM) brighter particles were identified as being the M_7C_3 type (1) and the smaller and darker particles as being the MC type (2).

The volume fractions of the MC- and M_7C_3-particles, as well as the total amount of carbides, as a function of the austenitizing temperature, are shown in **Figure 3**. In the soft-annealed (SA) state, the material contains 29.5 % of carbides. The volume fraction of M_7C_3 carbides was 15.6 % and the volume fraction of MC carbides was 13.9 %.

During austenitizing, the dissolution of carbides occurs. This is particularly so for the M_7C_3 particles. After austenitizing at a temperature of 1000 °C, their volume fraction was 7.3 % and it decreased further with increasing austenitizing temperature. Above 1100 °C, no M_7C_3 particles were found.

The amount of MC particles decreased only slightly with the austenitizing temperature up to 1150 °C. Beyond that, the decrease in the amount of the MC particles became more significant.

These results indicate that while the M_7C_3 particles dissolved completely in the austenite during heating to the austenitizing temperature, the MC phase remained very stable up to high temperature. Only at temperatures of about 1200 °C does it undergo dissolution to a limited extent.

Figure 4 shows the density of both the MC- and M_7C_3-particles as a function of austenitizing temperature. As shown, the density of M_7C_3 particles decreases with increasing austenitizing temperature. After austenitizing at a temperature of 1000 °C, the density was about 5000 M_7C_3 particles per square millimeter. After austenitizing at a temperature of 1100 °C, the density was lowered to about 1000 /mm². The austenitizing at temperatures above 1100 °C leads to complete dissolution of the M_7C_3 particles. The density of the MC particles, on the other hand, decreased only weakly up to a temperature of 1150 °C, and only above did it decrease more markedly. At a temperature of austenitizing of 1000 °C, the density was about 21 000 MC carbide particles per square millimeter. At a temperature of 1150 °C, the density was lowered to about 17 500 /mm² and more significant lowering, to a mean value of 12 500 /mm² was fixed when the material was austenitized at the temperature of 1200 °C.

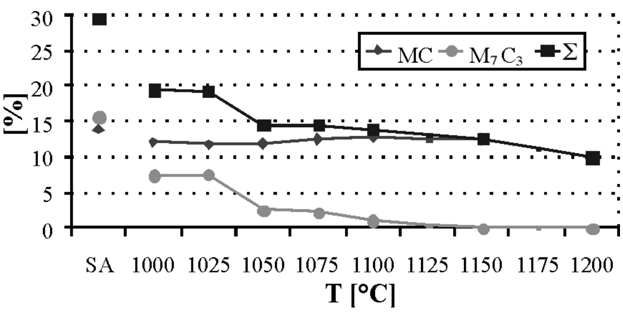

Figure 3: The amounts of carbides for samples of Vanadis 6 ledeburitic steel depending on the austenitizing temperature.

Slika 3: Količina karbidov za vzorce jekla Vanadis 6 v odvisnosti od temperature avstenitizacije

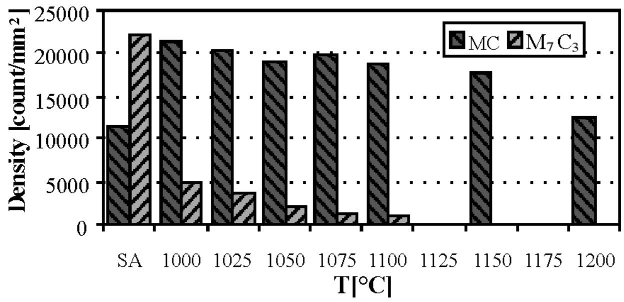

Figure 4: The density of carbides as a function of the austenitizing temperature

Slika 4: Gostota karbidov v odvisnosti od temperature avstenitizacije

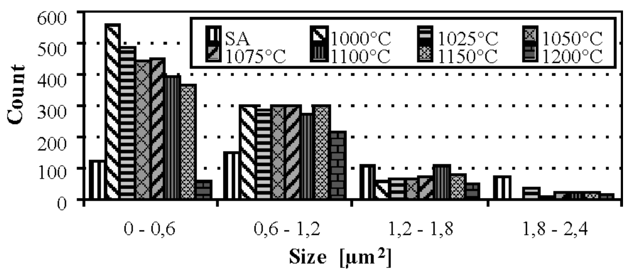

Figure 5: The size distribution of MC particles as a function of the austenitizing temperature

Slika 5: Velikostna porazdelitev MC-karbidov v odvisnosti od temperature avstenitizacije

Figure 5 documents the size distribution of the MC particles. Two phenomena are visible from the diagram. The first one is that finer particles have a tendency to dissolve in austenite in some, but a relatively limited extent. On the other hand, it seems that the larger MC particles remain practically unaffected.

Figure 6 shows the size distribution of the M_7C_3 particles. It can be seen that with an increased austenitizing temperature, the number of carbide particles of all size classes decreases rapidly. This confirms that the M_7C_3 phase is less stable than the MC phase and undergoes much more easily the dissolution in austenite.

Figure 7 shows SEM micrographs from samples austenitized at various temperatures (left column) and

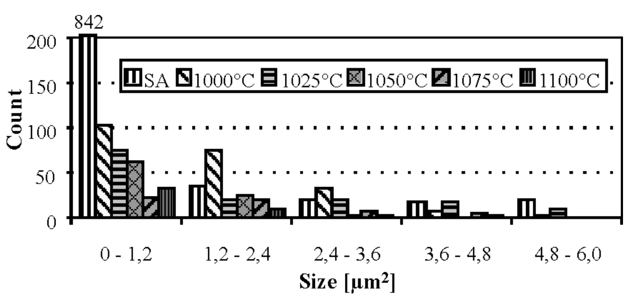

Figure 6: The size distribution of M_7C_3 particles as a function of the austenitizing temperature

Slika 6: Velikostna porazdelitev M_7C_3-karbidov v odvisnosti od temperature avstenitizacije

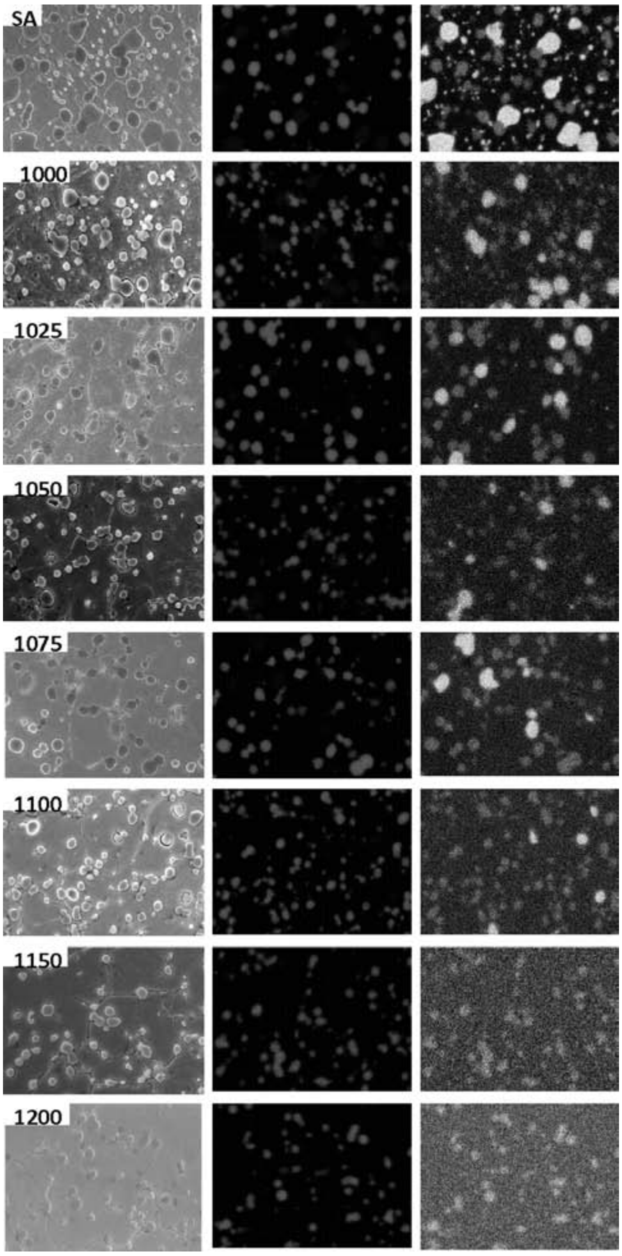

Figure 7: SEM micrographs and corresponding EDS-maps of the samples processed at various austenitizing temperatures

Slika 7: SEM-posnetki in ustrezni EDS-posnetki vzorcev, ki so bili procesirani pri različni temperaturi avstenitizacije

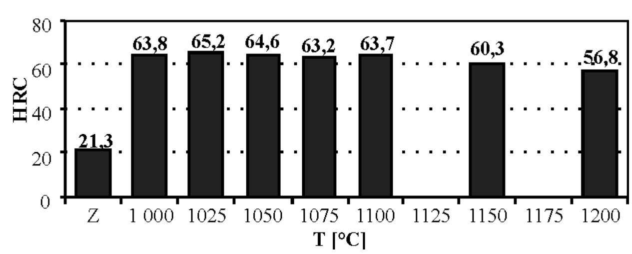

Figure 8: Hardness of the samples made from the Vanadis 6 steel depending on the austenitizing temperature

Slika 8: Trdota vzorcev jekla Vanadis 6 v odvisnosti od temperature avstenitizacije

the corresponding EDS-maps of the vanadium (central column) and chromium (right column). The micrographs and EDS-maps are in good agreement with the above-presented and discussed results of the investigations. It means that the total volume fraction of carbides decreases with the increasing austenitizing temperature. The phase that is more sensitive to dissolution in austenite is the M_7C_3.

Figure 8 shows the results of the hardness measurements of HRC. The heat treatment induced a rapid increase in the hardness.

After the maximum hardness peak, the hardness decreases slightly and for the steel austenitized above 1100 °C more rapidly. The hardness behavior can be explained as follows. Due to the dissolution of carbides, the austenite becomes saturated with carbon and the alloying elements. The saturation is higher when a higher austenitizing temperature was applied. The increased content of carbon and alloying elements increased the hardness of the martensite. But they also induce a decrease of the temperatures of M_S and M_F, respectively, which tends to increase the amount of retained austenite.[8] The final steel hardness is then a result of the competition between the martensite supersaturation (hardness increase) and the retained austenite amount (hardness decrease), with an optimum at the austenitizing temperature of 1025 °C.

4 CONCLUSIONS

We found that the microstructure of the material in the soft-annealed state consisted of a ferritic matrix and two types of carbides. The volume fraction of the MC particles was 13.9 % and the volume fraction of the M_7C_3 particles was 15.6 %.

After the heat treatment, the microstructure of the steel consists of martensite, retained austenite and both carbide phases or only MC particles. With an increasing temperature of austenitizing, the M_7C_3 carbides underwent dissolution, which reduced their density and size. The M_7C_3 particles were not detected above 1100 °C. The MC particles are stable up to a temperature of 1150 °C. Above this, the MC particles also began to dissolve in the matrix to a limited extent. The density of the MC particles decreased slightly with the increasing temperature of austenitizing.

Furthermore, it was found that the highest hardness of 65.2 HRC was for the steel austenitized at a temperature of 1025 °C. Any further increase of the austenitizing temperature induced a decrease of the hardness of the samples.

The obtained results confirmed that the M_7C_3 particles easily undergo the dissolution in austenite. The MC particles are stable and can effectively hinder the grain coarsening up to high temperatures.

5 REFERENCES

[1] Macek, K, Janovec, J., Jurči, P., Zuna, P.: Kovové materiály, ČVUT, Praha, 2006

[2] Jurči, P., Šuštaršič, B., Leskovšek, V.: Freacture charakteristics of the Cr-V ledeburitic steel Vanadis 6. Mater. Tehnol., 44 (**2010**), 77–84, ISSN 1580-2949

[3] Jurči, P.: *Nástrojové oceli ledeburitického typu,* ČVUT, Praha, 2009

[4] Fremunt, P., Krejčík, J., Podrabský.: Nástrojové oceli, Dům techniky Brno, 1994

[5] Jurči, P. Structural changes in Cr-V ledeburitic steel during austenitizing and quenching. *Materials Engineering*, 17 (**2010**) 1, 1–10

[6] Materiálový list firmy Uddeholm, Vanadis 6 – Super Clean High performance powder metallurgical cold work tool steel [online]. 2009 [cit. 2010-3-8]. WWW: http://www.bucorp.com/files/van_6_ds.pdf.

[7] Jurči, P., Hnilica, F., Suchánek, J., Stolař, P.: Microstructual features of Cr-V ledeburitic steel saturated with nitrogen, Mater. Tehnol., 38 (**2004**), 1–2

[8] Kraus, V. Tepelné zpracování a slinování : Přednášky [online]. Plzeň : ZČU, 2000 [cit. 2010-06-17]. WWW: http://tzs.kmm.zcu.cz/TZSprcelk.pdf