DEFORMATION BEHAVIOUR OF SECTIONS FROM X15CRNISI20-12 HEAT RESISTING STEEL IN ROLLING OF SPECIAL SECTIONS

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Abstract
The purpose of this paper is to give a comparison of the behaviour of heat-resistant austenitic stainless steel X15CrNiSi20-12 and the ordinary S355J0 steel grade during rolling of a special-purpose section for door hinges from 80 × 80 mm stock in caliber rolls under normal service conditions of VÚHŽ special section rolling plant. The X15CrNiSi20-12 steel grade possesses low thermal conductivity and high thermal expansion capacity. The latter leads, together with higher flow stress, to more pronounced spreading of this material. This paper deals with the entire rolling procedure of 61949-type section. The initial position of the rolled stock in caliber rolls plays an important role. Key parameters monitored in the process of plant rolling include the shape of the product, spreading, surface temperatures, surface quality, metallographic structure and torques. Comparisons are made in the first and second roll calibers which are open and do not constrain the spreading. The cross-section shape from the pass no. 5 was then compared with the cross-section obtained by mathematical modelling. The FEM-based software Forge3D enables full-scale rolling procedures to be simulated with flat and caliber rolls, in addition to simulations of forging, extrusion, punching and other processes. Finally, the usability of the simulation tool Forge 3D for VÚHŽ special section rolling plant was explored.

Key words: hot rolling, fine element method, special shape, stainless steel

1. INTRODUCTION
Faced with situation on the market in sections for automotive industry, VÚHŽ company special section rolling plant began to orientate towards rolling sections from materials with higher added value, such as stainless and tools steels, nickel alloys and others. As the experience of VÚHŽ in rolling such materials is not extensive and experimental trials are rather costly, other methods have been sought which could be used for verifying some rolling parameters. One of techniques is mathematical modelling [1], by means of which causes of defects [3 - 4] can be identified without expensive experimental testing, heat transfer or material flow parameters [5] can be determined and compared and rolling forces, flow stresses and other quantities explored.

This paper describes field experiments at VÚHŽ special section rolling plant. It also gives a comparison of one of cross-section “partial prints” with results of FEM-based mathematical modelling carried out in Forge3D, where the parameters were calculated at individual nodes. This work continues the studies described in the paper Mathematical Modelling of Deformation Behaviour of X15CrNiSi20-12 Heat Resisting Steel during Rolling of Special Sections [6]. It was devoted to comparing the behaviour of heat-resisting austenitic stainless steel X15CrNiSi20-12 with that of S355J0 ordinary grade by means of FEM modelling.

Programs employing the finite element method are ordinarily used for investigation of forging, thick sheet, strip and caliber rolling and other processes. Their use in manufacturing special sections is not common yet, as some rolling parameters, e.g. spreading, are rather difficult to formulate in non-symmetrical calibers. The paper is also intended to explore the usability of Forge 3D in VÚHŽ special section rolling plant.
2. SPECIAL SECTION ROLLING PLANT

VUHZ a.s. special section rolling plant produces special sections, namely for automotive, machinery and agricultural industries. The rolling plant includes one two-high rolling stand (Fig. 1.) with caliber rolls where the entire roll length contains roughing, pre-rolling, leader and finishing roll passes. Over recent five years, there were several upgrades to the rolling plant to increase the production capacity and enhance the quality of products. The important ones included the construction of a new walking beam gas furnace, an upgrade to the rolling stand drive, construction of a new cooling grate and installation of high-pressure spray descaling, connecting the manufacturing and storage halls and extending the maximum length of rolls by adapting their bearing, which led to an increase in roll body length from 800 to 930 mm.

![VÚHŽ Rolling mill](image1)

3. MATERIAL

Heat resisting X15CrNiSi20-12 steel shows good weldability and poor machinability. It is a material for tools used in ceramic industry, heating equipment (storage heaters) and for other refractory components usable up to 1,150°C. Tab. 1. shows the chemical composition of X15CrNiSi20-12 obtained from chemical analysis and FORGE 2009 database.

Table 1 Chemical composition of X15CrNiSi20-12 [wt. %]

<table>
<thead>
<tr>
<th>X15CrNiSi20-12</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem. analysis</td>
<td>0.165</td>
<td>1.56</td>
<td>1.85</td>
<td>0.026</td>
<td>0.002</td>
<td>19.35</td>
<td>11.28</td>
<td>0.067</td>
</tr>
<tr>
<td>FORGE</td>
<td>0.13</td>
<td>2.133</td>
<td>0.03</td>
<td>0.02</td>
<td>20</td>
<td>12</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

S355J0 is a common structural steel used for making car door hinges. It is also the material for producing bridge braces, components of pressure vessels or parts for heat power generation equipment. It has good weldability. Tab. 2. shows the chemical composition of S355J0 measured by chemical analysis.

Table 2 Chemical composition of S355J0 [wt. %]

<table>
<thead>
<tr>
<th>S355J0</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem. analysis</td>
<td>0.4</td>
<td>0.41</td>
<td>1.33</td>
<td>0.013</td>
<td>0.007</td>
</tr>
</tbody>
</table>
Fig. 2. shows the comparison between thermophysical properties of the investigated steels in dependence on temperature. Thermal conductivity of S355J0 is higher than that of the other steel throughout the temperature range. The difference within the interval of forming temperatures is less than 4 $\text{Wm}^{-2}\text{K}^{-1}$. Contrariwise, the specific heat of X15CrNiSi20-12 in the range between 600 °C and 1200 °C is higher than that of S355J0. Fig. 3. shows that thermal expansion coefficient of the heat-resisting steel above 500°C is up to 40% higher than that of the C-Mn steel. Fig. 4. indicates the flow stress values of both steels.

4. FIELD EXPERIMENT

For the rolling procedure trials on X15CrNiSi20-12 steel, section no. 61949 was selected. Tab. 2. contains the roll pass schedule with schematic drawings of rolled product shapes and basic dimensions achieved in individual passes, roll settings, tilting and intermediate dwells.

<table>
<thead>
<tr>
<th>Pass</th>
<th>Roll pass</th>
<th>Shape</th>
<th>Hot Dimension (mm)</th>
<th>Tilting</th>
<th>Roll Setting (mm)</th>
<th>Dwell time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>N</td>
<td>Ø 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>65 x 71</td>
<td>65 x 65</td>
<td>90°</td>
<td>+37</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>48 x 70</td>
<td>36 x 76</td>
<td>90°</td>
<td>+17</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td>+6</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
<td>90°</td>
<td>+12</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td>+90°</td>
<td>+6</td>
<td>10</td>
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<tr>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
<td>-90°</td>
<td>+1</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>-</td>
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<tr>
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<td>4</td>
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<td>0</td>
<td></td>
<td>-</td>
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<tr>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
<td>-0.7</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td></td>
<td></td>
<td>-0.2</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

The heating was carried out conventionally. The furnace temperature was set to 1,200°C. Rolling of bars was arranged in such a way that the first one was rolled all the way to the last pass (finishing roll pass),
rolling of the second was finished in next-to-last pass and the numbers of passes were reduced by one for each subsequent bar, down to the fifth pass. Bars from S355J0 were rolled in the same manner to provide reference materials for comparing the filling of individual calibers. Interpass temperatures are listed in Fig. 5. The large difference between temperatures for different grades is obvious. The actual difference, however, is smaller, as the emissivity value set on the radiation thermometer was the same for both grades. Fig. 6. lists torque values for both rolls. Highest values were found in fifth and eighth passes. In these two passes the largest changes in shape take place. Third highest torque value was found in 3rd pass where the reduction is the largest.

![Fig. 5. Temperatures between passes](image1)

![Fig. 6. Torque values for both rolls](image2)

Metallographic observation revealed that the microstructure consisted of austenite. The specimen, which was only rolled to the fifth caliber, showed the grain size of G 7.5. The specimen rolled through all passes had the grain size of G 10. Both microstructures are shown in Fig. 7. The specimen upon five passes is shown with the scale of 100 μm; specimen from the finishing roll caliber is shown with the sale of 200 μm.

![Fig. 7. – Microstructure of X15CrNiSi20-12](image3)

The surface of the stainless steel section showed impressions of roll surface irregularities. They were the result of normal wear during rolling of the 61949 batch. The test was conducted at the very end of the section 61949 batch rolling. Whereas almost no wear was apparent on the surface of S355J0, wrinkling on X15CrNiSi20-12 grade was noticeable (Fig. 8.).

![Fig. 8. Wrinkled surface of X15CrNiSi20-12](image4)
5. COMPARISON OF PARTIAL PRINTS UPON ROLLING

As the key point of is the spreading of stainless steel in shape calibers, cross-sections upon 5th through 7th pass will be compared (i.e. caliber 1 and 2). Cross sections formed in individual passes are shown in Fig. 9. Data for the grade S355J0 is shown in red; X15CrNiSi20-12 is shown in blue. Key dimension figures in red are in millimetres and pertain to maximum dimensions of partial prints of the S355J0 along x and y axes. The dimension figures in black denote the differences in spreading of the X15CrNiSi20-12 grade.

5.1. Pass no. 5

In this pass, both materials spread to the right where a massive flash forms. Higher flow stress of the X15CrNiSi20-12 grade has no influence on roll skipping, despite the assumptions for the first shape caliber. In the open section of the caliber, the X15CrNiSi20-12 grade spread about 0.86 mm along the x axis, of which 0.47 mm went to the flash.

5.2. Pass no. 6

Rolling in sixth pass is carried out in the first (box) pass. This pass prevents formation of laps, on the large flash from the previous pass. This pass is not enclosed in the x direction and therefore does not constrain greater spreading resulting from the flash. It was only this pass where roll skipping occurred with the X15CrNiSi20-12 steel, leading to product extension by 0.37 mm. The total spread along the x axis was about 1.76 mm.

5.3. Pass no. 7

The caliber no. 2 is fully closed in 7th pass. A flash forms on the right side again, posing a large risk of laps forming in the following, not fully closed shaped calibers. The stock from X15CrNiSi20-12 steel spread by 0.77 mm along the x axis in the flash region. On the left side, in the top open section, the product width was smaller than in S355J0 by 0.94 mm. This was probably caused by the bar rotation during manual feeding in the stand in this or some of the previous passes.

![Fig. 9 – Roll product shapes after 5th, 6th and 7th pass](image)

6. FEM ANALYSIS OF 5th PASS OF X15CrNiSi20-12

The purpose of the analysis was to compare the cross-section obtained in 5th pass of the pilot experiment and the cross section resulting from the mathematical analysis. Simulation of rolling of the section no. 61949 was based on reduction settings shown in Tab. 2. The comparisons are given in Fig. 10. Forge3D simulation suggests that the cross-section tends to spread in the direction of the larger open section of the caliber. Shifting the input stock in the flash direction by 2 mm results in Forge3D aligning the formed stock
almost perfectly with the original position. Total displacement of the shape obtained from FEM simulation is difficult to express accurately. Dimensions of the overflowed section differ across the cross section, exceeding 3 mm in the bottom left part. This might be due to different dimensions of the stock in preceding passes, for which there is no reference material, as the samples of rolled product were taken after fifth and subsequent passes at VUHZ rolling plant.

7. SUMMARY

Results of the field experiment suggest that rolling X15CrNiSi20-12 grade in VUHZ is feasible and should not pose any significant problems. Unlike the currently rolled stock, X15CrNiSi20-12 has much stricter requirements for torques, surface quality, roll condition and other parameters. One of important conditions will be the selection of durable wear resistant rolls, as the stainless steel is susceptible to impression of any surface irregularities. Comparison of actual cross sections and results of FEM analysis yielded ambiguous results. The field experiment highlighted different behaviours of steels in special calibers but the cross-section shift may be attributed, in part, to the different rolled product shape prior to fifth pass. Next steps will include verification of results in a new experiment.

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REFERENCES


