The Quantitative Analysis of Carbide Phase in High Speed Steels

W. Bochnowski
Institute of Technics, Rzeszow University, Rejtana 16 C, 35-310 Rzeszow, Poland
e-mail: wobochno@univ.rzeszow.pl

Received on: 16.04.2007; Approved for printing on: 27.04.2007

Abstract

The examinations of the structure and the quantitative analysis of the carbide in high speed steels HS 2-10-1-8, HS 6-5-2, HS 10-2-5-8 are concluded in this case study report. Analysis of structure was carried out based on the scanning electron microscopy images. Computer system of images analyzed by the Multiscan was used to measurement the diameters of carbides. The diameter mean distribution of the carbides was described by function, on the basis of the work by J. Cybo, S. Jura [1]. Coefficients of the approximate function were used to calculate the stereological parameters of the carbides.

Keywords: Metallography, Stereology, High speed steel, Carbide phase, Microstructure quantification, Image analysis

1. Introduction

High speed steels comprise a family of alloys mainly used for cutting tools and cold work application. The cutting performance is determined by their wear resistance, their resistance to tempering and their toughness. The required high properties of high speed steels are achieved by complex heat treatment by hardening and tempering which leads to primary and secondary carbides distributed in a martensitic matrix [2]. The primary carbides form during crystallization of liquid. The secondary carbides transform from solid state.

The distribution of the blocky carbides also has decisive influence on the toughness of the tools, because large primary carbides the microcracks which eventually cause rupture [3]. In present metallographic practice, the degree of carbide segregation was marked across comparison of the structure with pattern. The comparison of structure with pattern has a greater error of estimation, unstable characteristic as well as a large subjective opinion. To eliminate these shortcomings, we quantitatively analyze the structure, using the computer systems with image analysis. The image analysis obtained, determines the distribution and size of the studied particles - the primary carbides, which can be described as normal-logarithmic function.

The knowledge of parameters of normal-logarithmic function enables the analytical calculation of every stereological parameters of its structure.

The aim of the work was to calculate the selected stereological parameters on the basis of the function distribution of carbide phase in high speed steels.

2. Material and methodology

Examinations were performed on steels of grades: HS 2-10-1-8, HS 6-5-2, HS 10-2-5-8. Steel HS 6-5-2 obtained using conventional metallurgy. The steel falls into a tungsten group and is used to make extremely tough tools. The process of obtaining the steel HS 2-10-1-8 is similar to HS 6-5-2 by using the conventional metallurgy. Cobalt molybdenum high speed steel possesses extreme hardness, excellent cutting properties, high red hardness and excellent toughness. HS 2-10-1-8 is also available in the special grade for heavy duty tools. The steel is using for milling cutters, taps, twist drills, broachers tools, cold work tools. Steel HS 10-2-5-8 produced using the powder metallurgical route resulting with a greater resistance to wear and tear, red hardness and compressive strength. The powder metallurgical technique of production imparts excellent toughness and machinability levels.
This steel is used for heavy duty machining tools, and tools for non-ferrous metals such as titanium and nickel alloys: pinion type cutters, hobs milling, broaching tools, twist drills, reamers, punches and dies. All these steels were austenitised with 1180 °C temperature / at time 10 minutes, quenched in oil and tempered for 2 hours at 530 °C temperature. Surface of the specimens were polished, etched and images of carbide were obtained using a scanning electron microscopy.

3. Results

A representative images of the microstructures of the high speed steels were then austenitised with 1180 °C temperature in 10 minutes, quenched in oil and tempered for 2 hours at 530 °C temperature as shown below in Figure 1.

The SEM examination shows that the carbides have a homogeneous distribution in the matrix. The carbides stringers segregation in this steels structures was not observed. The matrix is consisted with the plate martensite end retained austenite. In the steels HS 2-10-1-8 and HS 6-5-2 was observed that the carbides phase (white particles) are about the diameters in the range 0.5 – 3 µm. A comparison of microstructures shows that the carbide size in steels obtained using conventional metallurgy is similar. However in the HS 10-2-5-8 steel the carbides had the smallest diameter. The differences in the composition and technology of production of the powders steel HS 2-10-1-8 determines the structure of the material.

The application of the method presented in work [1] - functional description of structures have been demonstrated in the calculation of the carbides stereological parameters in high speed steels.

The structure images were made at magnifications: 4000 x for steel HS 2-10-1-8 and HS 6-5-2 and 8000 x for HS 10-2-5-8. The total area of the images for steels grades: HS 2-10-1-8 and HS 6-5-2 encompassed to 31200 µm² and to 5400 µm² for HS 10-2-5-8 steel. The images of the microstructure were digitized with resolution 300 dots per inch. To remove the hums, the images were transformed using a median filter. The filtration process took place with the use of the filter median, the images point was exchanged on an average value calculated from the surrounding points, which results to its inability of the insertion of new points. After filtration the image has sharp edges, the value points decreases excessively and the local disturbance in areas of carbides do not influence on the effects shown in the below on Figure 2.

Fig. 2. Structure of high speed steel transformed with the use of median filter

The digitized images transformed into binary (black and white) images by a proper filtering and threshold operation (Figure 3). The smallest and the largest diameter of every carbides was measured from the photo. The size of the carbide was accepted by the arithmetical meaning and calculated from maximal and minimal diameter (Figure 4). Multiscan image analysis computer system was applied to investigation. The multiscan system enables the automatic detection of elements of the images and their measurement of parameters: area, contour, Feret diameters, length and width as well as orientation.
For every grades steels, calculated, the diameters of the carbides were grouped in geometrical progression. The largest carbides diameter is 6.6 µm in HS 2-10-1-8 steel, 6.2 µm in HS 6-5-2 steel and 3 µm in HS 10-2-5-8 steel. The quantity and the range of classes were established as product of the largest diameter (suitable for grades steel) and its progressive quotient (0.7943) [4]. Distributions of the carbides diameters are shown in the Table 1 and Figure 5, Figure 7.

Table 1.
The distribution of the carbides for HS 6-5-2 steel

<table>
<thead>
<tr>
<th>Number class</th>
<th>Diameter of carbides d, µm</th>
<th>Quantity of carbides Nₐ, mm⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19 ± 0.24</td>
<td>706</td>
</tr>
<tr>
<td>2</td>
<td>0.24 ± 0.31</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>0.31 ± 0.39</td>
<td>647</td>
</tr>
<tr>
<td>4</td>
<td>0.39 ± 0.49</td>
<td>1823</td>
</tr>
<tr>
<td>5</td>
<td>0.49 ± 0.61</td>
<td>3234</td>
</tr>
<tr>
<td>6</td>
<td>0.61 ± 0.78</td>
<td>3175</td>
</tr>
<tr>
<td>7</td>
<td>0.78 ± 0.98</td>
<td>4467</td>
</tr>
<tr>
<td>8</td>
<td>0.98 ± 1.23</td>
<td>5733</td>
</tr>
<tr>
<td>9</td>
<td>1.23 ± 1.55</td>
<td>5674</td>
</tr>
<tr>
<td>10</td>
<td>1.55 ± 1.96</td>
<td>6732</td>
</tr>
<tr>
<td>11</td>
<td>1.96 ± 2.46</td>
<td>5821</td>
</tr>
<tr>
<td>12</td>
<td>2.46 ± 3.10</td>
<td>2646</td>
</tr>
<tr>
<td>13</td>
<td>3.10 ± 3.91</td>
<td>1441</td>
</tr>
<tr>
<td>14</td>
<td>3.91 ± 4.92</td>
<td>853</td>
</tr>
<tr>
<td>15</td>
<td>4.92 ± 6.20</td>
<td>323</td>
</tr>
</tbody>
</table>
where: \( N_A \) - the carbides quantity in unit area, \( 1/\text{mm}^2 \), \( d \) - diameter of carbides, \( \mu \text{m} \), \( U \) - the coefficient of the globally carbides quantity, \( \mu \text{mm}/\text{mm}^2 \), \( \ln d \) - the mean of the logarithm of carbides diameter, \( \mu \text{m} \), \( Z \) - the coefficient of the size difference of the carbides, \( 1/\mu \text{m} \).

The calculated parameters: \( U, Z, \ln d \), of the function were based on counting the value of parameters stereological of the carbide phase. The calculation of the parameters was made according to procedure:

1. The diameter (\( \bar{d}, \mu \text{m} \)) mean values calculation (2) of the carbides:

\[
\bar{d} = \frac{2}{3\pi} \exp \left[ \ln d - \frac{1}{2} \left( \frac{\ln B^2}{Z} \right) \right]
\]

(2)

where: \( B \) - the coefficient of fitting the simulation function to the Gauss function.

2. The grain boundary area (\( SV, \text{mm}^2/\text{mm}^3 \)) calculation (3) in unit volume:

\[
SV = \frac{4}{\Lambda} U \exp \left[ \frac{1}{2} \left( \frac{\ln B^2}{Z} \right) \right]
\]

(3)

\( \Lambda \) - range of classes in which the diameter of the carbides was measured.

3. The volume fraction (\( V_V, \% \)) calculation (4) of the carbides phase:

\[
V_V = \frac{\pi}{4\Lambda} U \exp \left[ \frac{1}{2} \left( \frac{\ln B^2}{Z} \right) \right]
\]

(4)

4. The mean length between the carbides (\( \bar{\lambda}, \mu \text{m} \)) equates to the value given by (5):

\[
\bar{\lambda} = \frac{\Delta}{U \exp \left[ \frac{1}{2} \left( \frac{\ln B^2}{Z} \right) \right]}
\]

(5)

5. The curve mean (\( \bar{K}_s, \mu \text{m}^{-1} \)) values were counted using the following equation:

\[
\bar{K}_s = \frac{\pi}{2} \exp \left[ \frac{1}{2} \left( \frac{\ln B^2}{Z} \right) \right]
\]

(6)

Results of the calculated \( U, \ln d, Z \) coefficients of the distribution fitting function of the carbides are listed in Table 2.

<table>
<thead>
<tr>
<th>steel grades</th>
<th>U</th>
<th>\ln d</th>
<th>Z</th>
<th>standard deviation ( S_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS 6-5-2</td>
<td>12872,87</td>
<td>0,21</td>
<td>2,14</td>
<td>1520</td>
</tr>
<tr>
<td>HS 2-10-1-8</td>
<td>10686,68</td>
<td>0,43</td>
<td>2,49</td>
<td>637</td>
</tr>
<tr>
<td>HS 10-2-5-8</td>
<td>55362,16</td>
<td>-0,21</td>
<td>2,74</td>
<td>3845,79</td>
</tr>
</tbody>
</table>

The values of the stereological parameters of the carbide in examined high speed steels are shown in Table 3.

<table>
<thead>
<tr>
<th>steel grades</th>
<th>mean diameter ( \bar{d}, \mu \text{m} )</th>
<th>grain boundary area ( SV, \text{mm}^2/\text{mm}^3 )</th>
<th>volume fraction ( V_V, % )</th>
<th>mean length between carbides ( \bar{\lambda}, \mu \text{m} )</th>
<th>mean curve of the carbides ( \bar{K}_s, \mu \text{m}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS 6-5-2</td>
<td>1,7</td>
<td>349,8</td>
<td>12,9</td>
<td>11,4</td>
<td>0,83</td>
</tr>
<tr>
<td>HS 2-10-1-8</td>
<td>1,3</td>
<td>363,4</td>
<td>11,6</td>
<td>11,2</td>
<td>0,96</td>
</tr>
<tr>
<td>HS 10-2-5-8</td>
<td>0,9</td>
<td>922,2</td>
<td>17,4</td>
<td>4,3</td>
<td>1,64</td>
</tr>
</tbody>
</table>

4. Conclusions

The study exhibited that in the all analysed steels, the carbides distributions are equal. The mean value of diameters vary from 0,9 - 1,7 \( \mu \text{m} \). It can be noted that the HS 10-2-5-8 steel is characterized by the presence of small size carbide particles. In the steels which were obtained by using the conventional metallurgy, the volume fraction of the carbide phase was on similar level, approximately 12%. In HS 10-2-5-8 powder steel, the volume fraction of the carbide phase was approximately 18%.

References