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STEREOLOGICAL ASSESSMENT OF SECONDARY CARBIDE PARTICLES IN NONLEDEBURITIC HSS USING ELECTRON MICROSCOPY

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ABSTRACT

The secondary carbide particles in nonledeburitic high-speed steel has been investigated. It was found that employing the scanning electron microscopy was indispensable stage of the stereological assessment of the carbide phase in this steel. The $M_{23}C_6$ type carbides precipitated while tempering have been characterized by area fraction, mean size (mean area of plane section), size distributions, mean shape factor and shape factor distribution. Owing to longer time of austenitizing, area fraction and mean size of the secondary carbides increased, which were accompanied by more homogeneous distribution of these particles in the matrix.

Key words: carbide particles, heat treatment optimization, stereology, tool life.

INTRODUCTION

Insufficient resolution and magnification employed while measuring carbide particles in HSS seem to be the reasons of erroneous estimation of both local and integral stereological parameters of this phase. Moreover, confining to investigations based only on light microscopy makes it impossible to establish even qualitatively certain structural factors of HSS's performance. Consequently it is difficult to shape effectively these steels' microstructure through technology optimization. Obviously large particles of the size more than approximately 1 μm, also inhomogeneously distributed in a matrix, may be successfully assessed with image analysers working with light microscopy. Hence, proper selection of microscope's parameters is of importance and significantly affects accuracy of stereological investigations of dispersed phase in HSS (Richter, 1994).

MATERIAL

The alloying philosophy of nonledeburitic high speed steel (NHSS) consists in the proper balance of carbon's and carbide former's (mainly Ti and Nb) contents (Cwajna, 1991). Such a chemical composition (Tbl.1) assures replacement of eutectic carbides typical in common grades of HSS by uniformly distributed TiC and NbC primary carbides. Both metallographical specimens and lathe tools were made of the forged bars of 25 mm in diameter and given heat treatment by annealing, hardening and tempering of various parameters.

Table 1. Concentrations of relevant elements in the inestigated NHSS [wt %]

C	Mo	Cr	Ti	Nb	V
1.98	5.25	4.26	3.19	2.10	1.16

EXPERIMENTAL

In the previous work (Richter et al., 1994a) so called joined light and electron microscopy method permitted to assess thoroughly area fraction of carbide phase in the NHSS in question. Large primary MC type carbides of the size between 1 and 250 μm^2 were optically examined whereas the smaller fraction (below 1 μm^2) was observed and measured by means of electron microscopy.

Since final properties of cutting tools made of HSS are obtained on tempering, the specimens were given tempering (2x1 hour) in ten various temperatures. Previous hardening was also differentiated, it was performed in two variants - with austenitizing for 3 and 7 minutes. Then Rockwell hardness (HRC) was measured, the tempering curve (Fig.1) shows the influence of tempering temperature upon the investigated steel's hardness.

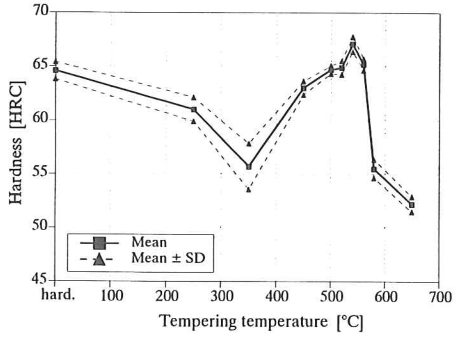


Fig.1. The influence of tempering temperature upon hardness of NHSS austenitized for 7 minutes.

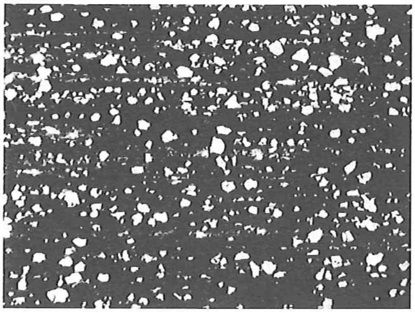


Fig.2. Structure of as - tempered (540°C) NHSS - primary MC type carbides light microscope, 620X.

It is to be seen (Fig.2) that light microscopy does not reveal the secondary carbides precipitaded while tempering and only large primary carbides are visible. Owing to higher resolution of scanning electron microscopy the secondary $M_{23}C_6$ type carbides (identified by electron and X-ray diffraction) become clearly visible (Fig.3).

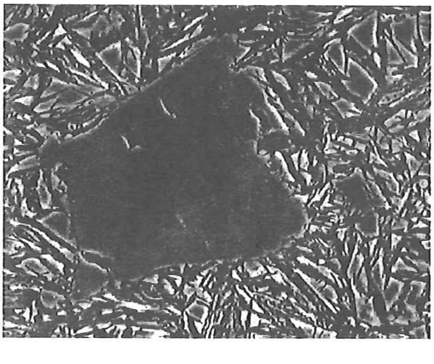
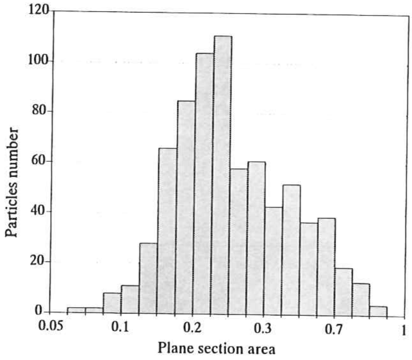


Fig.3. Structure of as - tempered (540°C) NHSS austenitized for 7 minutes - large MC type carbide in the centre, $M_{23}C_6$ type secondary carbides, SEM, BSE, 7500X.

Mean size (mean area of plane section) of these carbide particles amounts 0.36 μm^2, the carbides' size distributions were shown in Fig.4.



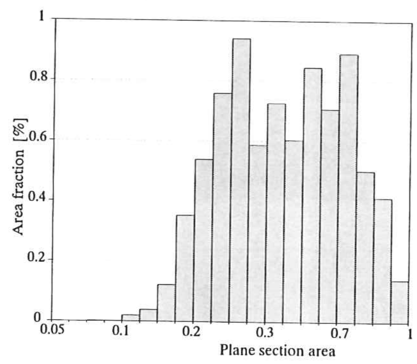


Fig.4. Statistical (left) and geometrical (right) distributions of secondary $M_{23}C_6$ type carbide particles' size [μm^2], austenitizing time - 7 minutes

Above results, like all rest ones concerning stereological features, were obtained with the Morphopericolor automatic image analyser and using morphological operations in order to improve image's quality.

Specific, arrow or plate-like, shape of the secondary $M_{23}C_6$ carbides was reflected by the mean value of shape factor $\xi=4*\pi*\text{area}/(\text{perimeter})^2$ amounting 0.4 (Richter et al., 1994a), the distribution of these particles' shape factor is shown in Fig.5.

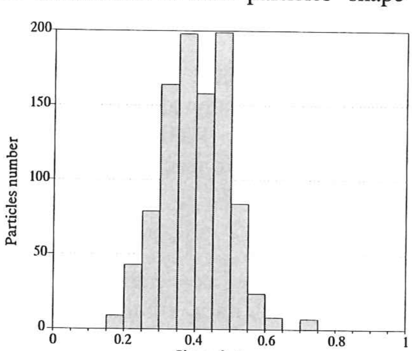


Fig.5. Distribution of secondary $M_{23}C_6$ type carbides' shape factor.

Area fraction of the discussed secondary carbides determined on the basis of the scanning microscope image is equal 6.34% (Richter et al., 1994a). This value concerns the NHSS tempered at 540°C and austenitized for 7 minutes. The specimens austenitized shorter (for 3 minutes) after similar tempering gained significantly (Student's test was applied) lower hardness - respectively 65.6 and 67.1 HRC. The $M_{23}C_6$ carbides in the steel treated this way are not distributed in the matrix as homogeneously as in the case of the specimens austenitized for 7 minutes - zones with no precipitations are to be seen (Fig.6). This phenomena is accompanied by the lower (4.48 %) area fraction in comparison with that of specimens austenitized longer (6.34 %). The next characteristic of the carbides precipitated while tempering the NHSS austenitized for 3 minutes is their mean size equal 0.27 μm^2 which is significantly smaller than that of secondary carbides in the specimens austenitized longer. The size distributions (Fig.7.), especially the geometrical one, show decrease in area fraction of the particles of the size about 1 μm^2.

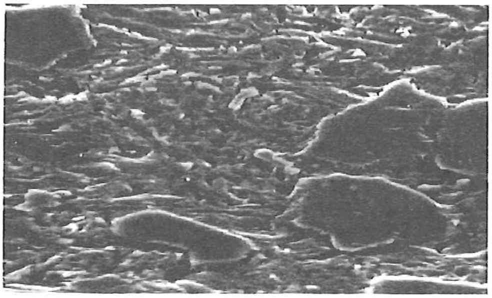


Fig.6. Structure of as - tempered (540°C) NHSS austenitized for 3 minutes - inhomogeneous distribution of secondary $M_{23}C_6$ carbides, SEM, SEI, 2560X

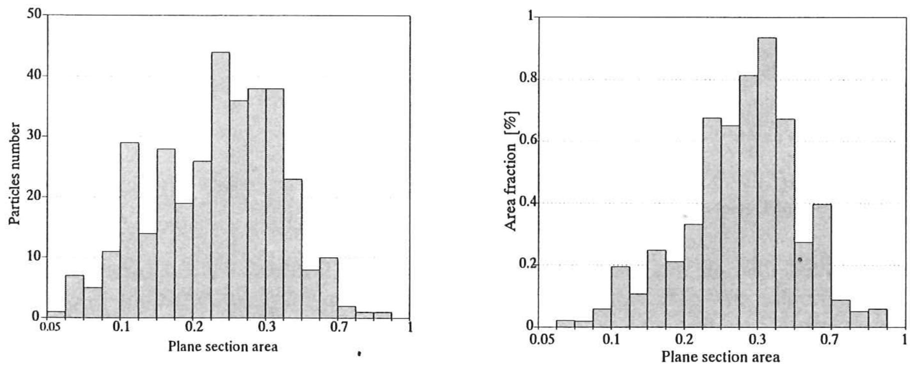


Fig.7. Statistical (left) and geometrical (right) distributions of secondary $M_{23}C_6$ type carbide particles' size [μm^2], austenitizing time - 3 minutes

It was found that fine sferoidical M_6C type carbides closely surrounded MC large primary carbides. Shape factor of the MC carbides when examined optically amounts to 0.67, whereas when employed scanning microscope it decreases to 0.48 (Richter, 1994). Still smaller, equal 0.41, value was obtained when the SEM magnification reached 25000 times (Fig.8).

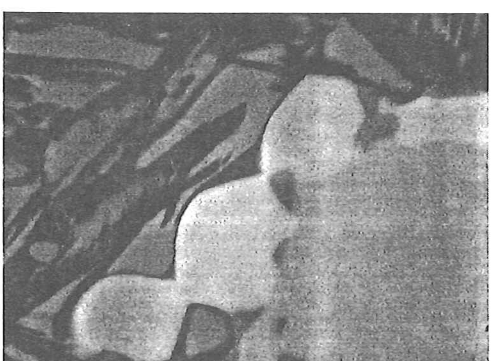


Fig.8. Structure of as - tempered NHSS - M_6C satellites around MC type carbides, SEM, BEI, 25000X

It is noteworthy that BEI image differentiates contrasts of MC and M_6C carbides due to difference in these carbides' mean atomic number, which is of interest as far as automatic detection is concerned. Although hardness is very important factor of HSS's structure optimization as the decisive criterion of its evaluation, properties of cutting tools were accepted. Therefore the lathe tools of the investigated steel were made. To estabilish the influence of heat treatment on cutting ability, service life of tools heat treated in various ways was tested. The degree of flank wear (Fig.9) was measured, the worn tools' sections preserved with nickel and copper electrodeposits were examined useing scanning electron microscopy (Fig.10).

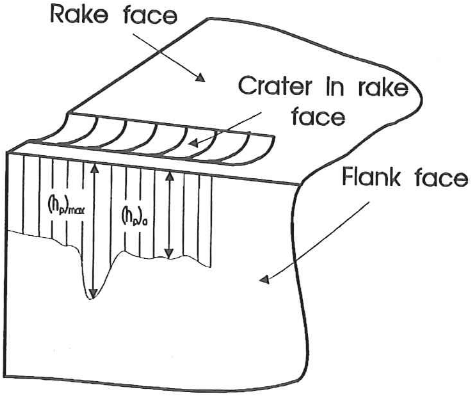


Fig.9. Diagram of tool tip showing wear zones

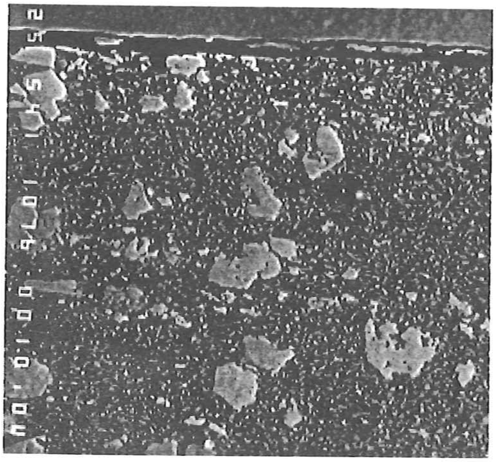


Fig.10. Section parallel to cutting edge - uniform wear of MC primary carbides, light microscope, 540X

The tests performed using a continuous cutting speed ranged from 40 to 70 m/min showed that the average flank wear $(h_p)_a$ of the lathe tools made of NHSS austenitized for 7 minutes was smaller in comparison with that of tools austenitized shorter.

CONCLUSIONS

On the basis of the obtained results we can state in conclusion that:

1. Employing the scanning electron microscopy to assess carbide phase in NHSS proved to be the indispensable stage of this steel's investigations. It enabled stereological description of the carbide particles smaller than 1 μm^2 precipitated while tempering as well as finding out the structural factors of cutting ability.
2. Changing of austenitizing parameters made it possible to shape stereological parameters of secondary carbides. Prolongation of the austenitizing time from 3 to 7 minutes caused the significant increase in these particles area fraction (4.48 and 6.38 % respectively) and in their mean size (0.27 and 0.36 μm^2 respectively). Owing to longer austenitizing secondary carbides precipitated while tempering more homogeneously in the matrix, with no areas free from precipitation.
3. The spheroidal M_6C satellite particles arround the large MC type carbides were revealed also in the as - tempered NHSS (they had been found earlier in the as - hardened specimens (Richter et al., 1994a))
4. The cutting ability tests provided the following observations:
   - the lathe tools made of the investigated NHSS given the optimal heat treatment (with prolonged to 7 minutes austenitizing time) wore less than these treated traditionally),
   - the large MC carbide particles were abraded uniformly rather than pulled out from the matrix, which corraborated the role of M_6C satellites in primary carbides' strong embedding in the matrix,
   - the homogenous distribution of the secondary $M_{23}C_6$ type carbides proved to be (El Rakayby et al., 1988) the factor increasing the tool life,
   - within the investigated range of heat treatment's and machining's parameters, saturations of the matrix with alloying elements (Richter et al., 1994b) and accompanying solution strengthening were less efective than increased area fraction of secondary $M_{23}C_6$ carbides as far as hardness and tool life are considered.

REFERENCES

Cwajna J. Tool alloys microstructure quantitative evaluation and its application (in Polish). DSc thesis, Zeszyty Naukowe Politechniki Śląskiej, Hutnictwo, z.39, Gliwice 1991.

El Rakayby AM, Mills B. On the microstructure and mechanical properties of high-speed steels. J Mater Sc 1988; 23: 4340-4344.

Richter J. Shaping of structure and properties of nonledeburitic HSS through heat treatment processes. PhD thesis, 1994.

Richter J, Cwajna J, Szala J. Quantitative estimation of particles with large size variation. Acta Stereol 1994; 13/2: 293-298.

Richter J, Wyciślik A, Cwajna J. Investigations of the carbide phase and the matrix of nonledeburitic high-speed steel with Ti and Nb by atomic absorption spectrometry and energy dispersive X-ray spectroscopy methods. Fresenius' J Anal Chem 1994b; 349: 153-154.