THE ASSESSMENT OF THE X2CRNIMO25-6-3 DUPLEX STEEL PLASTICITY

Grzegorz STRADOMSKI

Technical University of Częstochowa, Faculty of Production Engineering and Materials Technology, Institute of Plastic Forming Processes and Safety Engineering, Armii Krajowej 19, 42-200 Częstochowa, Poland, EU, gstradomski@wip.pcz.pl

Abstract

Among the steel and cast steel resistant to corrosion most modern and dynamically developing group are ferritic-austenitic alloys, commonly known as duplex. Higher than austenitic steels, mechanical properties and good corrosion resistance in both overall and pitting make duplex steels irreplaceable material in the petrochemical industry, power, pulp and paper, food. Duplex steels and cast steels characterized by multiphase microstructure have a complex plasticity due the fact of deforming two different phase austenite and ferrite. The chemical composition of a steel containing about 0.02% C, 26% Cr, 6.5% Ni, 3% Mo, 1.4% Mn, 0.2% N guarantees that already, in the raw state, immediately after casting is obtained ferritic - austenitic structure. In this work was assumed that the starting material for the plasticity test will be the X2CrNiMo25-6-3 cast steel. From the material were taken samples with dimensions of 10x15x20 mm, which were deformed with different speeds 0.1, 1 and 10 s⁻¹ in the temperature range from 800 to 1150°C. To determine the plasticity was taken the compression test and the study was performed on the simulator Gleeble 3800 physical processes. The resulting flow curves were used to develop the nine parameters Hansel - Spittle equations forming the base material used in the computer simulation of the rolling process. In addition, in the paper was analyzed the changes in the microstructure of the material being deformed with the changing conditions. To evaluate the microstructure changes Nikon MA 200 optical microscope was used and samples were etched with the Mi21Fe reagent. The microscope is connected with the NIS – Elements D software used for acquisition of image.

Keywords: duplex steel, innovative materials, plastic deformation, sigma phase.

1. THE INTRODUCTION

Current ecological regulations on CO₂ emissions and increasingly higher commodity prices have increased interest on so called alternative energy resources such as shale gas. Widely published in the media geological data, present that a large part of our country (Poland) is a potential place of industrial boreholes. Starting of industrial gas production, and perhaps crude oil from shale requires conducting a very large number of deep drillings reaching depths of 5000 m. Among the stainless steels of special importance gained ferritic – austenitic steels. This is due to the fact that these alloys are characterized by simultaneously high mechanical properties with high corrosion resistance. The main area of application of ferritic-austenitic steel and cast steel, also known as duplex are constructions and components subjected to high loads and environments conducive to stress corrosion, pitting and sliting. Under such conditions, these materials with comparable basic phases share ferrite and austenite, show better mechanical properties in comparison to conventionally used ferritic or austenitic steels [1-4].

2. MATERIAL AND METHODOLOGY OF RESEARCH

The object of the study was a ferritic-austenitic X2CrNiMoN25-6-3 cast steel, whose chemical composition is shown in Table 1. Cast steel melted under industrial conditions in the medium frequency induction furnace of about 150 kg capacity.
Table 1 The chemical compositions of tested material (mass%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>X2CrNiMoN25-6-3</td>
<td>0.02</td>
<td>1.46</td>
<td>0.93</td>
<td>0.01</td>
<td>0.08</td>
<td>26.70</td>
<td>6.48</td>
<td>3.10</td>
<td>0.02</td>
<td>0.23</td>
</tr>
</tbody>
</table>

The material was mold in the Y-shape cast sample of 25.0 mm test wall thickness. Figure 1 present a drawing and a photo of an exemplary cast. From the cast were taken 10x15x20 mm rectangular samples, which were next deformed with use of Gleeble 3800 physical processes simulator using the Hydrawedge module.

![Place of samples taking](image)

Fig. 1. Drawing of casting with the sinkhead and the appearance of the finished casting.

This module (Figure 2) allows for testing the uniaxial compression and compression test in straight strain. These processes may be used for research related to the deformation rolling conditions. Therefore, assuming that the test material will be deformed during rolling proces to determine the flow curves was selected as discussed above test [5-7].

![Hydrawedge module chamber](image)

Fig. 2. Hydrawedge module chamber and the appearance of applied sample.
3. RESULTS AND DISCUSSION

Studies on plasticity of X2CrNiMoN25-6-3 steel were performed for the range of temperature and strain shown in Table 2.

<table>
<thead>
<tr>
<th>The intensity of deformation</th>
<th>Temperature [°C]</th>
<th>Strain rate [1/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>800-1150</td>
<td>0.1; 1.0; 10.0</td>
</tr>
</tbody>
</table>

Selection of temperature - deformation processes parameters correspond to the hot rolling of sheet on a flat barrel. Because it was assumed that later conducted research will be made in direction of obtaining plates with a minimum thickness of 4 mm. As a result of deformation of the sample shown in Figure 1 were obtained samples as shown in Figure 3, and based on the record of the stress in relation to the applied reduction were generated flow curves for the material.

![Flow curves](attachment:flow_curves.png)

Fig. 3. The appearance of samples after deformation in order to obtain flow curves. From left to right 800°C - 1150°C

The curves subsequently were approximated to obtain a nine-parameter equation Hensle-Spittle. Sample flow curves for the temperature of 800 and 1000°C were presented in Figures 4 and 5.

![Flow curves](attachment:flow_curves_800_1000.png)

Fig. 4. Strengthening curves for a temperature of 800°C
Data presented in Figures 4 and 5 indicate that with increasing temperature the yield stress value decreases as a result of the significant effect of the used parameters. As a result of approximation (solid lines) of experimental curves (dotted lines) was obtained for most cases a good representation of the analyzed temperature - deformation parameters. In most cases the differences appear only at large deformation of about 75 - 80%, such deformation in one pass is not used.

Due to the fact that steels and duplex cast steel have very complex plasticity and literature data on the developed flow curves consist mainly of species similar to steel 2205, so it is important to determine such relationship for the tested steel. The test steel containing about 0.021% C, 26.7% Cr, 6.5% Ni, 3.1% Mo and 0.23% N has a different ductility than steel 2205. In addition, the designated nine-parameter equation much better match to the real conditions than the frequently presented equation of four parameter. In the equation Hensle-spittle value of yield stress $\sigma_p$ is dependent to the deformation parameters. The resulting equation is shown below:

$$\sigma_p = A_1 \cdot \dot{\varepsilon}^{A_4} \exp \left( \frac{A_2}{\varepsilon} \right) \exp \left( A_3 \cdot \dot{\varepsilon} \right) \exp \left( A_4 \cdot (1 + \varepsilon)^{A_5} \cdot \dot{\varepsilon}^{A_6} \cdot \dot{\varepsilon}^{A_7} \cdot T^{A_8} \right) \exp \left( A_9 \cdot T \right)$$

(1)

Where: $\varepsilon$ - the intensity of deformation, $\dot{\varepsilon}$ - strain rate $s^{-1}$, $T$ - temperature °C, A1-A9 – the coefficients dependent on steel species and the chemical composition.

Table 3 present the obtained values of the A1-A9 parameters determining the approximating function for the equation (1).

<table>
<thead>
<tr>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>$A_5$</th>
<th>$A_6$</th>
<th>$A_7$</th>
<th>$A_8$</th>
<th>$A_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10072.520</td>
<td>49064.0</td>
<td>0.00019</td>
<td>0.83349</td>
<td>0.00144</td>
<td>0.735978</td>
<td>0.00082</td>
<td>0.07712</td>
<td>0.00318</td>
</tr>
</tbody>
</table>

During the tests it was observed that for some range of temperatures, and strain rate were appeared crack on samples which cause the need for repeating tests. Such behavior of tested material has prompted the author to perform the analysis of the microstructure. The analysis was performed for selected sample at different variants deformation and temperatures as well as the non-deformed sample. Exemplary micrographs are shown in Figure 6.
The analysis of the base sample microstructure showed that the material has a ferritic–austenitic structure with a small fraction of \( \sigma \) phase precipitates. This phase, as described in literature, has a very negative effect on the mechanical and plastic properties [8-10]. Analysis of the samples subjected to deformation of both cracked and not show that the material deformed very much and uniformly have deformed two phases. For samples that cracks study focused on the response where lay the initiator of this phenomenon. Helpful in this proved to be recorded flow curves that indicated at which stress and strain at which rupture occurred. Shown in Figure 6 e) and f) mikrostrukturc of cracked samples indicated that in all cases the rupture proceeded through the boundary of ferrite - austenite. This point in the base samples was observed the \( \sigma \) phase precipitations. Close inspection of the area of the sample showed the presence of ruptured at this stage is shown in Figure 6 f.
4. CONCLUSIONS

Designated by the physical simulation of flow curves and their approximation enables to determine with high accuracy Hensle - Spittle equation describing the behavior of the material during plastic deformation. High impact of used temperature - deformation parameters on the test steel grade makes it difficult to create a universal base material, so in the case of such processes with higher strain rates will be necessary to introduce the correction and repetition of part of the research. Due to the observed appearance of cracks, for example variant deformed on the temperature of 1100°C with strain rate $10.0 \text{ s}^{-1}$, were made analysis of the microstructure. Due to the fact that the initial state sample contains a negligible, several percent, amount of sigma phase was assumed that the entire volume of casting in which the sample was obtained is similar. This assumption was correct, however, its distribution of the ferrite grain boundaries caused that with a large deformations this phase is likely to become the initiator of cracking. It is worth mentioning that the use of very large deformations, the total deformation 1.3, in most cases did not lead to the appearance of cracks. It provides a good yield of the test material provided proper selection of process parameters and strict adherence to the technology.

LITERATURE

[7] LABER K., DYJA H., Analiza parametrów energetyczno-siłowych podczas walcowania normalizującego prętów okrągłych gładkich o średnicy 38 mm w ciągłej walcowni bruzdowej., Archiwum Technologii Maszyn i Automatyzacji Vol.30 nr 3 2010, s.139-146.