THE MICROSTRUCTURES AND HARDNESS ANALYSIS
OF A NEW HYPOEUTECTOID STEELS WITH 0.3 % MO

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Abstract
The results of a microstructure analysis and hardness investigations of the hypoeutectoid steels with 0.3 %Mo, imitating by its chemical composition toughening steels, are presented in the paper. The methodology of a dilatometric samples preparation and the method of the critical points determination were described. The paper presents metallographic research, as well as hardness measurements. For hypoeutectoid steels determined critical temperatures and appropriate austenitising temperatures. The austenitising temperature was defined in a standard way i. e. 30 °C + 50 °C higher than Ac3 temperature for hypoeutectoid steels. The technology of full annealing was proposed for the iron based alloy.

The microstructure of the investigated material was examined by the light microscope Axiovert 200 MAT. The hardness measurements were performed with the Vickers HPO 250 type, which imposes a force equal to 10 kG and 30 kG. The dilatometric measurements were performed with the L78 R.I.T.A. dilatometer.

Keywords: hypoeutectoid steel, microstructure, hardness, austenitising temperature, heat treatment

1. INTRODUCTION

Pure metals, due to their unsatisfactory mechanical properties, are seldom applied in material engineering except for special applications. Therefore to improve metal properties certain additions of others elements, called alloying elements, are introduced. At that time, strength properties are the most often improved, while plastic properties, thermal and electric conductivity as well as corrosion resistance are decreased. Such multi-component metallic materials are called alloys. Molybdenum is one of several alloying additions. Its good points are: quite wide abundance in the nature and the well developed production technology. However, the main fault of molybdenum and its alloys is the lack of the resistance to corroding influences of atmospheric gases, especially oxygen at higher temperatures (above 650°C). At higher temperatures Mo oxidises and its oxides sublimate in the temperature range: 680 ÷ 700 °C. Thus, elements made of molybdenum require protection coatings [1, 2]. The largest part of molybdenum is applied as alloying additions in steels, alloys and superalloys in order to improve their mechanical properties [3 – 6].

Due to that, in order to achieve the required mechanical properties the appropriate chemical composition and the microstructure (obtained as the result of the designed heat treatment) should be selected - in practice - individually for each alloy. From this point of view, the analysis of microgradients of the chemical composition in steels of a weak background of alloying elements such as: Mn, Mo, Cr, Ni, Co, Si and others, seems to be essential. Up to now, an influence of each element was considered separately, sometimes only indicating the group of alloys in which this influence was estimated [7 + 10]. It should be noted, that the interaction of two or more alloying elements is significantly different from the sum of effects of these elements added separately. The most important can be the common effect of: molybdenum and chromium, molybdenum and nickel, chromium and nickel, manganese and chromium, manganese and nickel, manganese and molybdenum, manganese and cobalt. These mutual interactions of various elements on the effects of the others, may be the basis for the assessment of the impact magnitude of each of them on e.g. hardenability.
of steel under conditions of the presence of even one or several other elements in the above mentioned alloys of iron based steels.

The obtained investigation results of hypoeutectoid steels, containing: 0.35 % ÷ 0.40 % C and app. 0.30 % Mo and other alloying elements, are presented in the hereby paper. The assessment of the influence of the selected alloying elements on critical and austenitising temperatures and microstructures of the tested steels was performed.

2. RESEARCH MATERIAL

The material for study were three hypoeutectoid: steels: 40Mo3, 37MnMo6-3 and 39CrMo4-3 (marked in accordance with PN-EN 10027-1:1994 standard). Steels in the form of model alloys were supplied as cast by Z. J. Głuchowski S. C. Kooperacja Przemysłowo – Handlowa in Gliwice, and then were reforged in INTECH – MET S. C. plant in Gliwice. Chemical compositions of tested steels are shown in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Steel Symbol</th>
<th>C %</th>
<th>Mn %</th>
<th>Si %</th>
<th>P %</th>
<th>S %</th>
<th>Cr %</th>
<th>Mo %</th>
<th>Al %</th>
<th>Cu %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40Mo3</td>
<td>0.40</td>
<td>0.10</td>
<td>0.013</td>
<td>0.004</td>
<td>0.006</td>
<td>-</td>
<td>0.36</td>
<td>0.0</td>
<td>0.027</td>
</tr>
<tr>
<td>2</td>
<td>37MnMo6-3</td>
<td>0.37</td>
<td>1.47</td>
<td>0.014</td>
<td>0.006</td>
<td>0.020</td>
<td>-</td>
<td>0.27</td>
<td>0.0</td>
<td>0.030</td>
</tr>
<tr>
<td>3</td>
<td>35CrMo4-3</td>
<td>0.35</td>
<td>0.08</td>
<td>-</td>
<td>0.005</td>
<td>0.010</td>
<td>0.98</td>
<td>0.31</td>
<td>-</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Both tested steels are hypoeutectoid with a carbon content of about 0.4 % and similar content of molybdenum (app. 0.3 %). They differ in the content of alloying elements such as manganese and chromium. The microstructures of tested steels in the state after reforging is shown in Figure 1.

Figure 1 The microstructures of hypoeutectoid steels after reforging. Etched with 3 % vol. HNO₃ in C₂H₅OH

As can be seen, 40Mo3 and 39CrMo4-3 steels in a state after forging have pearlite-ferritic microstructure, but they differ in the content of structural components (pearlite and ferrite). The microstructure of steel with 1.47 % Mn (compare with Fig. 1b) is characterized by a ferrite, pearlite and bainite.

In order to determine the correct critical temperatures (critical points) for both tested steels after forging the sample were heated at the rate of 0.05 °C/s to a temperature of 1100 °C and then cooled at the rate of 1 °C/s to room temperature. Critical temperatures read are shown in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Steel Symbol</th>
<th>Ac₁s [°C]</th>
<th>Ac₃f [°C]</th>
<th>Ac₃ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40Mo3</td>
<td>690</td>
<td>760</td>
<td>820</td>
</tr>
<tr>
<td>2</td>
<td>37MnMo6-3</td>
<td>685</td>
<td>715</td>
<td>800</td>
</tr>
<tr>
<td>3</td>
<td>35CrMo4-3</td>
<td>740</td>
<td>765</td>
<td>820</td>
</tr>
</tbody>
</table>
Temperatures of critical points confirm the behavior of alloying elements in the studied steels. Chromium and molybdenum, which are highly ferrite creative significantly shifts the critical temperatures upward. The biggest difference can be seen for 35CrMo4-3 steel.

3. EXPERIMENTAL PROCEDURE

The chemical composition of the model alloy was designed in the Laboratory of Phase Transformations, Department of Physical and Powder Metallurgy, AGH University of Science and Technology. The microstructure of the investigated material was examined using the light microscope Axiovert 200 MAT. The hardness measurements were performed with the Vickers HPO250 apparatus. The dilatometric measurements were performed with the L78 R.I.T.A. dilatometer.

4. RESULTS AND DISCUSSION

4.1 Heat treatment

In order to obtain a microstructure similar to the equilibrium state the full annealing was performed for the tested steels. After such annealing the necessary treatment for mechanical testing and to remove the internal stress and improve the workability is easier to perform.

Full annealing was performed in a Carbolite RHF 16/19 laboratory oven. Samples were heated to a temperature by 50 °C higher than the Ac3 for test steels, maintained at this temperature for 2 hours and then cooled at the rate of 3 °C/min to a temperature of 500 °C and further at the rate of 30 °C/min to room temperature. The microstructures tested steels in state after full annealing are shown in Figure 2.

![Figure 2](image_url)

The microstructures of steels tested is not significantly different from the microstructure of these steels after forging (compare with Fig. 1).

4.2 Effect of austenitising temperature on hardness of hypoeutectoid steels

Determination of critical temperatures (transformation temperatures) is necessary for investigations of the phase transformations kinetics of undercooled austenite. Only on the basis of the CCT diagram various variants of the heat treatment can be developed. Therefore these results are constitutes the basis for performing the correct CCT diagrams for the investigated hypoeutectoid steel. Quenching series for assessing the austenitising temperatures T_A of three investigating hypoeutectoid steels were performed within the hereby study.

Samples of 40Mo3, 37MnMo6-3 and 35CrMo4-3 steels with dimensions of 20x30x40 mm were austenitized for 20 minutes at the temperatures from the range 760 °C + 1000 °C (elevating temperature every 20 °C or 25 °C up to T_A = 900 °C, and then every 50 °C up to T_A = 1000 °C), and after that cooled in water. Figure 3 presents the influence of austenitising temperature T_A of the samples of test hypoeutectoid 37MnMo6-3 steel on their hardness after cooling in water.
Figure 3 Effect of austenitising temperature on hardness of samples of investigated hypoeutectoid steels cooled in water

As can be seen, with the austenitising temperature increase $T_A$ the hardness of steel samples increases – for steel 40Mo3 to $T_A=825$ °C, for steel 37MnMo6-3 to $T_A=840$ °C and for steel 35CrMo4-3 to $T_A=830$ °C. This hardness increase is the most probably related to the increasing martensite fraction, which transformed from austenite. However, starting from a temperature app. $T_A = 880$°C the hardness of samples of three investigating hypoeutectoid steels decreases, which can be related to a slow grain growth of the prior austenite. This drop is the most probably related to an increased fraction of the retained austenite. The detailed metallographic analysis was also performed, and the microstructures of selected samples of the investigated hypoeutectoid steels (used for hardness series) are presented in Figure 4.
As can be seen, at the temperature $T_A = 760^\circ C$ (for steel 37MnMo6-3) and $T_A = 775^\circ C$ (for steels 40Mo3, 35CrMo4-3) occurs still ferrite. Whereas, starting from $T_A = 780^\circ C$ there is martensite and its fraction is increasing in the microstructure of quenched samples of 37MnMo6-3 steel. Microstructures of samples of the other investigated steels are analogous.

5. **SUMMARY AND CONCLUSIONS**

Within investigations performed for three hypoeutectoid steels containing app. 0.4\% C and app. 0.3\% Mo and various amounts of other alloying elements (Mn and Cr), the critical temperatures of these steels - after forging – were estimated, full annealing was performed and the austenitising temperature influence on the microstructure and hardness of quenched samples was assessed.

It was found that:

- The determined transformation temperatures: $A_{C1s}$; $A_{C1f}$ and $A_{C3}$ in steel which contains 1.5\% of manganese (37MnMo6-3). This confirms the fact that manganese (austenite forming element) decreases temperatures $A_1$ and $A_3$ in hypoeutectoid steels of a very weak background of other alloying elements (in this case only 0.3 \% Mo).
- The character of hardness changes of quenched samples (water cooled) is very similar in tested steels: 35CrMo4-3 and 40Mo3 and different for steel with manganese (37MnMo6-3). The hardness of samples hardened steels tested increases austenitising temperature $T_A$, at which only austenite occurs in the microstructures of these steels. This is (the most probably) the temperature $A_{C3}$ of the given hypoeutectoid steel.
- After exceeding of the temperature $A_{C3}$ probably the growth of austenite grains occurs in samples of quenched steels, which manifests itself in decreasing of the samples hardness with the austenitising temperature increasing.

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**LITERATURE**


