THE ANALYSIS OF AUSTENITE CHANGES DURING CONTINOUS COOLING AFTER HOT DEFORMTION PLASTIC OF HIGH CARBON BAINITIC STEEL

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Abstract
The results of numerical and physical simulation of thermo – mechanical treatment of high carbon bainitic steel are presented in this article. The computer program TTSteel for computer simulation were used. The experiments were carried out for two logarithmic deformations $\varepsilon_1=0,3$ and $\varepsilon_2=0,6$. After deformation the cooling rates for range 0,01÷100°C/s were used. After that the physical simulation by the dilatometer DIL 805A/D with possibility of deformation were done. The experiments were carried out for the parameters that were used during numerical simulations. The metallographic analysis and hardness measured were done. The results of researches were used for building the Continuous - Cooling - Transformation - Deformation (CCTD) diagrams for continuous cooling condition.

1. INTRODUCTION
The industrial development require new materials characterized highest mechanical properties. The conditions of thermo mechanical treatment proved to highest level of mechanical properties for high carbon bainitic steel. Mechanical properties depends on microstructure.

In the article the results of phase transformations of austenite during physical simulations of continuous cooling after hot plastic deformation were presented. For researches the experimental high bainitic steel were used. The chemical composition of steel was presented in table 1.

Table 1. Main components of high – carbon bainic steel.

<table>
<thead>
<tr>
<th>% mass</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Mo</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,82</td>
<td>2,20</td>
<td>1,63</td>
<td>0,35</td>
<td>1,62</td>
<td></td>
</tr>
</tbody>
</table>

The experimental material was prepared and made in Institute of Ferrous Metallurgy in Gliwice. The bainitic steel were used for plate characterized high level of hardness (up to 700HV) and tensile strength (up to 2,5 GPa).

2. RESEARCHES AND THE RESULTS
The main aim of researches were developed CCTD diagrams. In experimental studies have been used steel alloy whose main components are presented Table 1. The preliminary study were conducted to determinate cooling conditions after plastic deformation. For determinate cooling rate numerical simulation of thermo - mechanical treatment were done. The commercial program TTSteel for simulations were used. The CTT diagrams were generation on the basis of chemical composition for two values of true strain $\varepsilon_1=0,3$ and $\varepsilon_2=0,6$. The developed by computer program CCTD diagram were present on fig. 1 and 2.
The results of simulation were used for determined conditions of thermo – mechanical treatment during physical simulation. Tests were performed in the Institute of Process Modeling and Automation of Plastic Processing Technical University of Czestochowa. For tests was used dilatometer DIL 805A/D equipped with a plastometric snap. For experiment the cylindrical samples with a length of 10 mm and 5 mm in diameter were used. The samples were subject to five step process of thermo – mechanical treatment:

- heated to a temperature of 1100°C
- hold at a temperature of 180s
- cooled to temperature of 950°C with cooling rate 10K/s
- deformed with true strain $\varepsilon_1 = 0.3$ or $\varepsilon_2 = 0.6$
- cooled to ambient temperature with rates from range $100 \div 0.01$K/s

The metallographic researches were done. The receive structure of high carbon bainitic steel after treatment are shown on fig. 3, 4 and 5.
During simulation dilatometer curves were recorded. The temperatures of phase transformations in according Polish standards PN-68/H-04500 after analysis of dilatometers curves were obtained. The exemplary dilatograms are presented on fig. 6 and 7.

The characteristic points are obtained on dilatometric curves. During cooling with rate \(0.1^\circ C/s\) after deformation \(\varepsilon_1=0.3\) determined temperatures of start bainitic transformation \(B_s\) was 593°C and ending bainitic transformation \(B_f\) was 294°C. The temperature of started martensitic transformation \(M_s\) was 160°C. The diagram of cooled high carbon bainitic steel after deformation \(\varepsilon_2=0.6\) in a temperature 950°C with cooling rate \(0.1^\circ C/s\) were presented on fig. 7. In this case temperatures bainite start \(B_s\) was observed at 610°C ending of bainitic transformation \(B_f\) was deformation at 298°C. The temperature martensite start transformation \(M_s\) was 175°C. The Vicker’s hardens of samples were determinated. The results of measuring are presented in tab.2.

The all results of investigation make possible to developed CCTD diagrams of high carbon bainitic steel deformed in temperature 950°C with the true strains \(\varepsilon_1=0.3\) and \(\varepsilon_2=0.6\). The CCDT diagrams are presented on fig. 8 and 9.
The results of experiments provided information of influence of thermo – mechanical treatment conditions on structure and properties of experimental high carbon bainitic steel.

3. SUMMARY AND CONCLUSIONS

The analysis of kinetic phase – transformations of deformed austenite during continuous cooling samples of samples from high carbon bainitic steel were done. Based on chemical compositions pre – generated CCTD diagrams using program TTSteel for values of true strain \( \varepsilon_1=0.3 \) and \( \varepsilon_2=0.6 \) were done. The physical simulation of thermo - mechanical treatment for determinate the temperatures of phase transformation were done. The dilatometer DIL 805A/D was used. The metallographic researches were done too. The type of structure and hardness of samples were determinated. The hardness of samples deformed \( \varepsilon_1=0.3 \) confirmed the martensitic – bainitic type of structure in the range of cooling rate from 0.1÷30°C/s. The hardness in this case was 606÷792 HV. The effect of increase of cooling rate up to 100°C/s was chang of structure. The structure of steel consist on martensite only. The hardness of sampled is oscillated from 792 to 890HV. The structure of samples cooling with cooling rate up 80°C/s after deformation \( \varepsilon_2=0.6 \) consist of bainite and martensite. The hardness of this samples are from 498 HV for cooling rate 0.1°C/s to 782 HV for cooling rate 80°C/s. The increase cooling rate up to 100°C/s gives hardness about 840 HV. On the basis of dilatation test results, metallographic and hardness measurements have been built CCTD diagrams for two values of the true strain \( \varepsilon_1=0.3 \) and \( \varepsilon_2=0.6 \) of high carbon bainitic steel. The CCTD diagrams will be used for develop a technology of hot rolling process of plates from high carbon bainitic steel characterized properties and a structure for low temperature treatment.

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