THE MORPHOLOGY AND DISTRIBUTION OF MnS IN LOW CARBON STEEL

Non-metallic inclusions are very important (harmful) in steelmaking practice. After oxygen, sulphur is the most important non-metallic element in field of steel metallurgy and sulphides therefore form a second important group of inclusions. Since the morphology of these sulphide inclusions has significant effects on the various properties of steel, numerous studies focusing on morphology and distribution of the MnS inclusions have been conducted over the years. This paper presents the results of the investigation of the MnS inclusion shape and distribution in low carbon steel.

Key words: steel, non-metallic inclusions, sulphides, shape, distribution

Morfologija i raspored MnS u niskouglijičnom čeliku. Nemetalni uključci su veoma važni (štetni) u metalurškoj proizvodnji. U području metalurgije čelika sumpor je drugi po važnosti nemetalni element, nakon kisika, te stoga i sulfid, po važnosti, predstavljaju drugu grupu uključaka u čeliku. Jer je morfologija i raspored ove vrste sulfida taj bitni faktor koji ima presudan utjecaj na razna svojstva čelika izvedena su mnoga istraživanja na tom polju tijekom zadnjih nekoliko godina. U ovom radu su predstavljeni rezultati istraživanja morfologije i rasporeda MnS uključaka u niskouglijičnom čeliku.

Ključne riječi: čelik, nemetalni uključci, sulfidi, oblik, raspored

INTRODUCTION

Because non-metallic inclusions play one of the main roles in determination of material properties, considerable efforts have been directed towards the development of alloys and processes to reduce their presence in steel to a minimum. However, the utilisation of inclusions for the control of microstructures is becoming a subject of considerable interest for improving the mechanical properties of steels.

MnS inclusions are found in most steel and their beneficial effects in improving machinability and retarding grain growth in steels are well known. Since the morphology of these sulphide inclusions has significant effects on the various properties of steel, numerous studies focusing on morphology and distribution of the MnS inclusions have been conducted over the years.

According to the classical work by Sims and Dhale [1] the morphology of MnS can be broadly classified into three types: i.e. randomly dispersed globular sulphides (type 1), grain boundary sulphides (type 2) and angular sulphides (type 3) [1 - 3].

In view of these facts, the present study has been undertaken with a view to identifying the morphology and distribution of MnS inclusions in low carbon steel.

EXPERIMENTAL PROCEDURE

An experimental investigation was done of low carbon steel (JUS: Č. 1120, DIN C10). The Experiment can be divided into four steps as follows:

a) sample preparation,
b) heat treatment of the samples,
c) metallographical investigation and
d) collecting and the analysis of the data.

Sample preparation

For the purpose of the experiment, a steel bar was cut into six cylindrical samples (Ø 5× 10 mm) which were then prepared for further investigation. The chemical composition of the steel bar is given in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Chemical composition of the steel bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1. Kemijski sastav čelične šipke</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>% wt</td>
<td>0,11</td>
<td>0,31</td>
<td>0,35</td>
<td>0,011</td>
<td>0,015</td>
</tr>
</tbody>
</table>

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Heat treatment of the samples

This step is a basis for the whole experiment. Firstly, the temperature of MnS dissolution was very precisely determined. This temperature was calculated from the MnS stability product equation in low carbon steel [4, 5]:

$$\log K_{\text{MnS}} = \frac{A}{T} + B$$

where:

- $K_{\text{MnS}} = [\text{Mn %}] \times [\text{S %}]$,
- $T$ - temperature / K,
- $A, B$ - constants.

The dissolution temperature having been calculated, cycles for heat treatment for each six samples were chosen [3]. The heat treatment for all samples generally consists of five steps:

- heating of the samples to a temperature above their melting point,
- holding at that temperature,
- cooling to the investigated temperature,
- holding at that temperature,
- cooling to the room temperature.

The heat treatment cycles for each sample are presented in Table 2 and Figure 1. Cooling/heating rates in applied treatments are shown in Table 3.

### Table 2

<table>
<thead>
<tr>
<th>Sample I</th>
<th>Sample II</th>
<th>Sample III</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp / °C</td>
<td>time / s</td>
<td>temp / °C</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>1535</td>
<td>302</td>
<td>1535</td>
</tr>
<tr>
<td>1535</td>
<td>542</td>
<td>1535</td>
</tr>
<tr>
<td>1510</td>
<td>604,5</td>
<td>1510</td>
</tr>
<tr>
<td>1100</td>
<td>645,5</td>
<td>1200</td>
</tr>
<tr>
<td>1100</td>
<td>670,5</td>
<td>1200</td>
</tr>
<tr>
<td>25</td>
<td>685,5</td>
<td>25</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Sample IV</th>
<th>Sample V</th>
<th>Sample VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp / °C</td>
<td>time / s</td>
<td>temp / °C</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>1535</td>
<td>302</td>
<td>1535</td>
</tr>
<tr>
<td>1535</td>
<td>542</td>
<td>1535</td>
</tr>
<tr>
<td>1510</td>
<td>604,5</td>
<td>1510</td>
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<tr>
<td>1300</td>
<td>625,5</td>
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### Table 3

<table>
<thead>
<tr>
<th>Temperature interval / °C</th>
<th>Cooling/heating rates / °C-s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 - 1535</td>
<td>5</td>
</tr>
<tr>
<td>1535 - 1510</td>
<td>0.4</td>
</tr>
<tr>
<td>1510 - 1100</td>
<td>10*</td>
</tr>
<tr>
<td>1100 - 25</td>
<td>cooling at the air*</td>
</tr>
</tbody>
</table>

*The same cooling/heating rates are used for all other investigated temperatures.

### Metallographic investigation

After heat treatment, the microstructure of the samples was studied by optical microscopy techniques using “Image analysis” supporting software [1]. There were eight microscopy zones investigated on each sample and from each zone the following data were collected:

- the number of inclusions,
- the area of each inclusion,
- the max. diameter of each inclusion,
- the min. diameter of each inclusion,
- the average diameter of each inclusion,
- the factor of shape of each inclusion1.
The results having been obtained by measurements, the data were statistically processed [6].

The data collected for all inclusions areas at all temperatures investigated (1100 °C, 1200 °C, 1250 °C, 1300 °C, 1350 °C and 1400 °C) were divided into fifty classes ranging from 0 to 10 \( \mu \text{m}^2 \) in area size (the step being 0.2 \( \mu \text{m}^2 \)). All inclusions with area greater than 10 \( \mu \text{m}^2 \) were put into the last class (9.8 - 10.0 \( \mu \text{m}^2 \)). The same procedure was applied in analysing the data concerning of average inclusion diameter (classes ranging between 0 and 10 \( \mu \text{m} \), step 0.2 \( \mu \text{m} \)).

A graphical presentation of dependence of inclusion area and average diameter on temperature is shown in Figures 2. and 3. (the temperature investigated being: 1100 °C).

\[ \text{Figure 2. Percent of the area of the inclusions at classes at 1100 °C} \]
\[ \text{Slika 2. Postotak površine uključaka i razreda na temperaturi 1100 °C} \]

\[ \text{Figure 3. Percent of the average diameter of inclusions at classes at 1100 °C} \]
\[ \text{Slika 3. Postotak srednjih vrijednosti promjera uključaka i razreda na temperaturi 1100 °C} \]

Due to space limitation, no graphical presentation for each investigated temperature can be presented. Instead, Figures 4. and 5. shown the dependence of inclusion areas

\[ \text{Figure 4. Percent of area of inclusions at classes for all investigated temperature} \]
\[ \text{Slika 4. Postotak površine uključaka i razreda za sve ispitivane temperature} \]

\[ \text{Figure 5. Percent of the average diameter of the inclusions at classes for all investigated temperature} \]
\[ \text{Slika 5. Postotak srednjih vrijednosti promjera uključaka i razreda za sve ispitivane temperature} \]

\[ \text{Figure 6. Shape factor of inclusions for all investigated temperature} \]
\[ \text{Slika 6. Faktor oblika uključaka za sve ispitivane temperature} \]
and average diameters on temperature for all temperature cycles applied.

The data concerning inclusion shape factors were divided into ten classes ranging between 0 and 1.0, step being 0.1. A schematic showing the dependence of inclusion shape factor on temperature for all temperature cycles applied is presented in Figure 6.

All the above-mentioned data give no information about the precipitation place of MnS inclusions. This information was obtained on performing microstructural etching the etching results for three investigated temperatures are presented in Figure 7.

CONCLUSIONS

The following conclusions were based on the theoretical background and the results obtained during the investigation:

1. The inclusions are nearly spherical in shape.
2. The behaviour of the inclusion areas is almost the same for each applied temperature cycle.
3. The behaviour of the inclusion diameters is almost the same for each applied temperature cycle.
4. The behaviour of the inclusion shape factors is almost the same for each applied temperature cycle.
5. The inclusions within the grain can be classified as type 1 of MnS inclusions.
6. The inclusions on the grain borders can be classified as type 2 of MnS inclusions.

REFERENCES