ACTA STEREOL 1994; 13/2: 329-334
PROC 6ECS PRAGUE, 1993
ORIGINAL SCIENTIFIC PAPER

MODELLING OF HOT REDUCTION EFFECT ON CARBIDE PHASE OF TOOL ALLOYS

Marian MALIŃSKI, Jan CWAJNA, Janusz SZALA and Franciszek GROSMAN*

Silesian University of Technology
Department of Materials Science
Department of Mechanics and Plastic Working Technology*
Krasińskiego 8, PL-40-019 KATOWICE, POLAND

ABSTRACT

The subject of this study was the influence of local deformation on carbide particles size, shape and distribution in bars of diameter ranging from ϕ 150 mm to ϕ 40 mm made of S 6-5-2 ESR and SC 0-5-1-2Nb high-speed steels.
The local deformations distribution on the transverse cross-sections of the bars forged in radial-forging machine was calculated by means of the finite-elements method (thermo-mechanical modelling). Carbide particles size, shape and distribution were evaluated with an image analyser MORPHO-PERICOLOR.
The empirical equations showing the effect of local deformation on stereological and morphological parameters of carbide particles were determined. The "structural maps" show-ing the variation of microstructure on the transverse cross-section of the bars were plotted.
The final result of this work is a programme for selection of forging parameters (local deformation distribution) with respect to the initial values of carbide particles stereological parameters as well as to the assumed microstructure variation on transverse cross-section of the final product.

Key words: tools alloys, quantitative metallography, computer simulation and modelling, plastic working.

INTRODUCTION

Hot reduction is a stage in multistage processing of high-speed steels controlling the carbide particles macro- and microsegregation, i.e. the microstructural features significantly affecting the technological and mechanical properties of the steel as well as the tool life time. In the modern radial-forging process the stock round bar is forged between the dies which compress the material from four sides. Total plastic deformation of the bars is a result of small portional reductions applied in a large number of subsequent strokes. Each cycle of radial-forging process consists of a stroke which is followed by a feeding movement of a bar. The variables in the process are: forging scheme, initial and final temperature of forging, feeding rate of the bar, deformation under single impact, deformation in roll-pass as well as the total reduction. They influence the following criteria of the bars quality evaluation: dimensional deviations, circularity, surface roughness, internal voids as well as the microstructure refinement and inhomogeneity.
An extensive review of works dealing with a radial-forging is given by Grosman (1980). In this thesis and in the work (Grosman, 1986) the quantitative relationships between the local deformation, determined by "compound bar" method, and carbide particles size and segregation are shown. Over

a few recent years these studies have been continued and extended. An application of the finite-elements method (thermo-mechanical modelling) made it possible to calculate more precisely the local deformations distribution on transverse cross-section of the radial forged bars (Piela, 1992,). Moreover, the methods of quantitative assessment of carbide particles size, shape and distribution inhomogeneity were improved (Cwajna, 1991). Their accuracy and practical applicability were verified in the investigations of conventional and nonledeburitic high-speed steels with elevated hardness (Cwajna et al., 1991 and 1992). As a results there were created the conditions for the versatility evaluation of previously mentioned empirical equations and also for the improvement of the PC-computer program for radial-forging parameters selection in accordance to the bars destination for specific tools. To this end the following programme of the investigations was performed:

- the calculation of a local deformations distribution on transverse cross-section of the bars as a function of radial-forging parameters with the finite-elements method,
- the quantitative evaluation of carbide particles size, shape and distribution variability on the transverse cross-section of the bars made of conventional and new high-speed steels,
- the determination of empirical equations showing the effect of local deformation on carbide particles morphological and stereological parameters.

MATERIALS TESTED

Chemical composition of electro-slag remelted steel S 6-5-2 ESR and economical high-speed steel of elevated hardness SC 1-5-1-2Nb is presented in Table 1.

Table 1. Chemical composition of investigated high-speed steels

Steel	C	Mn	Si	Cr	W	Mo	V	Nb	P	S
SC 1-5-1-2Nb	1.59	0.37	0.41	4.45	1.07	5.20	1.26	1.93	0.30	0.29
S 6-5-2 ESR	0.84	0.27	0.48	3.87	6.85	5.90	2.10	-	0.23	0.13

The bars made of S 6-5-2 ESR steel with diameter ranging from ϕ 156 mm to ϕ 48 mm were forged from the same ingot ◪ 330/290×1200 mm of about 860 kg of weight. SC 1-5-1-2Nb steel bars of ϕ 130 mm to ϕ 40 mm in diameter were produced from the ingot ◪ 320/290×1100 mm weighing 550 kg, casted from steel molten in a vacuum induction furnace with a basic lining. The bars of the steels were radial-forged by conventional technology with hot reduction rates: 5.5, 6.4, 8.5, 11.6, 19.9, 33.6 and 52.5.

TESTING METHOD

The local deformation distributions on the transverse cross-sections of the bars were calculated by the method in which the rigid-plastic flow formulation and generalized plane strain finite-element approach were applied to the simulation of metal flow and thermal effects in radial-forging. As a result the distributions of strain rates, strains and temperature on cross-section of the bars were obtained.

The microstructure was examined on longitudinal sections in an axial zone and in the microregions laying in the distance 0.25R, 0.5R, 0.75R and R (bar radius) from the bar symmetry axis. Quantitative evaluation of carbide particles size and shape was performed at the microscope magnification 500× with the method presented in details in the previously quoted our works.

Carbide particles distribution inhomogeneity was assessed by means of systematic scanning and variance analysis method (Szala et al., 1989 and Wiśniewski et al., 1992), at the magnification 100×. Ten measuring frames of area ranging from 12.99 μm^2 to 116.95 μm^2 were applied in this method. Fractal dimension of coefficient of variation $v(A_A)= s(A_A)/\overline{A}_A$ ($\overline{A}_A$ - mean area fraction of particles in measuring frame; $s(A_A)$ - empirical standard deviation), was applied as a carbide particles distribution inhomogeneity factor (Fig. 1).

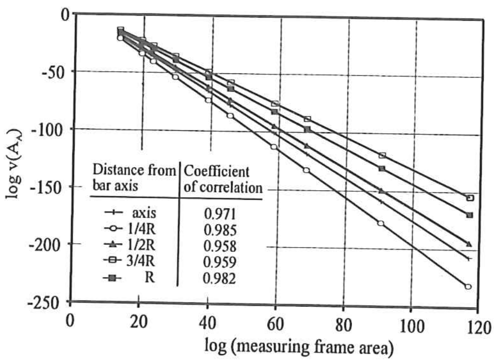

Fig. 1. Log-log plot of coefficient of variation of carbide particles area fraction, measuring frame area in systematic scaning and variance analysis method.

RESULTS AND CONCLUDING REMARKS

Selected results of quantitative evaluation of carbide phase in the investigated bars are presented as "structural maps" (Fig. 2 and 3) as well as the distributions reflecting carbides segregation (Fig. 4). The examples of local deformation distributions on transverse cross-section of the bars are shown in Fig. 5. With a help of relevant statistical methods the empirical equations describing the effect of local deformation on carbide particles size, shape and distribution inhomogeneity were determined (Fig. 6). The comparison of "structural maps" plotted on the basis of quantitative metallography data and obtained by modelling with the application of worked-out PC-computer program is demonstrated in Fig. 7.

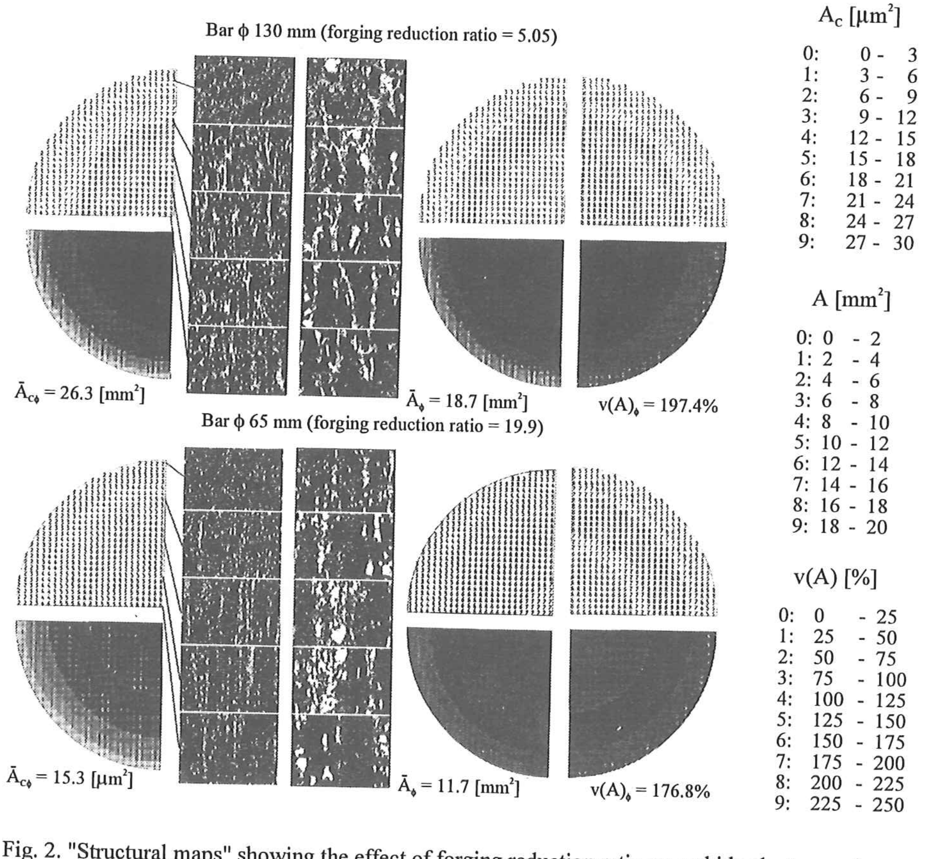

Fig. 2. "Structural maps" showing the effect of forging reduction ratio on carbide clusters and particles size variation on transverse cross-section of SC 1-5-1-2Nb high-speed steel bars.

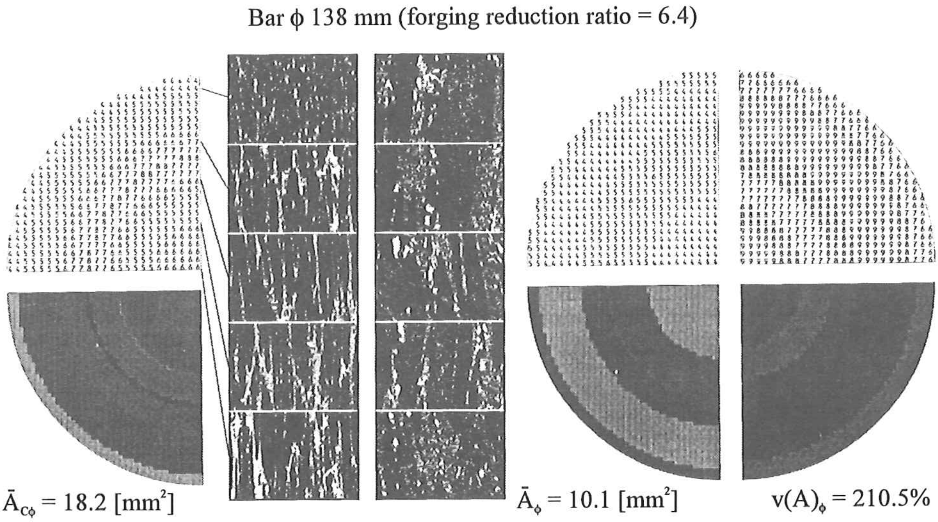

Fig. 3. "Structural maps" showing carbide clusters and particles size variation on transverse cross-section of S 6-5-2 ESR high-speed steel bar (notation as in Fig. 2).

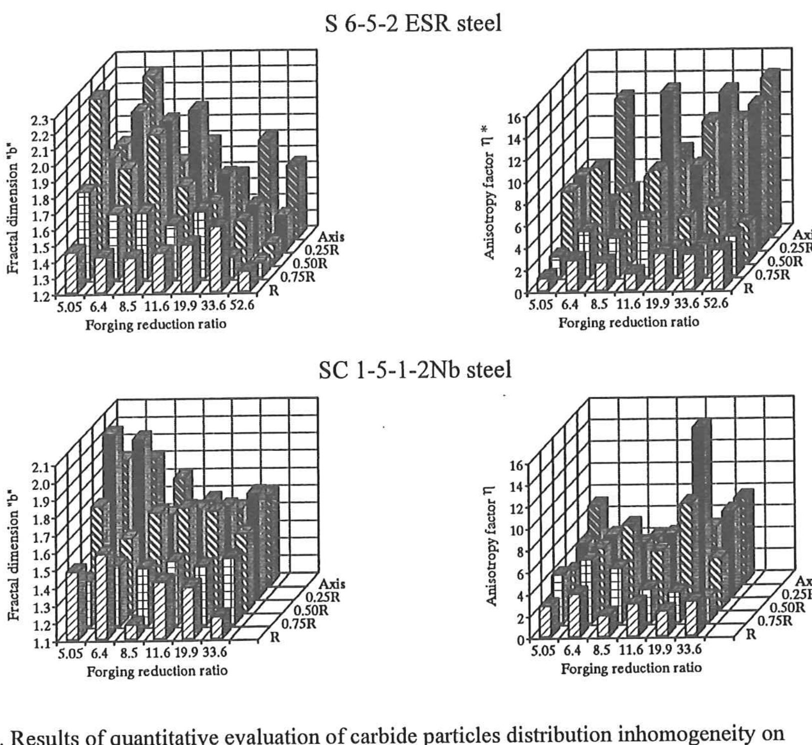

Fig. 4. Results of quantitative evaluation of carbide particles distribution inhomogeneity on transverse cross-sections of the investigated bars.
* data for measuring frame area 29.2 μm²

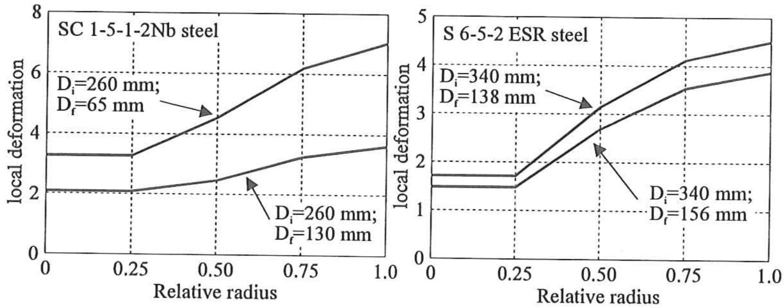

Fig. 5. Example local deformation distributions on transverse cross-section of investigated bras, determined by finite element method.

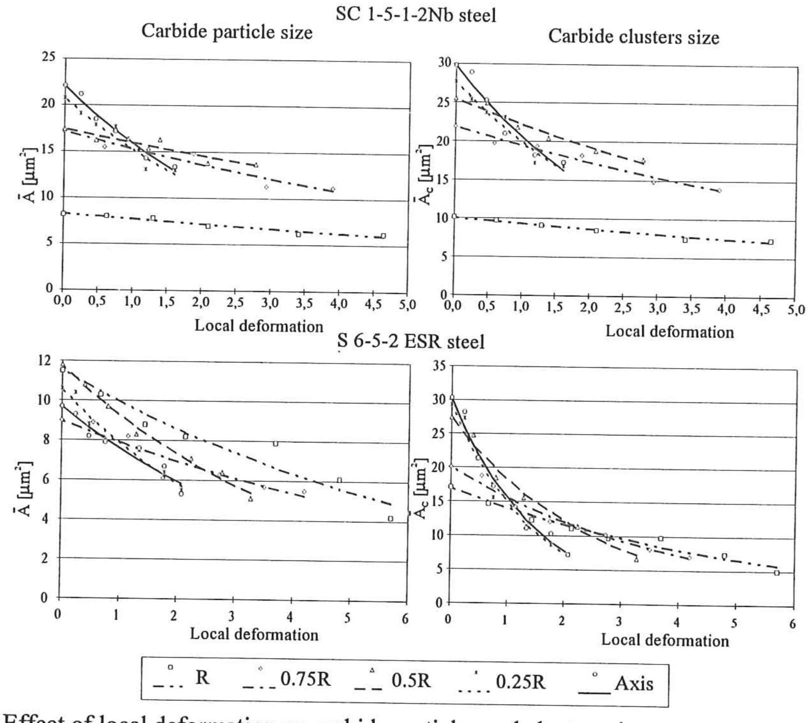

Fig. 6. Effect of local deformation on carbide particles and clusters size.

The conclusions that can be drawn from the analysis of these data are the following:

1. The increase of local deformation causes a significant carbide particles refinement [$\overline{A}\downarrow$ and $v(A)\downarrow$] and rounding [$\xi\uparrow$ and $v(\xi)\downarrow$] as well as the distinct improvement of microstructure homogeneity [$\overline{A}_C\downarrow$ and $b\downarrow$] of both steels. This effect is more intensive for carbide particles and their clusters of larger initial size.
2. The feature that distinguishes economical SC 1-5-1-2Nb steel from conventional S 6-5-2 ESR steel is a considerably smaller inhomogeneity distribution [$b<$, $\eta<$] of larger carbide particles [$\overline{A}>$] with more homogenous size [$v(A)<$] and shape [$v(\xi)<$]. S 6-5-2 ESR steel shows larger tendency to form cluster of carbides [$\overline{A}_C/\overline{A}>$]. This is particularly valid for large diameter bars.

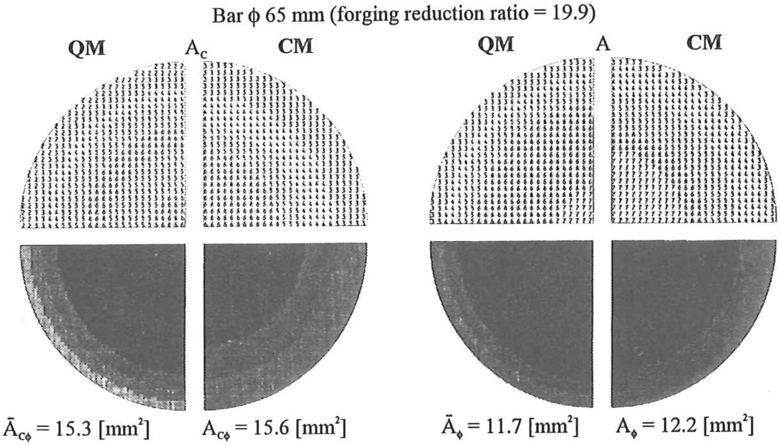

Fig. 7. Comparison of the results of quantitative evaluation (QM) and computer modelling (CM) of carbide clusters and particles size on transverse cross-section of SC 1-5-1-2Nb steel bar (notation as in Fig. 3).

3. Radial-forging reduction ratio ensures substantial decrease of microstructure variability on transverse cross-sections of the bars. However, the inheritance of microstructure inhomogeneity is clearly presented by "structural maps" of the bars with large and small diameter.
4. For all microregions of investigated bars on the curves showing the influence of local deformation on carbides distribution inhomogeneity factors the several peaks can be observed. Therefore, it seems that there exist some critical deformation rates at which the microstructure detoriates. These findings correspond to those obtained for computer simulated net structures (Szala et al., 1989) and cluster structures (Wiśniewski et al., 1992).
5. "Structural maps" shown in Fig. 7. indicate, that the work-out PC-computer program ensures correct modelling of radial-forging parameters effect on high-speed steel microstructure.

ACKNOWLEDGEMENTS

This work was supported by the Polish Committee for Scientific Research, under grant No 708309101.

REFERENCES

Cwajna J., Richter J., Szala J. Stereological Parameters of Carbide Particles and Properties of Conventional and Nonledeburitic High-Speed Steels. Acta Stereol. 1991; 10/1: 63-71.

Cwajna J., Myalska-Olszówka A., Szala J. Stereological Parameters of Carbide Particles and Properties of Economical High-Speed Steels of Elevated Hardness. Acta Stereol. 1992; 11/suppl. 1: 431-438.

Cwajna J. Tool Alloys Microstructure Quantitative Evaluation and Its Application. DSc Thesis. Zeszyty Naukowe Politechniki Śląskiej, "Hutnictwo", z. 39, Gliwice; 1991.

Grosman F. Analiza wpływu procesu kucia w kowarkach na własności wyrobu. Zeszyty Naukowe Politechniki Śląskiej, "Hutnictwo", z. 22, Gliwice; 1980.

Grosman F. The effect of plastic defarmation on the carbide phase on high-speed SKC-steel. Archiwum Hutnictwa, 1986, tom 31/4: 721 - 736.

Piela A. Studies on the applicability of the finite element method to the analysis of swaging proces. Archives of Metallurgy, 1992, V. 37/4: 425 - 443.

Szala J., Cwajna J., Wiśniewski A. The Systematic Scanning and Variance Analysis Method for Evaluation of Particles Distribution. Acta Stereol. 1989; 8/2: 237-242.

Wiśniewski A., Szala J., Cwajna J. The Systematic Scanning and Variance Analysis Method for Evaluation of Cluster Structures. Acta Stereol. 1992; 11/suppl. 1: 617-623.