Highly Alloyed Steel Matrix for Tools Fabricated by Powder Metallurgy

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Both Spark Plasma Sintering (SPS) and conventional sintering were applied to obtain bulks of ledeburitic highly alloyed steels for tools fabrication. Powder mixtures of the component elements, of compounds or of powders obtained through ball milling of the chips resulting from the processing of parts from steels of interest were used. When compared with traditional technologies (casting and plastic deformation), SPS and the use of milled chips resulted in the formation of microstructures with a high degree of distribution homogeneity and dimensional uniformity of the carbides. As is well known, the improvement of these parameters leads to the maximization of the functional properties of tools.

Keywords: *powders, highly alloyed steels, chips, sintering, spark plasma sintering.*

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INTRODUCTION

Among metal products, tools are special since they are used under specific and complex load conditions. Tools serve to shape the intermediate products obtained by different technologies such as casting, plastic deformation, cutting and so on, to their final functional geometry.

Of high interest are tools from highly alloyed steels with a high concentration of carbon and high quenching capacity. Tools fabricated from such steels show excellent durability and productivity [1–3]. Typical steels of this category are: R_{p3} (0.70÷0.78%C; 3.8÷4.5%Cr; 17.5÷18.5%W; 1.0÷1.2%V; ≤0.6%Co) – for cutting tools and 205Cr115 (1.90÷2.20%C; 11÷12%Cr) [4] – for plastic deformation and chipless cutting at room temperature of metallic materials. Both mentioned steels are of ledeburitic type. The structure of these steels after casting is characterized by a high degree of chemical and structural nonhomogeneity. After subsequent hot plastic deformation one can observe a structure with carbides oriented along the flow direction of the material. The size of the carbides depends on the applied reduction degree. After the final quenching and tempering heat treatments (simple or multiple, depending on steel) in the steel matrix along with (tempering) martensite and residual austenite, primary and secondary carbides are present. In both steels, the anisotropy of the properties strictly correlates with the size and distribution of carbides. To decrease the anisotropy, it is required to obtain the carbides distribution as uniform as possible. Owing to a high concentration of Cr (11–12%) and of C (~ 2.1%) in 205Cr115 steel, the main carbides are $(Cr, Fe)_7C_3$ and $(Fe, Cr)_3C$, while in R_{p3}, considering the presence of other alloying elements, additional carbides such as Fe_3W_3C, $Cr_{23}C_6$, and VC are also present.

A distribution of carbides as uniformly as possible in the steel matrix allows for the high performace of the tools produced from such steels. Therefore, processing of the steels under discussion should target such structures. Fine carbides that are uniformly distributed in the matrix make it possible to get a homogeneous austenite during heating for quenching. Distribution of carbides in the steel matrix influences the behavior during quenching and, hence, strongly influences the functional properties of the the steel for tools in general and of those belonging to the ledeburite group, in particular. In the case of Rp_3 steel, a high content of W promotes the formation of a higher amount of primary ledeburitic carbides separated directly from the melt. Those cabides (as well as some of the secondary ones) do not disolve in austenite during further thermal processing.

Nonuniformity of the carbides size and distribution in the matrix of the steels for tools, after hot plastic deformation, amplifies the level of the residual stress that occurs during quenching. Powder metallurgy offers convenient solutions to achive top performance of the tools from highly alloyed steels. This is because powder metallurgy ensures a higher degree of dimensional and distribution uniformity of the carbides in comparison to traditional methods usually consisting of casting, plastic deformation, and other processing steps. Through melt spining of the metal [1] powders of steels are obtained. Processing of those powders will lead to an adequate

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distribution of carbides ensuring their high performace. Steels obtained by powder metallurgy are characterized by high hardness and toughness, high stability and strength at elevated temperatures after quenching and tempering [1]. In the given paper we report the exploitation of highly alloyed steel matrix, obtained from powders, for cutting or cold mechanical processing tools with a high durability and productivity. The purpose of our experimental research was to select the raw powders most convenient to be used for the production of steel matrix that meets, as closely as possible, the requirements of high dimensional and distribution uniformity of the carbides in steels for tools. Different types of powder mixtures were used employing Spark Plasma Sintering (SPS). This modern technique is recognized to take advantage of unconventional activation processes [5–10]. The consequences are sintering at lower temperatures and for shorter times, and a higher flexibility, e.g. the possibility of high heating and cooling rates is advantageous to supress particle growth. In a few cases SPS was also shown to promote reactive processes otherwise not observed at conventional sintering [11]. This aspect is of special interest for the control of carbides in steels and it deserves attention.

EXPERIMENTAL

In our case of a highly alloyed steel for cutting tools, chemical and microstructural features followed, as a model, steel Rp_3. The steel for our investigations was prepared via two routes: (i) Powders of W or WC or of pure elements such as V, Mo, Co or Cr (or an alloy containing Cr-FeCr) were added to a powder of Fe or of carbon steel. Compositions were: Fe + 15% (WC+15%Co) denoted composition A; Fe + 1%C + 14% (WC+15%Co), denoted composition B; Fe + 1%C + + 24% (WC+15%Co) + 11% (FeCr) + 3%V + + 1%Mo, denoted composition C; steel powder (Fe, ~ 0.4%C, ~ 0.2%Si, ~ 0.04%P, ~ 1.1%Mn, ~ 0.04%S, ~ 0.15%Al) +24% (WC+15%Co) +11% (FeCr)+3%V+1%Mo), denoted composition D; Fe + 1%C + 4.5%Cr + 18%W + 3%V + 1%Mo + 6%Co, denoted composition *E*.

Powder mixtures were prepared in a double cone mixing device for 30 min in the ambient air. (ii) Powders were obtained by ball milling of the chips of R_{p3} and 205Cr115. In our experiments we used powder fractions below 150 µm.

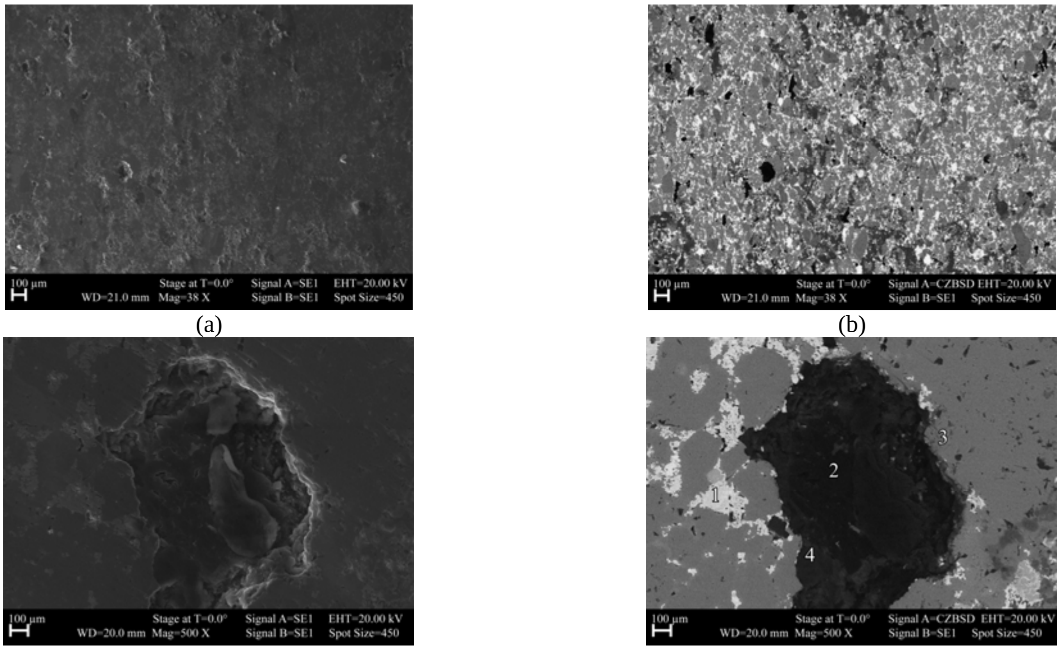
Powder mixtures were uniaxially pressed (720 MPa) at room temperature into cylinders with the dimeter of 16 mm. The samples were sintered at 1050^{o}C for 4 hrs in natural gas used in households and industry (content of methane is within 65–80%). In another series of experiments samples were obtained by SPS applying a uniaxial pressure on the punches of a graphite mould loaded with the powder to be sintered. The maximum applied pressure was 95 MPa. The inner diameter of the mould was 20 mm. Powder was wrapped in a graphite foil for easy extraction of the sintered bulk from the mould. On the graphite punches, a pulsed current was also applied for the sample heating. The heating rate was 150°/min, the processing temperature – 1050°C, and the dwell time – 4 min. The SPS chamber was washed twice with argon; heating during SPS processing was performed in vacuum of 30–40 Pa. The applied current had the following parameters: the maximum current and voltage were 1600 A and 5 V, respectively, the pulse cycle was ~ 0.04s (12 on/2 off with a period of 3 ms).

The samples were characterized by optical and electronic microscopy. A chemical analysis was carried out by the energy dispersive spectrometry (EDS) using detectors attached to electronic microscopes.

RESULTS AND DISCUSSION

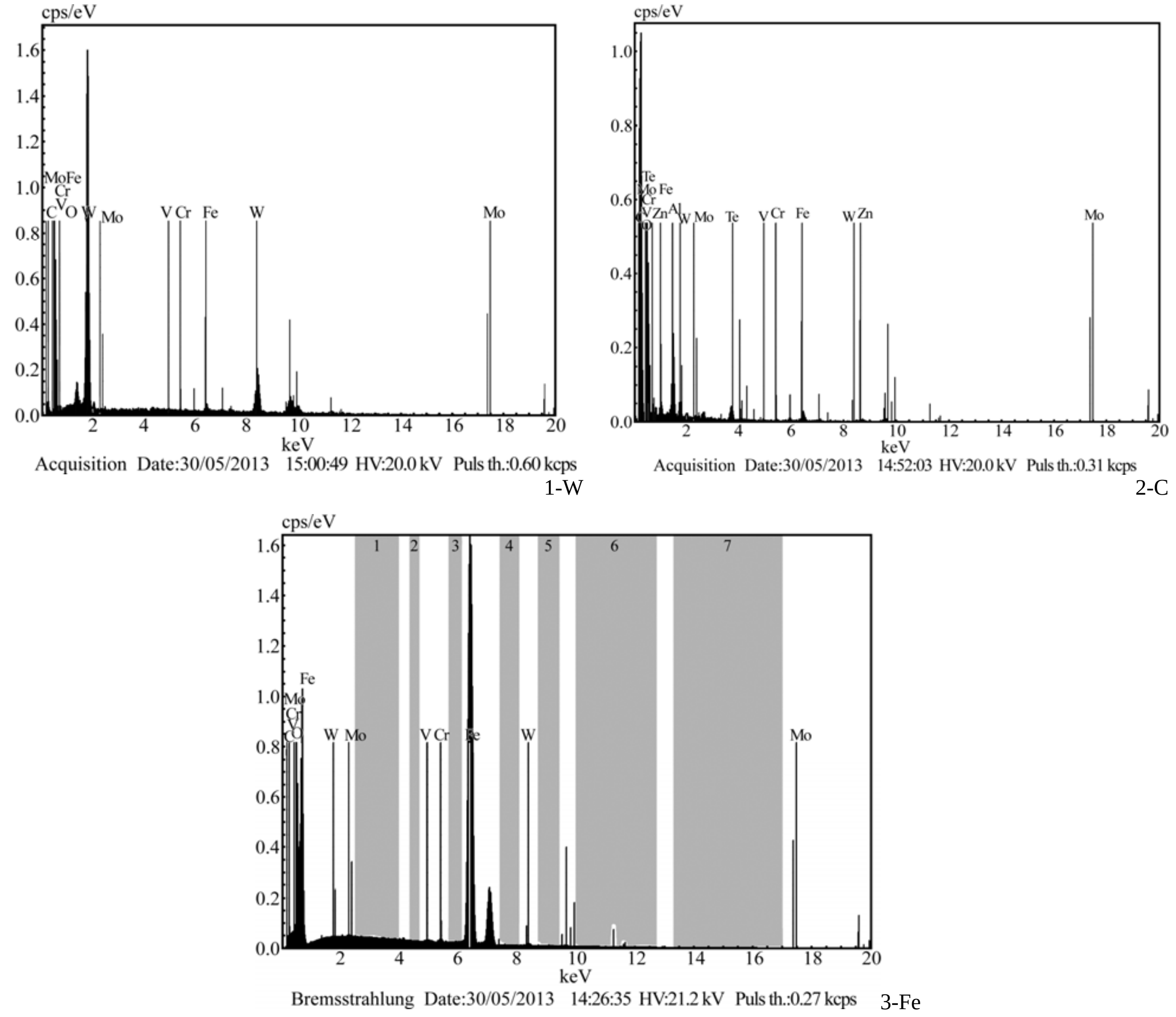
The results of experiments aimed at establishing the optimum synthesis and processing route for the highly alloyed steel matrix for tools using powder metallurgy demonstrate that the most convenient route is when using powders obtained by milling of the steel chips.

Attempts to produce a highly alloyed steel matrix with a high degree of chemical and microstructural homogeneity from powder mixtures were not successful either with traditional sintering or SPS. Namely, both optical and electronic microscopy combined with EDS on the samples with relatively simple compositions of Fe-WC-Co produced by the traditional powder metallurgy processing from the powder mixtures of the component elements (Fe, Co) or compounds (WC) revealed that transition of W into a solid solution with other elements is limited, if at all. Tungsten remains in its initial state as a primary carbide WC. Further increase of the steel components does not change the situation and, in fact, amplifies the chemical and microstructural nonhomogeneity. This is also working against reaching a high density in the sintered samples. The presented results suggest that mixing of the powder components is among major problems. The differences in the densities of the components determine their segregation during mixing thus influencing the next steps of processing, homogeneity, and the final functional characteristcs of the tools. Very different densities of carbon (ρ = 2250 Kg/m^3), compared to those of metals (7870 kg/m^3 for Fe, 18850 kg/m^3 for W, and so on) or of WC (15600 Kg/m^3) from the mixtures with compositions of the highly alloyed steel matrix, generate major obstacles towards formation of



(a) (b) (c) (d)

Fig. 1. SEM images at low magnification (a) and (b) and at higher magnification (c) and (d) taken on sample processed by SPS from the powders mixture with composition C (Fe+1%C+24%(WC+15%Co)+11%FeCr+3%V+1%Mo). Images (a) and (b) are measured for secondary electrons mode, while (c) and (d) in backscattering mode. For a flat surface, in the backscattering mode heavier elements (W, V, Mo and Cr) are visible with lighter nuances than Fe.



1-W 2-C 3-Fe

Fig. 2. Local EDS spectra (see Fig. 1d) taken on locations 1–4 show high intensity lines of W in 1, C in 2, and Fe in 3.

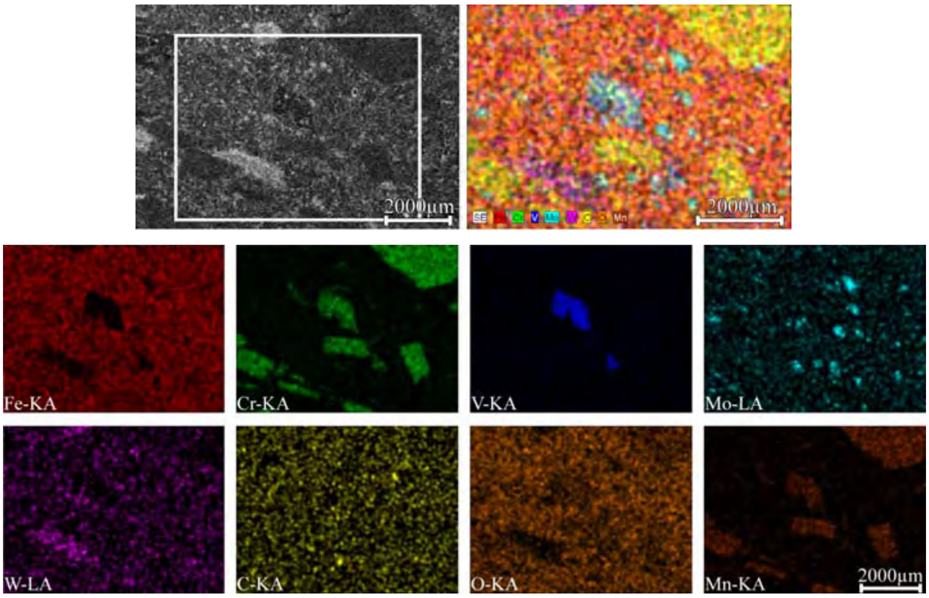
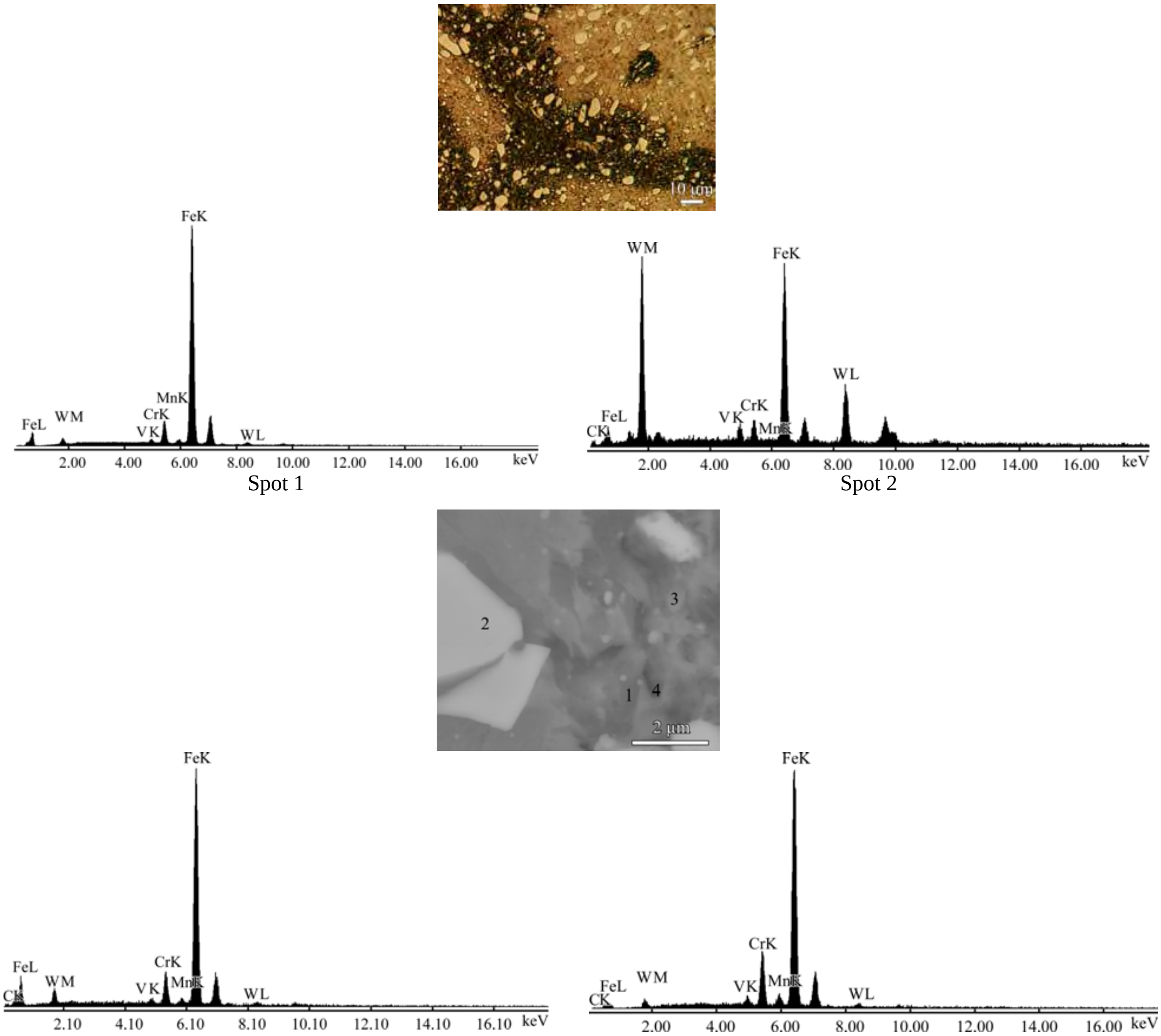


Fig. 3. SEM image and EDS maps of Fe, Cr, V, Mo, W, C, O and Mn taken on sample obtained by SPS from a powder mixture with composition D (Fe, ~ 0,4%C, ~ 0,2%Si, ~ 0,04%P, ~ 1,1%Mn, ~ 0,04%S, ~ 0,15%Al) + 24% (WC+15%Co) + 11% (FeCr) +3%V+1%Mo). RGB image of the indicated maps is also presented and it shows a strong separation of the metals.



Spot 1

Spot 2

Spot 3

Spot 4

Fig. 4. Optical microscopy (surface was etched with 5% HNO_3 in H_2O) and SEM images taken on the same location of the sample obtained by SPS from milled chips of R_{p3} steel. Local EDS spectra were taken on locations 1–4 and (except for spot 2) they show a good uniformity of the matrix.

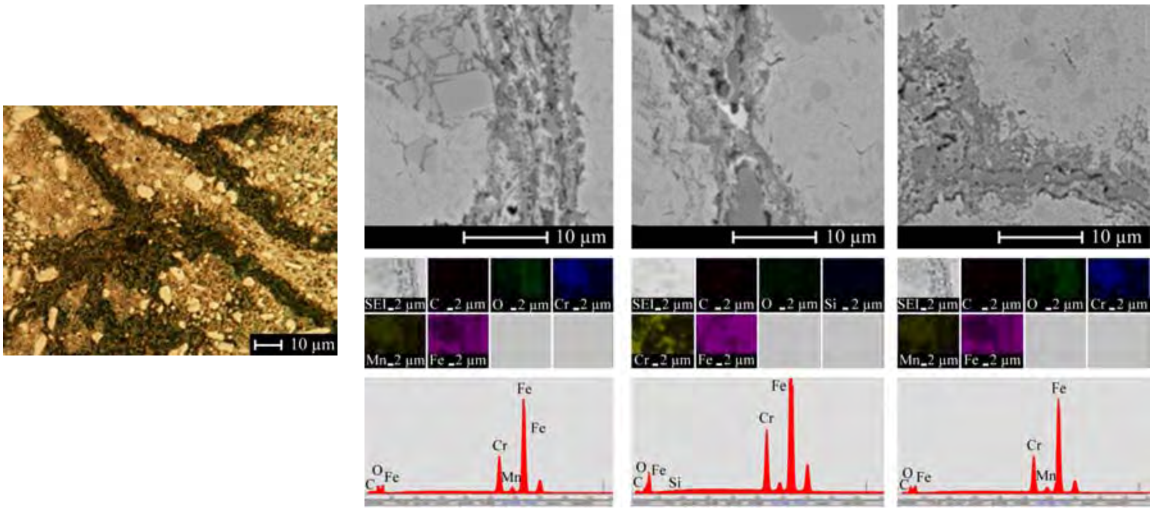


Fig. 5. Optical microscopy (surface was etched with 5% HNO_3 in H_2O) and SEM images taken on different locations on the sample obtained by SPS from milled chips of 205Cr115 steel. EDS maps and local EDS spectra measured on the matrix visible in the three SEM images show a good uniformity of the matrix.

homogeneous mixtures: agglomerations are frequently observed that can induce undesirable chemical and microstructural discontinuities in the steel matrix (for example, see Figs. 1–2 and 3 for compositions C and D, respectively).

To avoid the problems mentioned in the previous paragraph it is necessary to use powders of the indicated steels obtained by melt spraying or by milling of the steel chips. We tested the second way.

Indeed, a highly alloyed steel matrix for tools obtained by either traditional sintering or SPS of the powders prepared by milling of the chips shows high uniformity of the carbides size and distribution. Optical microscopy in Figs. 4 and 5 reveals such improved homogeneity. SEM and EDS taken on different locations confirm this result and also indicate that there are solid solutions of the main alloying elements in the regions between the observable grains and inside those grains. The grains have the specific morphology and composition of simple or complex carbides. It is worth noting here that the EDS spectra taken on the matrix (the region between carbides) show less variation for steel 205Cr115 than for steel R_{p3}. This suggests a high uniformity of Cr distribution in the matrix and a higher homogeneity of the 205Cr115 matrix steel than of the R_{p3} steel matrix.

Although SPS was not promoting interdiffusion of elements in order to obtain solid solutions and samples homogenization when using powder mixtures the formation of a graded layer of about 20–50 µm on the surface of the samples rich in carbon (Fig. 6) is noteworthy. This layer with a decreasing concentration of carbon from the surface into the inner part of the samples contains a high amount of hard carbides and can be useful during the work of the tools. Introduction of a high amount of carbon required in general in steels for cutting tools is not trivial and SPS can contribute in this direction. This has an extra added value considering that the SPS processing time (a few tens of minutes) is very short when compared to traditional sintering (several hours).

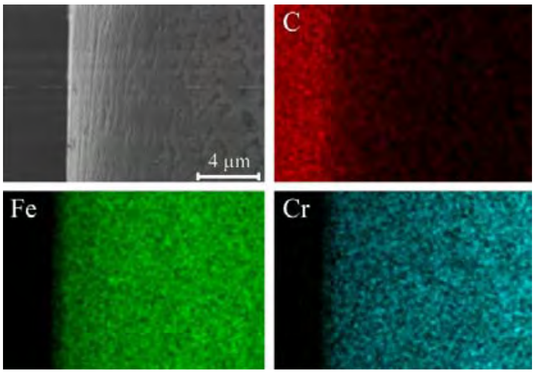


Fig. 6. SEM image of SPSed sample showing formation of the superficial graded layer (~ 20 µm from the metal surface) rich in carbon.

CONCLUSIONS

Usage of either traditional sintering or SPS for the synthesis of steels for cutting and chipless cold cutting tools from precursor powders obtained by milling of the chips resulting from the mechanical processing of the intermediate steel products produced by conventional casting, plastic deformation and heat treatments is a convenient technical solution in order to obtain steel matrix with fine and well distributed carbides. It has been proved that SPS is faster than traditional sintering and provides a graded superficial layer rich in carbides that can be useful during the work of tools.

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Реферат

Как плазменно-искровое спекание (ПИС), так и традиционное спекание были использованы для получения высоко-сплавленной, ледебуритной стали для производства резцов. Использовались порошковые смеси различных соединений и/или компонентов соединений, а также порошки, получаемые при гранулировании стружки, образующейся из исследуемой стали, удаляемой при заготовке деталей. При сравнении с традиционными технологиями (такими как литье и пластическая деформация), применение ПИС и гранулированной стружки приводит к формированию микроструктур с высокой степенью однородности распределения и размерности в твердосплавном режущем инструменте. Как известно, улучшение таких параметров ведет к максимальной эффективности функциональных характеристик режущих инструментов.

Ключевые слова: порошки, высоко-сплавленная сталь, стружка, спекание, плазменно-искровое спекание.