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STEREOLOGICAL PARAMETERS OF CARBIDE PARTICLES AND PROPERTIES OF CONVENTIONAL AND NONLEDEBURITIC HIGH-SPEED STEELS

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ABSTRACT

Using new methods of quantitative description of the microstructure, stereological parameters of primary carbides in conventional and nonledeburitic economical tool alloys were compared. It was established that nonledeburitic alloys, produced with a technology similar to that of typical high-speed steels, present no carbide macrosegregation and only a slight microsegregation, a considerably smaller carbide shape and size inhomogeneity and also a significantly smaller variability of microstructure on the transverse section of forged bars. These alloys show competitive in service properties to those of typical high-speed steels. The results indicate a fundamental importance of carbides segregation and its effect on tool life. The findings also confirm that large carbides of subcritical size diminish less the properties of tool alloys than fine, close lying carbide particles.

Keywords: high-speed steels, quantitative metallography, size, shape and disribution of carbide particles.

INTRODUCTION

A new group of economical, nonledeburitic tool alloys was worked out in the Institute of Materials Science and Engineering (Silesian Technical University) in the late 1980s (Cwajna, 1991). Owing to proper selection of chemical composition some alloys were obtained in which titanium and/or niobium carbide particles were uniformly distributed in a matrix saturated with carbon, tungsten, molybdenum and vanadium, thus with elements ensuring the typical properties of the heat treated high-speed steels. Carbides of MC, M_6C and M_2C types were replaced in these alloys by titanium and niobium carbides i.e by carbides of cheaper elements possesing greater, in comparison with W, Mo, V chemical affinity to carbon.

On the basis of tests carried out in laboratory scale it was found that chemical composition and technological parameters affect all geometrical features of primary carbides in nonledeburitic tool alloys (Cwajna et al., 1989; Malinski et al., 1989).Therefore, the quantitative assessment of the microstructure of new alloys played an important part in the program of industrial tests. It was assumed that the application of quantitative structural criteria for the evaluation of the alloys quality should enable:

- an increase of the efficiency of research works aimed in the development of economical nonledeburitic tool alloys;
- an objective comparison of the microstructure of conventional and nonledeburitic tool materials and the determination of new data on the correlations between microstructure and properties, thus very significant data for further development of the theory of the properties of heterogeneous multicomponent metallic materials.

To compare objectively conventional and nonledeburitic high-speed steels it was necessary to improve the techniques of quantitative assessment of size and shape of carbides (Cwajna et al., 1989; Malinski et al., 1989), as well as to work out the method for quantitative assessment of the inhomogeneity of carbides distribution (Cwajna et al., 1989; Szala et al., 1989; Veit et al., 1989;) and for the quantitative description of the matrix grain size of tool alloys in quenched state (Cwajna et al., 1989). These problems have been comprehensively described in the thesis of Cwajna (1991).

COMPARATIVE STUDIES OF CARBIDE PARTICLES OF CONVENTIONAL HIGH-SPEED STEELS AND NONLEDEBURITIC TOOL ALLOYS

Material tested. S 6-5-2 steel bars of 130 mm in diameter chosen for this comparative studies were produced by conventional technology. SC 0-5-1-2Ti economical nonledeburitic high-speed steel bars of the same diameter were forged from ingots of about 200 kg in weight, total length of 1003 mm, top diameter of 270 mm and bottom diameter of 190 mm. The ingots were cast from steel molten in a vacuum induction furnace with basic lining. The hot working processing of this alloy presented similar difficulties as that of typical high-speed steels.

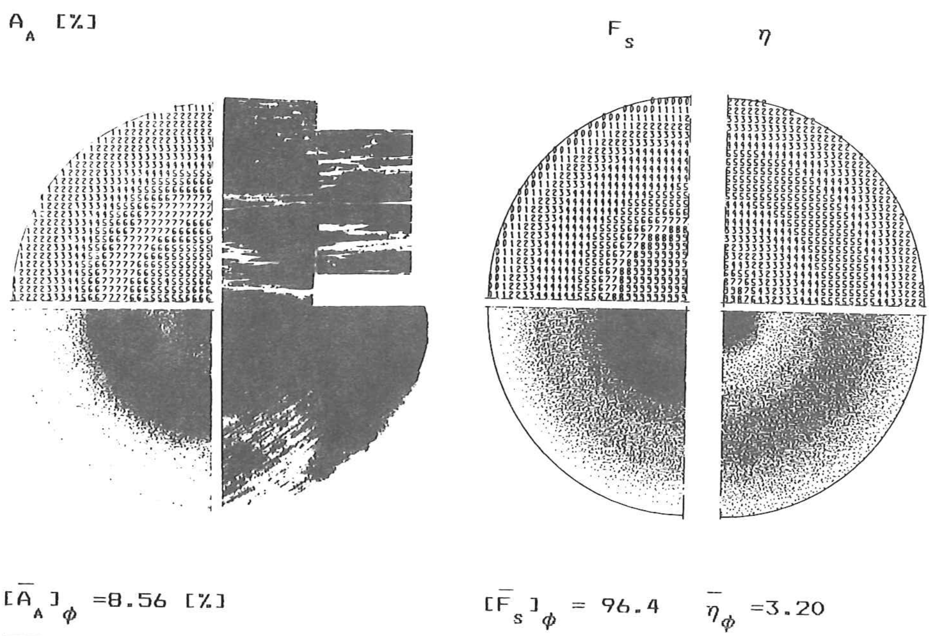
Testing methods. The quantitative evaluation of carbides size and shape was carried out applying the techniques described in earlier works (Cwajna et al., 1989a; Malinski et al., 1989). In accordance with a recommendation given in the paper of Fischmeister et al.(1988), the carbide particles at mutual distance smaller than a diameter of the plastic deformation zone at a microcrack tip, i.e about 1 μm, were processed using a mathematical morphology operation called "closing" in the way presented in the paper (Szala and Malinski, 1990). It arises from the assumption that carbide clusters have the same effect on properties of tool material as a single large precipitate. The segregation of carbides was quantitatively evaluated by the method presented in works (Szala et al., 1989; Cwajna, 1991) and also the image of the microstructure was modiefied by the method already described (Szala and Malinski, 1990).

Results. The nonledeburitic tool material shows no significant carbide macrosegregation. The essential feature of its microstructure is a trace carbide microsegregation which is well illustrated in structural maps (Fig.1 and 2). Particulary worth of mention is the fact that no anisotropy of microstructure was found in the SC 0-5-1-2Ti steel bar of diameter of 130 mm after a very small deformation (of forging reduction ratio amounts to [2.9]). The size of carbide clusters in this bar, characterized by mean chord and its variation coefficient amounts to $\bar{l}_N$=3.7 μm, v(l_N)=62.6 % at the surface of the bar and is less than a half of the thickness of the carbide segregation bands in the S 6-5-2 steel bar of diameter of 130 mm ($\bar{l}_S$=8.9 μm, v(l_S)=87 %). In axial zone the differences are significantly larger ($\bar{l}_N$=4.6 μm and v(l_N)=56.4 %; $\bar{l}_S$=36.9 μm and v(l_S)=144.7 % respectively).

The segregation factor F_S and the anisotropy factor η in the whole transverse cross-section of the bar attain a value of several to more than ten times smaller than in the S 6-5-2 steel (Fig.1÷3).

A feature that distinguishes the economical nonledeburitic tool materials from the conventional high-speed steel is the considerably smaller level of carbide segregation on the transverse cross-section of the bars, which is well shown in structural maps (Fig.1 and 2).

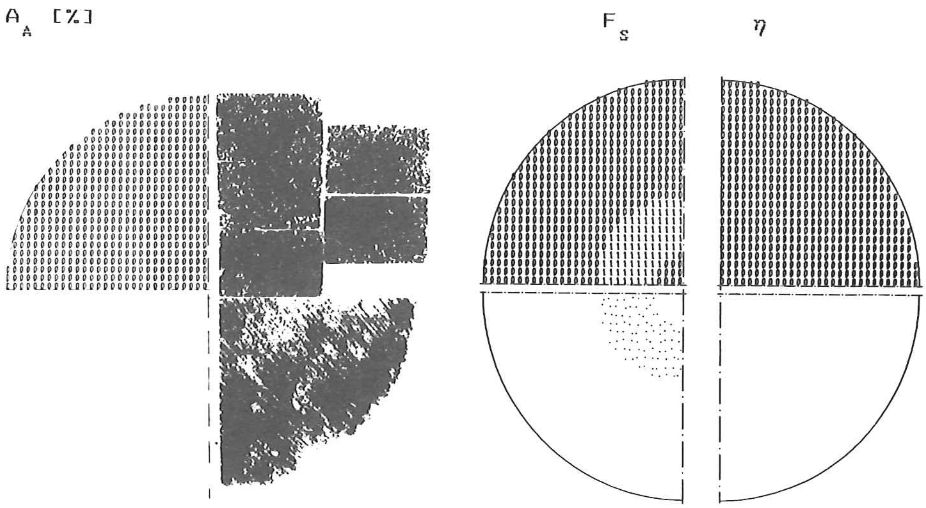
S 6-5-2 steel bar φ 130 [7.1]



A_A 0: 5.0÷5.7; 1: 5.7÷6.4; ... 8: 10.6÷11.3; 9: 11.3÷12.0
F_S 0: 20÷28; 1: 28÷36; ... 8: 84÷92; 9: 92÷100
η 0: 1.0÷1.4; 1: 1.4÷1.8; ... 8: 4.2÷4.6; 9: 4.6÷5.0

Fig.1. Structural maps of carbide segregation in the S 6-5-2 steel bar of diameter of 130 mm.

SC 0-5-1-2Ti alloy bar ϕ 130 [2.9]



$[\bar{A}_A]_\phi$ =3.8 [%] $[\bar{F}_s]_\phi$ = 23.8 $\bar{\eta}_\phi$ =1.10

A_A	0: 5.0÷5.7;	1: 5.7÷6.4;	...	8: 10.6÷11.3;	9: 11.3÷12.0
F_S	0: 20÷28;	1: 28÷36;	...	8: 84÷92;	9: 92÷100
η	0: 1.0÷1.4;	1: 1.4÷1.8;	...	8: 4.2÷4.6;	9: 4.6÷5.0

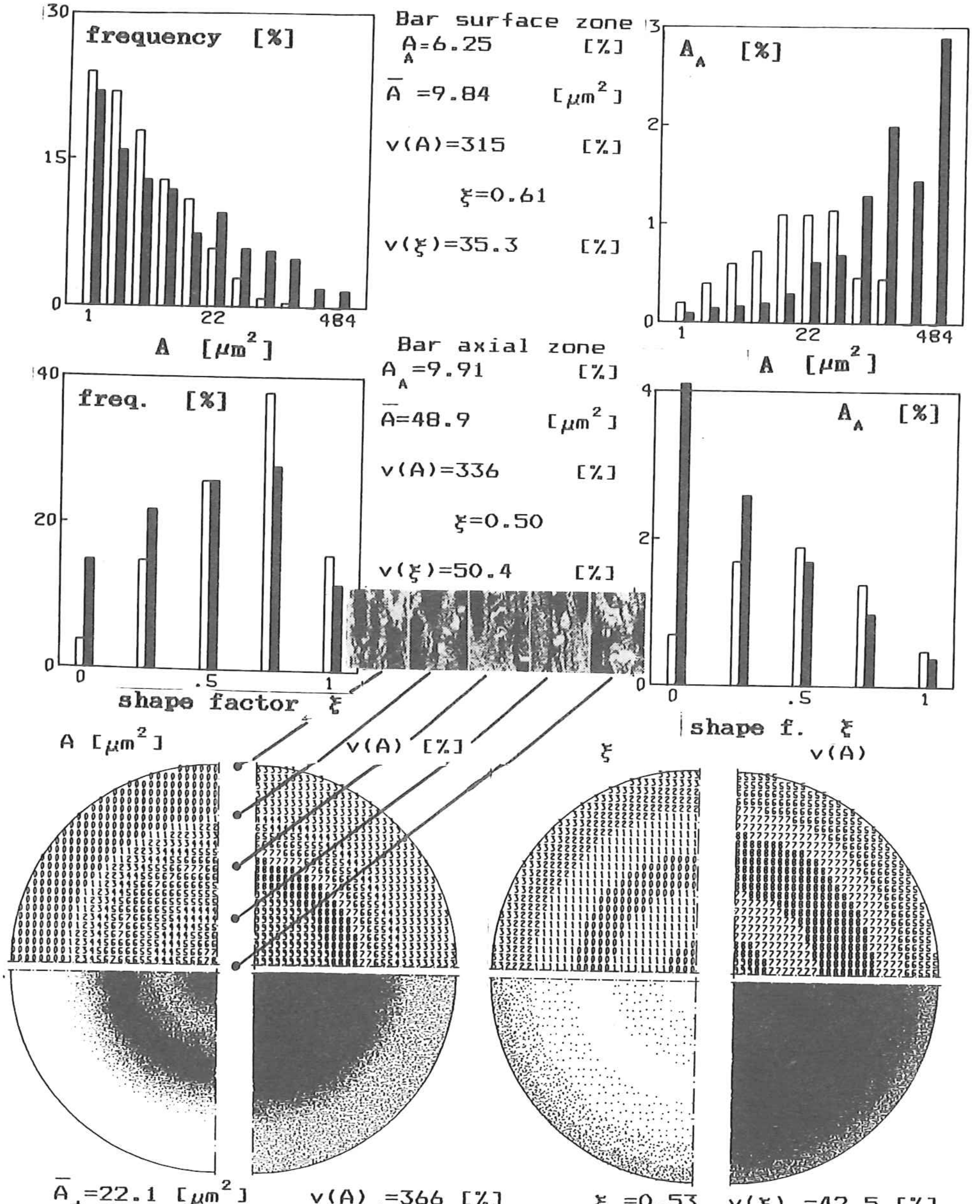
Fig.2. Structural maps of carbide segregation in the SC 0-5-1-2Ti steel bar of diameter of 130 mm.

It was found that the distributions of the $A_{Ai}=f(A_i)$ type reflect considerably better the features of carbide phase in the tool material than the commonly used distributions of $n_i=f(A_i)$ type (Fig.3 and 4).

The comparison of quantitative data on carbide particles in the S 6-5-2 steel bar of diameter of 130 mm (Fig.3) with results published in earlier works (Cwajna et al., 1989; Malinski et al., 1989) confirms a strong tendency of this steel to form clusters of carbides with a mutual distance smaller than 1 μm. The "closing" operation that allows to consider the clusters as singular precipitate leads to a considerable increase in the apparent carbides size and volume fraction.

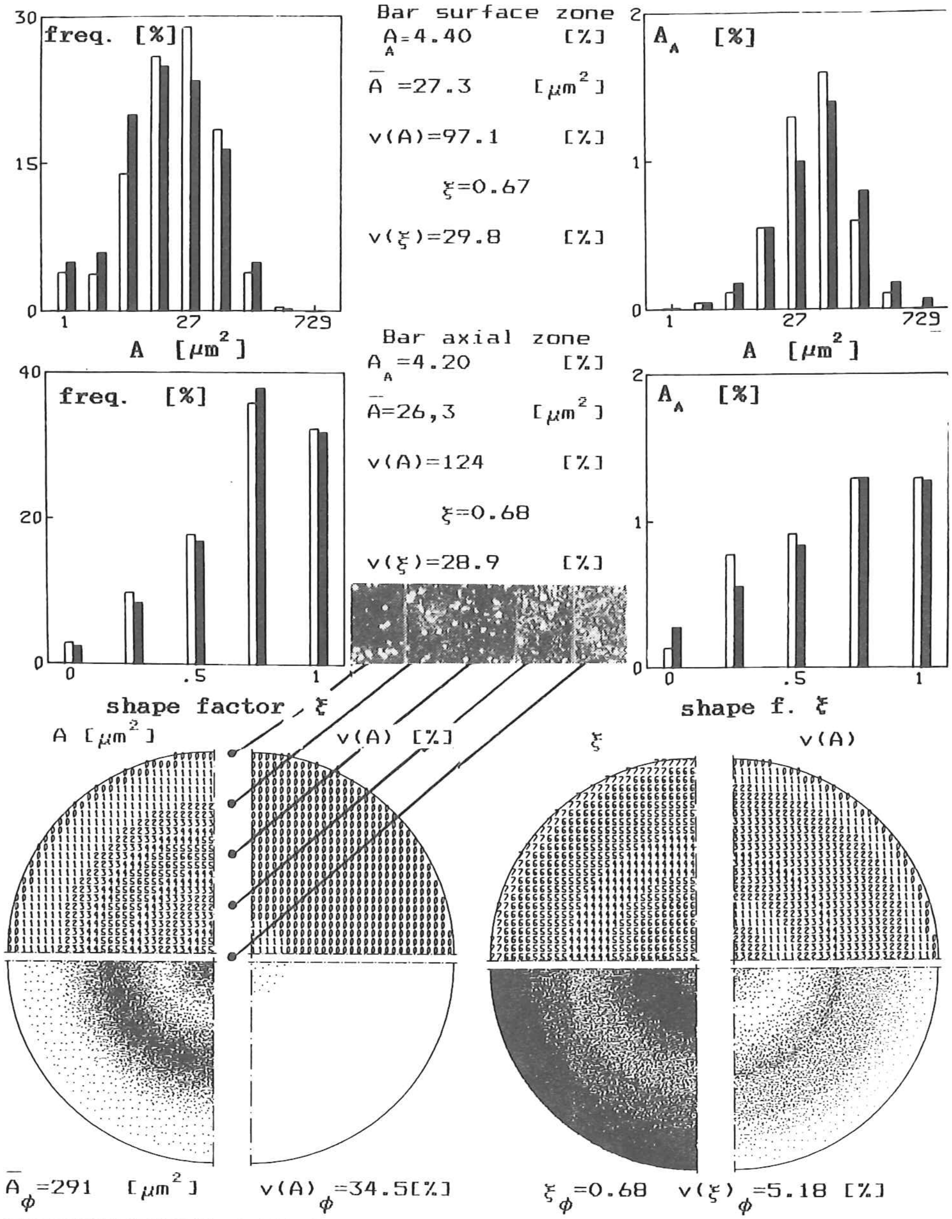
The analysis of data concerning the size of carbides both in a conventional S 6-5-2 grade of high-speed steel (Fig.3) and a nonledeburitic steel (Fig.4) leads to the following conclusions:

1. The differences in carbide shape and size on the transverse cross-section of the bar are considerably smaller in the nonledeburitic alloy than in the S 6-5-2 steel;



$\bar{A}$	0: 15÷19;	1: 19÷23;	...8: 47÷51;	9: 51÷55
v(A)	0: 100÷125;	1: 125÷150;	...8: 300÷325;	9: 325÷350
ξ	0: 0.50÷0.53;	1: 0.53÷0.56;	...8: 0.74÷0.77;	9: 0.77÷0.80
v(ξ)	0: 20÷23;	1: 23÷26;	...8: 44÷47;	9: 47÷50

Fig.3. Quantitative characteristic of carbide particles size and shape in S 6-5-2 steel φ 130 mm bar (forging reduction ratio = 7.1)



$\bar{A}$	0:	15÷19;	1:	19÷23;	...8:	47÷51;	9:	51÷55
v(A)	0:	100÷125;	1:	125÷150;	...8:	300÷325;	9:	325÷350
ξ	0:	0.50÷0.53;	1:	0.53÷0.56;	...8:	0.74÷0.77;	9:	0.77÷0.80
v(ξ)	0:	20÷23;	1:	23÷26;	...8:	44÷47;	9:	47÷50

Fig.4. Quantitative characteristic of carbide particles size and shape in SC 0-5-1-2Ti steel φ 130 mm bar (forging reduction ratio = 2.9)

2. In SC 0-5-1-2-Ti and S 6-5-2 bars of equal diameter carbides of similar mean size are present. In spite of this the carbide inhomogeneity of the nonledeburitic alloy is significantly smaller;
3. A high volume fraction of large carbides with low shape factors (of lamellar and complex shape) in the axial zone of the bar is a specific feature of the high-speed steel, and it is not found in the nonledeburitic alloy;
4. The carbides show in nonledeburitic alloy larger mean values of shape factor and also a considerably smaller variation coefficient of this stereological parameter.

Tool produced from nonledeburitic alloys showed in various applications a tool life longer by 20 % or at least equal to that of the tools produced from conventional high-speed steels (Table 1). Chipping of tool points or cracking was in no case the reason of wear of the tools.

Table 1. Results of performance tests of tools produced from nonledeburitic SC 0-5-1-2Ti alloy

Steel grade and kind of a tool	Production plant (producing and testing tools)	Results of performance tests
SC 0-5-1-2Ti Profile cutter for twist drill machining	Steel Plant BAILDON Katowice	118.5 % tool life of that of previously used cutters made of S 18-0-1 (SW18) steel grade
SC 0-5-1-2Ti Rolling segments for roll forming of spiral drills	Steel Plant BAILDON Katowice	Tool life similar to that of previously used segments made of S 12-1-5-5 (SK5V) steel grade
SC 0-5-1-2Ti Profile cutter for saw blades machining	Saws and Tools Factory WAPIENICA Bielsko-Biala	116.7 % tool life of that of previously used cutters made of S 6-5-2 (SW7M) steel grade
SC 0-5-1-2Ti Gear cutting hob	FSM Bielsko-Biala	Tool life similar to that of previously used cutters made of S 6-5-2 (SW7M) steel grade

The main feature of nonledeburitic alloys is their considerably smaller inhomogeneity of all microstructural parameters in comparison to that of conventional high-speed steels.Data concerning the matrix grain size of tested materials in quenched state were presented elsewhere (Cwajna, 1991).

The obtained results confirm the fundamental importance of carbide segregation for the tool life and confirm the conclusion of Lee and Worzala (1981), Shelton and Wronski (1983), Karagoz and Fischmeister (1987), Wronski and Rebbeck (1988) as much as Pacyna (1988), that the presence of large carbides (but of the size not exceeding that of critical defect), is more desirable for the quality of tools than that of fine closely packed carbides.

CONCLUDING REMARKS

The investigations concerning the relations between microstructure and properties of tool materials were, up to the present, carried out predominantly on specimens with dispersed phase particles of similar size, evenly distributed in a matrix. The techniques of quantitative assassment of tool materials microstructure presented in this paper and in earlier work (Cwajna et. al., 1989a), are appropriate also for the investigation of metallurgical products and tools of middle and large transverse dimensions i.e to materials with inhomogeneously distributed carbide particles of considerably various shape and size.

Namely, the following problems were solved:

- the objective method of the inference about the type and the intensity of inhomogeneity of carbide particles distibution;
- the determination of the fraction of carbides of various size and shape;
- the quantitative description of matrix grain size in quenched state;
- the characterization of the inhomogeneity of microstructure on the transverse and longitudinal sections of bars and tools with the structural maps.

The findings could facilitate the studies of these relations and could lead to a revision of the accepted views on the optimal microstructure of the tool alloys. The conclusion issuing from the quoted references concerning the fundamental importance of the segregation of carbide particles on tool life, as well as the conclusion of a more desirable influence on this property of large carbides of subcritical size than fine particles at small distance were confirmed. Moreover, the existence of the correlation between the tool life and the as-quenched matrix grain size inhomogeneity (associated with chemical and structure inhomogeneity of alloys matrix after heat treatment) was proved (Cwajna, 1991).

The structural maps presented in this work show a considerable variability of the microstructurere of metallic tool materials on both transverse and longitudinal sections of metallurgical products. Therefore, random selection of a tested microregion, commonly applied in the investigations of the relations between tool materials properties and microstructure, seems to be a methodical mistake. The application of the structural maps is then indispensable for the proper selection of correlated data.

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