Microstructure of advanced tool steels produced by powder metallurgy

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In this work, the microstructure and mechanical properties of three types of high-speed tool steels (Vanadis 60, ASP 2052 and S 705) were studied. The steel S 705 was made by conventional ingot metallurgy technology, and other types of steels were manufactured by powder metallurgy technology. The studied steels were examined both in the soft state and further in the hardened condition with subsequent tempering. Microstructure of metallographic cuts and fracture areas was studied by electron microscopy. Hardness, tensile properties and notch toughness were determined. Significant differences in the properties of steels in both studied states have been documented.

Keywords: high-speed steels, microstructure, mechanical properties

1 Introduction

At present, we observe the development and optimization of manufacturing techniques throughout the industrial scale. There is an attempt to maximize the potential of production tools. This applies, of course, to the problems of cutting tools, which are subject to ever higher demands. In particular, the technological properties such as the hardness and workability are important in the production of these materials, and also the properties characterizing these materials during their use - high hardness, toughness, dimensional stability and resistance to tempering at elevated temperatures and high machining speeds. High requirements for cutting tool materials lead to the development of new high-speed steels at the same time as well asthe use of modern technology in their production. The highest quality high-speed materials include steel produced by powder metallurgy technology. Extremely fine-grained microstructure provides high mechanical properties and homogeneous microstructure, which are key factors that have an impact in ensuring long-term service life of machine tools. All the studied steels are used for demanding cold machining. They are mostly used in of shaping and rolling milling machines, drills, shearing tools and durable pressure molds. The properties of high-speed steels depend mainly on their chemical composition. C, Cr, W, Mo, V and Co are the most important alloying elements. Carbide-forming elements Cr, W, Mo and V create very hard carbide phases. Due to Co high-speed steels improve their resistance to temper. In addition to the above elements, it is necessary to control the content of some elements (especially Mn, S and P), which even in small quantities can greatly reduce the mechanical resistance of these steels [1-2].

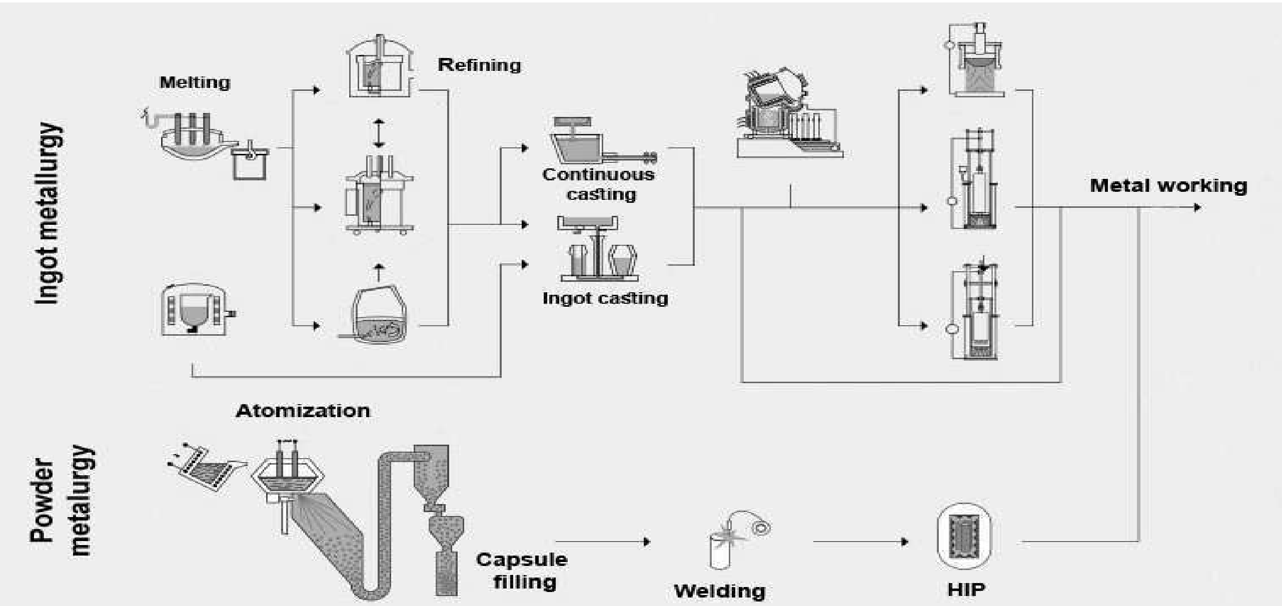

***Fig. 1** Scheme of production of semi-finished products from high-speed steels [3]*

Modern high-speed steels are produced either by conventional foundry technology or by powder metallurgy, as shown in Fig.1. [4-5]. Semi-finished products made of high-speed steels are supplied in a soft-annealed state to be further processed. They are then heat-treated to achieve the final hardness. A typical example of the heat treatment of high-speed steels is shown in Fig.2. Typical for these steels is a repeated tempering process that leads to the removal of internal stress and further processes of transformation of residual austenite to martensite together with the precipitation of fine carbide phases [6-8].

The aim of this work was to compare the microstructure and mechanical properties of 2 selected high-speed steels produced by the powder metallurgy method with one steel made by the classic foundryand ingot metallurgy process.

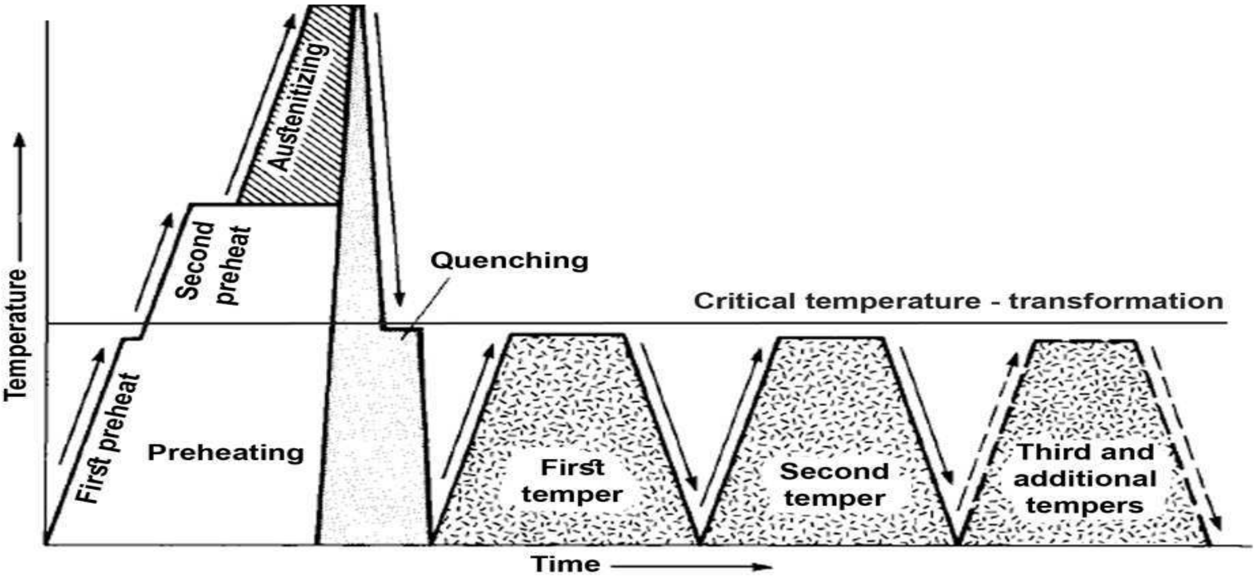

Fig. 2 *Scheme of a typical heat treatment of high-speed steels [3]*

2 Experiment

For the experiments, high-speed steels were used, the chemical composition of which is in Tab. 1. These are commercially available materials. Vanadis 60 steel was supplied by Uddeholm, ASP 2052 steel by Erasteel and S705 steel by Böhler.

Tab. 1 *Chemical composition of high-speed steels [wt.%]*

HS Steel	C	Cr	Mo	W	Co	V	Fe
Vanadis 60	2.30	4.20	7.00	6.50	10.50	6.50	bal.
ASP 2052	1.60	4.80	2.00	10.50	8.00	5.00	bal.
S 705	0.92	4.10	5.00	6.20	4.80	1.90	bal.

Tab. 2 *Soft-annealing regimes for the studied high-speed steels*

Steel	**Annealing temperature** [°C]	**Holding time** [h]	**Cooling rate** [K/h]
Vanadis 60	850 - 950	3	10
ASP 2052	850 - 950	3	10
S 705	770 - 840	3	10 - 20

Vanadis 60 and ASP2052 HS steels were produced by powder metallurgy. Steel S 705 was made by classical ingot metalurgy. All the studied steels were examined both in the soft-annealed state (as supplied) and further in a hardened state with subsequent tempering. From semi-finished products in a soft-annealed state, samples for microstructure study, uniaxial tensile test, hardness and notch toughness were prepared by machining. Tab. 2 and 3 show the recommended conditions for their heat treatment. The hardening and tempering regime was the same for all steels. The heat tretment was carried out in a Rübig VH669 vacuum furnace, see Fig. 3.

Tab .3 *Hardening and tempering regime for studied steels*

1. Preheating						**2. Austenitization**		
No.1			**No.2**					
Temperature [°C]	Heating rate $[Kmin^{-1}]$	Holding time [h]	Temperature [°C]	Heating rate $[Kmin^{-1}]$	Holding time [h]	Temperature [°C]	Heating rate $[Kmin^{-1}]$	Holding time [min]
650	20	2	830	20	1	1180	20	2

3. Quenching (triple)		**4. Tempering (triple)**			
Cooling rate $[Ks^{-1}]$	Medium	Temperature [°C]	Heating rate $[Kmin^{-1}]$	Holding time [min]	Cooling rate $[Kmin^{-1}]$
10	N_2	540	20	1	20

The microstructure of steels was studied using a TESCAN VEGA 3 electron microscope. The phase composition of the steels was determined using the Bruker AXS D8 X-ray diffractometer. The uniaxial tensile test was carried out on the WEB 50 / Tempos UTS universal testing machine and the measurements of each type of steel were performed 3 times. Rockwell hardness was determined on the WPM hardness tester and each sample was measured 10 times. Impact toughness measurement was performed on a Charpy hammer and each steel was measured 3 times. Steel samples used for experiments are in the Fig.4.

Fig. 3 *Quenching furnace Rübig VH669*

3 Results and discussion

Microstructure

The microstructure of studied high-speed steels was very fine, so an electron microscope was used for the documentation. The microstructure of all the steels was very similar. It was composed up of a carbide phase deposited in a metal matrix, see Fig.5. In this figure there is a difference in the microstructure of a soft-annealed and hardened + tempered sample. In the first case, a higher proportion of the carbide phase in the metal matrix is apparent. Steel in the hardened and tempered state has a lower amount of carbide phase in the microstructure and the other carbide phases are very fine, forming precipitates that are not visible at this magnification.

Fig. 4 *Samples used for experiments*

Although there are differences in the chemical composition between the studied steels, analysis of the phase composition by electron diffraction analysis did not show a significant difference in the composition of the carbide phase. For all steels, two types of carbide particles were observed. The first type are mixed carbides containing high amounts of W and Mo second type are carbide particles containing high amount of V. Both types of carbidic phases contain also Cr. These carbidic phases are deposited in the martensitic matrix.

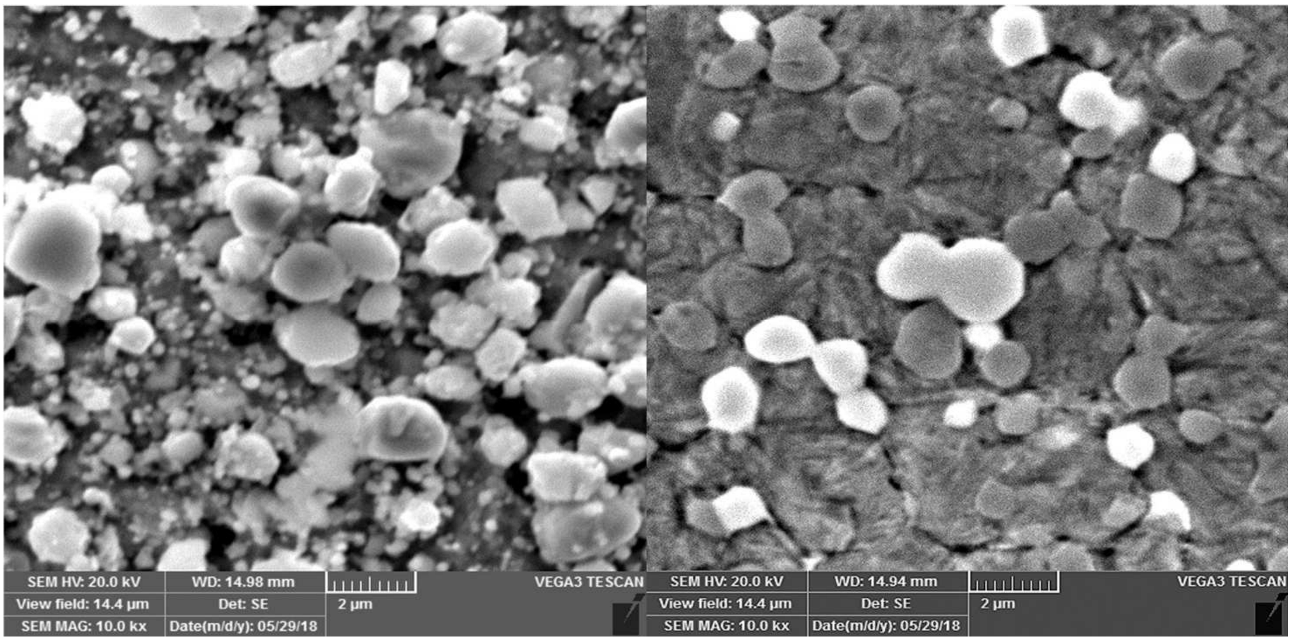

Fig. 5 *Microstructure of ASP 2052 steel, soft-annealed state (left) and state after hardening + tempering (right)*

Only a small amount of residual austenite was found in the ASP 2052 steel in the hardened + tempered state. The composition of the carbide phase is also documented by the elemental distribution maps of Figs. 6-8. Microstructure in the Fig.8 shows large carbide particle in S705 steel. Occasional occurrence of coarse carbidic phase is typical for high-speed steel produced by ingot metallurgy. Microstructure of PM high-speed steels is more uniform, which is a requirement for high mechanical properties.

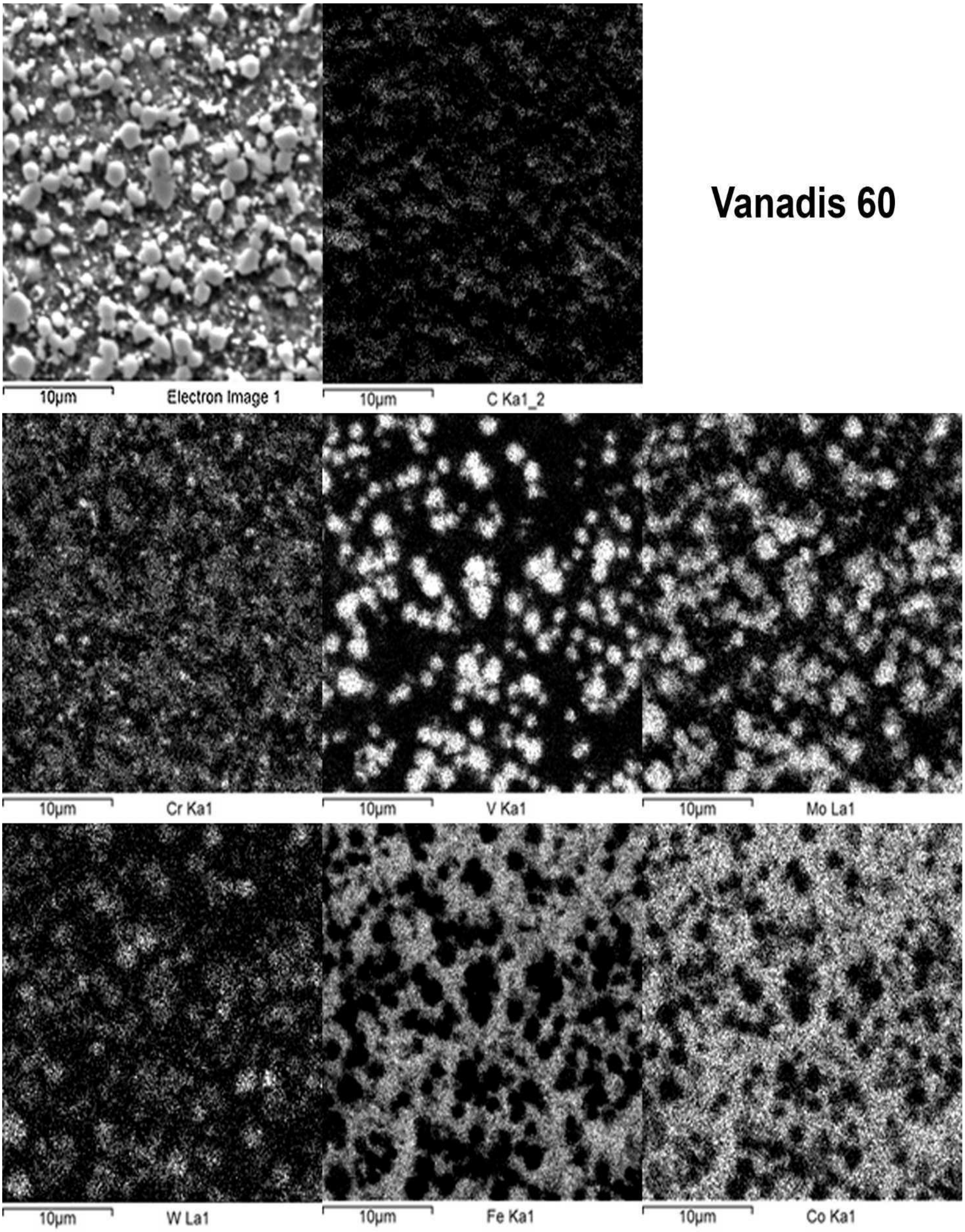

Fig. 6 *Microstructure of Vanadis 60 steel (soft-annealed state) and maps of alloying elements*

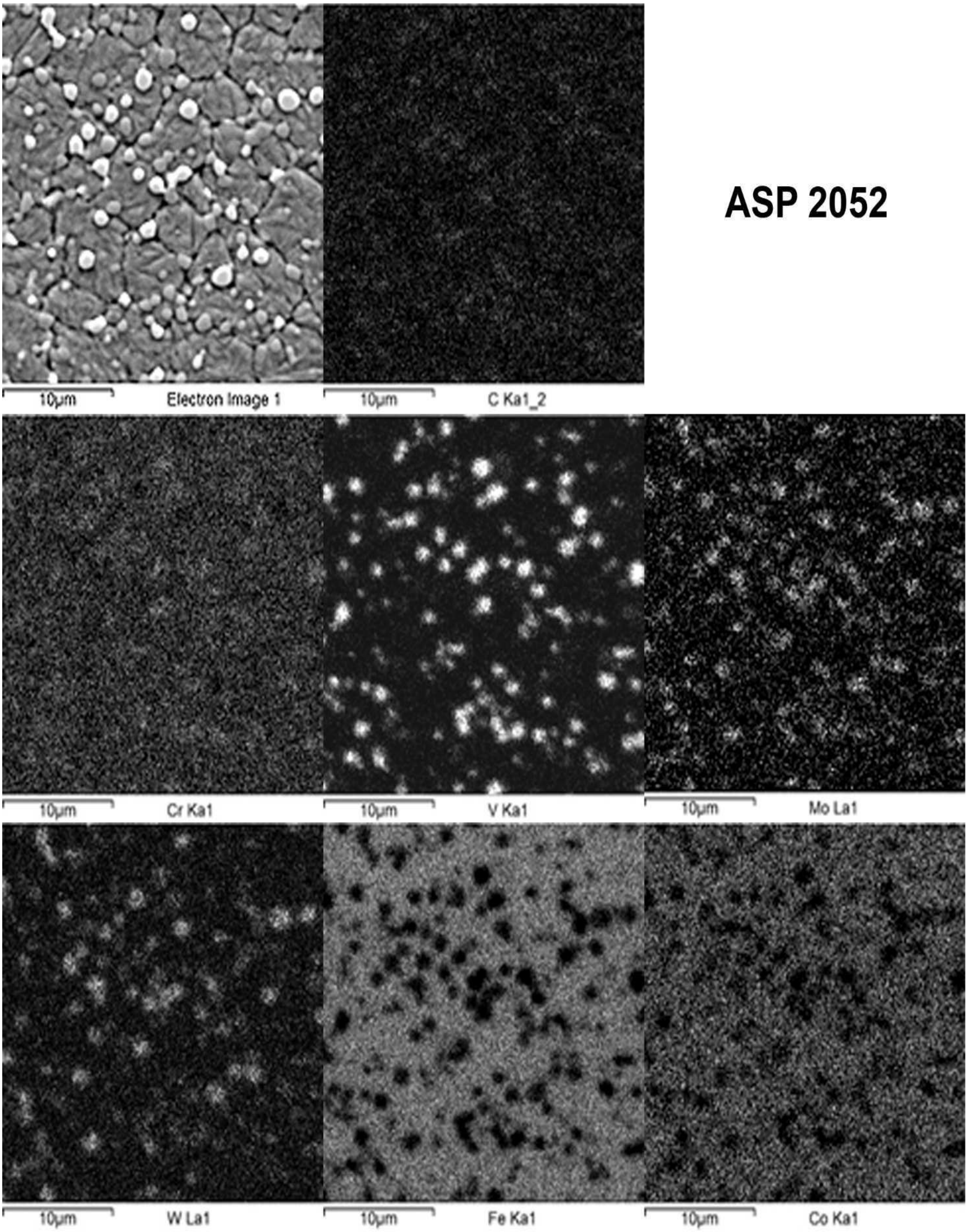

Fig. *7 Microstructure of ASP 2052 steel (hardened + tempered state) and maps of alloying elements*

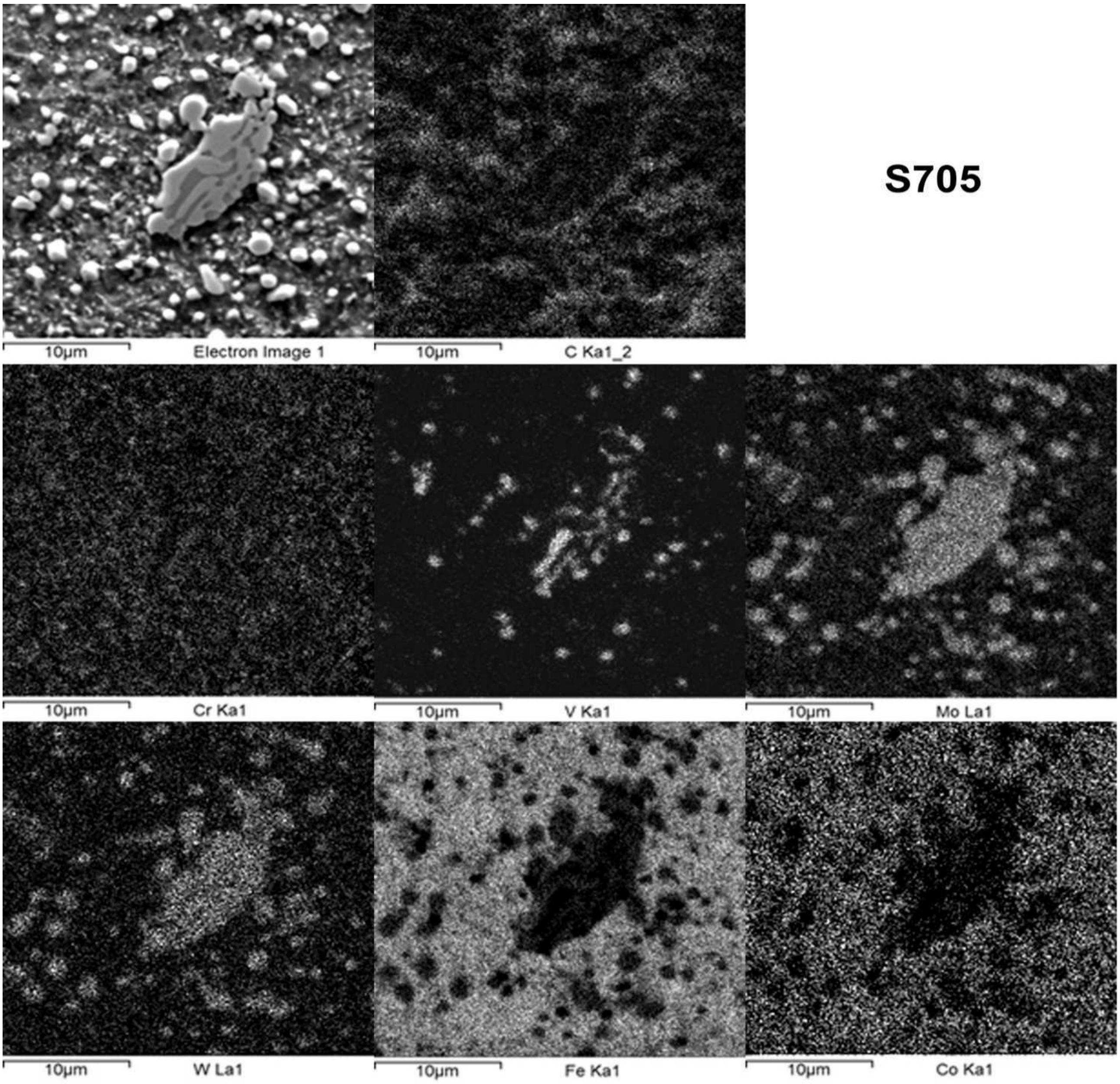

Fig. 8 *Microstructure of S705 steel (soft-annealed state) and maps of alloying elements*

Tab. 4 *Mechanical properties of HS Steels (YS and UTS denotes the yield strength or ultimate tensile strength of the alloy)*

	Vanadis 60		ASP 2052		S705	
	soft-an-nealed	**hardened+ tempered**	**soft-an-nealed**	**hardened+ tempered**	**soft-an-nealed**	**hardened+ tempered**
Rockwell hardness, HRC	34.8	68.6	26.3	66.5	20.7	65.1
YS [MPa]	839	-	669	-	676	-
UTS [MPa]	1 134	-	1 015	-	964	-
Elongation [%]	4.2	-	11.5	-	10.3	-
KC [Jcm^{-2}]	2.1	0.6	3.1	1.6	2.5	1.3

Mechanical properties

Mechanical properties of studied high-speed steels in soft-annealed and hardened + tempered conditions are in Tab. 4.

Major differences in mechanical properties of steels in soft and hardened condition are shown in the Tab.4. Differences in mechanical properties of steels in the same state are not significant despite the different chemical composition. In the Fig. 9, for example, the fracture area of the samples after determination of the notched toughness of the Vanadis 60 steel is shown. A pair of images is typical of other steels in two their different states. Samples in soft state are roughly twice the value of notched toughness versus hardened. Fracture areas also correspond. Steels in the soft state exhibit typical ductile features on fracture surfaces, while the hardened fracture surfaces of the steels have a planar character.

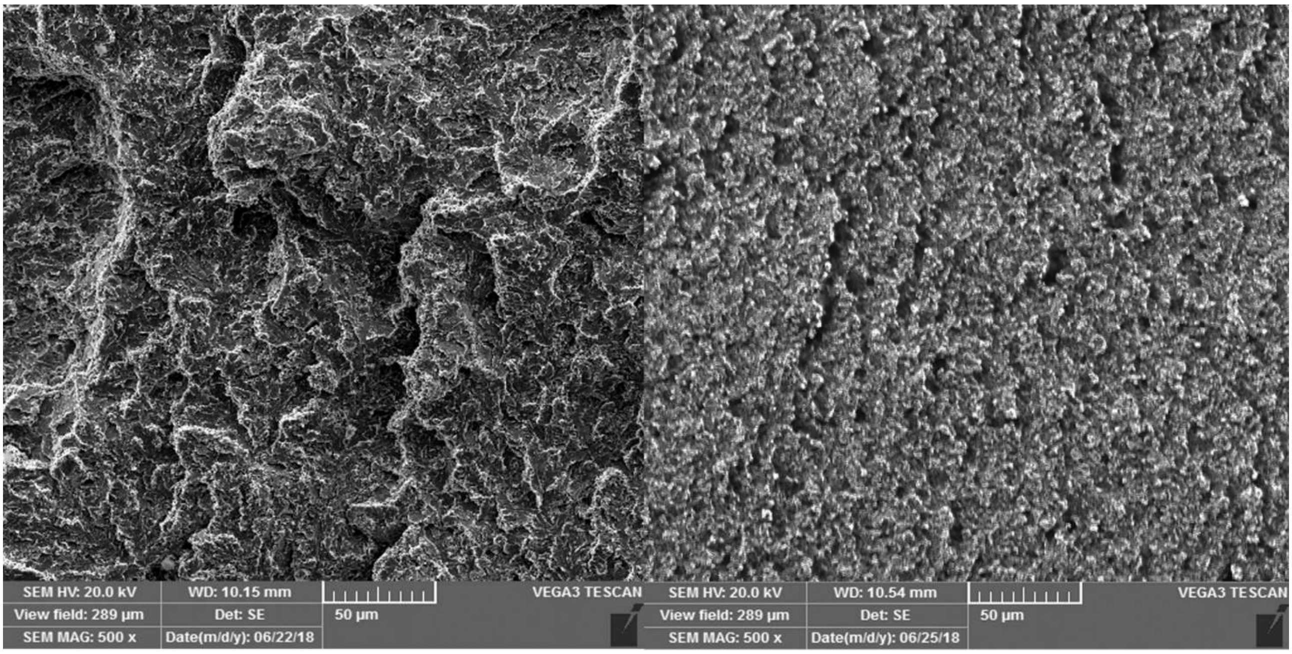

Fig. 9 *Fracture areas of Vanadis 60 HS steel, soft-annealed condition (left) and after hardening + tempering (right)*

4 Conclusion

The microstructure, phase composition and mechanical properties of the three progressive high-speed steels (Vanadis 60, ASP 2052 and S705) containing W, Mo, Co, Cr and V alloying elements were compared. The microstructure of PM high-speed steels (Vanadis 60 and ASP2052) was relatively uniform, whereas in the case of the steel produced by the ingot metallurgy (S 705), coarse carbide particles were observed to disturb its uniformity. Carbidic phase was deposited in martenzitic matrix. Two types of carbide phase (mixed carbides - containing W and Mo and VC carbides) were observed. After heat treatment, the proportion of the coarse carbide phase decreased, and part of the carbides was probably present in the form of very fine precipitates which, however, could not be distinguished by the SEM technique.

The highest content of carbide-forming elements had Vanadis 60 PM steel and the lowest had the S 705 steel. Vanadis 60 had the highest Rockwell hardness and the S 705 has the lowest Rockwell hardness in both soft-annealed and hardened + tempered condition. Vanadis 60 steel had also the highest yield and tensile strength of all studied high-speed steels. The notched toughness of all steels in soft-annealed state had approximately a double value compared to steels in hardened + tempererd state.

Acknowledgement

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