RELATIONSHIP BETWEEN MEAN VALUES OF INTERLAMELLAR SPACINGS IN CASE OF LAMELLAR MICROSTRUCTURE LIKE PEARLITE

ZALEŻNOŚCI POMIĘDZY WARTOŚCIAMI ŚREDNIMI ODLEGŁOŚCI MIĘDZYPLYTKOWYCH W PRZYPADKU STRUKTUR LAMELARNYCH TAKICH JAK PERLIT

This paper deals with the stereology of lamellar microstructures like pearlite in steels. Using a stereological model of this microstructure interpretation and relationship between a mean true of interlамellar spacing and a mean apparent or mean random of interlамellar spacing was presented. Theoretical considerations are compared with experimental results. As a material for experiments the pearlite – lamellar microstructure being a product of eutectoid reaction in Fe-Fe₃C system – has been chosen.

W pracy przedstawiono stereologiczny opis mikrostruktury płytkowej na przykładzie perlitu. Dokonano kompletnej probabilistycznej interpretacji używanych powszechnie w opis tej mikrostruktury średnich wartości odległości międzyplytkowych oraz przedstawiono zależności pomiędzy nimi. Rozważania teoretyczne porównano z wynikami pomiarów eksperymentalnych.

1. Introduction

Pearlite is a product of eutectoid reaction in Fe-Fe₃C system. A growth interaction between ferrite and cementite grains forms a microstructure with lamellar morphology [1-3]. Lamellar morphology of parallel ferrite and cementite platelets in large colonies is dominating.

This kind of microstructures is quantitatively characterized by interlамellar spacings. The following denotations are usually used: \( l_t \) – true interlамellar spacing, \( l_r \) – random interlамellar spacing, \( l_a \) – apparent interlамellar spacing. All these quantities are random variables. Using the above parameters the comprehensive stereological description of lamellar microstructure consists in estimating the true interlамellar spacing distribution on the ground of the apparent interlамellar spacing or the random interlамellar spacing distribution [4-6].

The above mentioned exact, complete description of the lamellar microstructure is difficult computationally and from the practical point of view – not always needful. During examinations of the relationship between a microstructure and mechanical properties it is very often sufficient to determine a mean true interlамellar spacing on the basis of a mean random or mean apparent interlамellar spacing. Average values of apparent and random interlамellar spacing are accessible as a result of direct measurements [7-12].

2. Stereological relationships for lamellar microstructure

Stereological model of the lamellar microstructure, interesting from the view-point of interlамellar spacings can be represented by “planes batch”. The planes are sets of points which correspond to the centers of thicknesses of the two nearest platelets of the same phase. These planes are parallel and the distance between both nearest planes is \( l_t \) (the distribution of the true interlамellar spacing \( l_t \) is given by density function \( f(l_t) \)).

On the basis of this model Czarski and Ryś [13, 14] made a full probabilistic interpretation of mean values used in the quantitative description of lamellar microstructure:

- the mean random interlамellar spacing : \( l_r \) is the estimator of the reciprocal of expected value \( E(l_r^{-1}) \)

\[
\tilde{l}_r = E^{-1}(l_r^{-1}) \tag{1}
\]

- the mean apparent interlамellar spacing : \( l_a \) is the estimator of the reciprocal of expected value \( E(l_a^{-1}) \)
\[
\tilde{I}_a = E^{-1}(l_a^{-1})
\]

(2)

\[
\tilde{I}_r = E^{-1}(l_r^{-1})
\]

(3)

Considering the definitions (1), (2), (3) Czarski and Ryś [13,14] introduced using a new manner (comparing with Salykov [15], Underwood [4], DeHoff and Rhines [5], Vander Voort and Roosz [6]), the well known and important relation between the mean values of interlamellar spacings:

\[
\tilde{I}_r = 2\tilde{I}_r
\]

(4)

\[
\tilde{I}_a = \frac{4}{\pi}\tilde{I}_r.
\]

(5)

Making a comparison of the equations (4) and (5) it is easy to prove that:

\[
\tilde{I}_r = \frac{\pi}{2}\tilde{I}_a.
\]

(6)

3. Experimental procedure

A high-purity model Fe-Fe₃C alloy has been used for experiment. The chemical composition of the material is given in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Al</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.800</td>
<td>0.060</td>
<td></td>
<td>0.003</td>
<td>0.010</td>
<td>0.040</td>
<td>0.030</td>
<td>traces</td>
<td>0.010</td>
<td>0.006</td>
</tr>
</tbody>
</table>

In order to produce a coarse lamellar pearlite microstructure, the material was subjected to the following heat treatment: (1) austenitizing (900°C/0.5h) with subsequent transfer to lead bath at temperature 705°C, (2) isothermal annealing in the bath (705°C/3h). Microstructure has been examined using optical microscope and is shown in Fig. 1.

![Fig. 1. Microstructure with coarse lamellar pearlite (etched in picral)](image)

The measurements have been carried out on the image of a microstructure at total magnification ×2500. The measurement of a random interlamellar spacing \( l_a \) has been performed on a random secant. The measurement of an apparent interlamellar spacing \( l_r \) has been carried out as follows: from the point of intersection of the center of a randomly selected cementite lamella with a secant a normal has being put out; the spacing of this point to the center of the next cementite lamella (on the arbitrary selected side of the secant) is an apparent interlamellar spacing \( l_r \) (Fig. 2).
Fig. 2. Scheme of a single measurement of a random interlamellar spacing \( l_1 \) and an apparent interlamellar spacing \( l_a \)

Accuracy of a single measurement was \( 0.2 \times 10^{-3} \) mm, that corresponds to 0.5 mm at magnification \( x2500 \). The results of measurements are presented in Figures 3-6 and in Table 2.

Fig. 3. Experimental distribution of random interlamellar spacing

Fig. 4. Experimental distribution of random interlamellar spacing inverse
Fig. 5. Experimental distribution of apparent interlamellar spacing

Fig. 6. Experimental distribution of random interlamellar spacing inverse

TABLE 2

<table>
<thead>
<tr>
<th></th>
<th>( L \cdot 10^3 \text{ mm} )</th>
<th>( L_a^{-1} \cdot 10^3 \text{ mm}^{-1} )</th>
<th>( L_{\text{a}} \cdot 10^3 \text{ mm} )</th>
<th>( l_{a}^{-1} \cdot 10^3 \text{ mm}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of measurements</td>
<td>769</td>
<td>423</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>(<em>{\text{—}}^*</em>{\text{—}})</td>
<td>0,6468</td>
<td>1,263</td>
<td>0,9995</td>
</tr>
<tr>
<td>Minimum</td>
<td>0,4</td>
<td>0</td>
<td>0,4</td>
<td>0</td>
</tr>
<tr>
<td>Maximum</td>
<td>16,1</td>
<td>2,5</td>
<td>5,2</td>
<td>2,5</td>
</tr>
</tbody>
</table>

*From theoretical point of view not exist

Taking advantage of definitions (4), (5) the adequate mean random interlamellar spacing \( l_{r} \) and mean apparent interlamellar spacing mean \( l_{a} \) have been determined. Then, on the basis of relationships (5), (6) the true interlamellar spacing mean \( l_{t} \) has been defined. The results of calculations are presented in Table 3.
4. Discussion

As it could be expected the minimal values of apparent and random interlamellar spacing are equal with value of 0.4x10^3 mm (Tab.2). Not making a mistake we assume that a minimal value of true interlamellar spacing is a minimal value of apparent (and random) interlamellar spacing that is 0.4x10^3 mm.

The values of true interlamellar spacing mean \( \bar{l} \) determined on the basis of a mean random interlamellar spacing \( \bar{l}_r \) and a mean apparent interlamellar spacing \( \bar{l}_a \) are very close (Tab.3). Moreover the quotient of mean values \( \bar{l}_r \) and \( \bar{l}_a \) in case of the analysed microstructure equals 1.542, what means that the relationship (6) according to which the quotient should be \( \pi/2 \) is fulfilled with satisfied accuracy.

All achieved results allow to formulate a conclusion, that the considered model of the lamellar microstructure is suitable for the stereological description of a pearlite microstructure.

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References
