ON MONITORING OF MECHANICAL CHARACTERISTICS OF HOT ROLLED S355J2 STEEL

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ABSTRACT

Hot rolling normalization technology for producing sheets from low-carbon Steel S355J2, used in the Bulgarian Metallurgical Plant “STOMANA Industry SA” is under investigation. A newly introduced automatic application optimization procedure to this technology is an important step that leads to avoiding traditional heat treatment, improving steel mechanical characteristics, increasing production efficiency, all resulting in high quality final products. On the basis of the final mechanical rolled-sheet characteristics - yield strengths, $R_e$, ultimate tensile strengths, $R_m$, absorbed energies in impact tests, $K$, and elongations after fracture - some energy-stress and energy-stress-elongation constructions-spaces have been plotted. These spaces can be used for general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour.

Keywords: hot rolling, low-carbon steel S355J2, rolled-sheet, mechanical characteristics, prediction of steel-sheet mechanical behaviour.

INTRODUCTION

Development of modern metallurgy and engineering is characterized not only by increasing production volume and enriching production range, but by sufficient improve in quality - increase of metal-product’s service life in combination with high reliability of structures, machines and devices [1 - 3].

Industrial processing of metals (forming) by plastic deformation is one of the major and most important industries in global economy. It provides a constant chemical composition, micro- and macrostructure, geometric shapes and sizes and guaranteed physical and mechanical properties.

This is of essential importance as the metal products quality depends primarily on their mechanical properties, their behavior in processing and exploitation, and their microstructure [1-5].

The aim of this work is to investigate and control the technological process of forming of hot-rolled steel plate (sheet) of Steel S355J2+N in attempt to improve mechanical characteristics of the final product.

EXPERIMENTAL

Conventional hot rolling technology for producing thick sheets

Thick sheets (30 mm and 40 mm) from low-carbon Steel S355J2+N were produced by normalization rolling at the Bulgarian Metallurgical Plant “STOMANA Industry SA” for more than 60 years [6 - 7].

Standard chemical composition and mechanical properties

Steel S355J2+N is low-carbon, low-alloy structural steel with chemical composition shown in Table 1 and mechanical properties presented in Table 2, both in accord with standard EN 10025-2:2004 “Hot rolled products of structural steel”.
Equipment and technological experiments

According to EN 10025-2:2004, 40 experiments were carried out - two groups of 20 experiments to obtain two different thicknesses of the finished product (final plate/sheet), of 30 mm and 40 mm, respectively. The rolling mill used is schematically presented in Fig. 1 as a complex of mechanical components and equipment for hot rolling of heavy plates/sheets, their further processing and transportation. The mill consisted of a reverse Roll Mill type “Quarto”, and equipment for straightening, cutting and marking the finished products [6 - 7].

Two speed-temperature-deformation regimes - Regime A and Regime B were developed and experimentally tested to adjust the parameters of the rolling mill for receiving quality products with desired properties by total thickness of 30 mm and 40 mm. Each profile size (30 mm and 40 mm) was obtained, performing deformation process in these two regimes; 10 pieces from each thickness were tested.

Specific features of the different rolling regimes

Regime A. The rolling process was carried out when the parameters of the rolling mill were set up as follows: large rolling forces (up to 75 % of the maximum for the mill or up to 16,000 kN); high torque (running over to the equipment nominal value); large difference between the metal initial and final thickness concerning each pass, ΔH, mm, respectively a high degree of deformation (reduction by ca 20 % of the thickness within each pass). The speed-temperature-deformation normalization rolling in case of Regime A was designed with 21 passes.

Regime B. Normalization rolling process was performed with a new setting of the rolling stand parameters providing less stress (up to 68 %), a low torque, small difference between the metal initial and final thickness concerning all passes (ΔH is between 13 mm and 16 mm) and decreased deformation to maximum 16 - 20 %. This increased the number of passes to 25. Regime

Fig. 1. Scheme of Quarto Reversing Rolling Stand for hot-rolled steel plates/sheets at the Bulgarian Metallurgical Plant “STOMANA Industry SA”.

Table 1. Chemical composition of Steel S355J2+N (mass %).

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Mo</th>
<th>As</th>
<th>Al</th>
<th>V</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>1.10</td>
<td>0.20</td>
<td>0.008</td>
<td>0.002</td>
<td>0.040</td>
<td>0.060</td>
<td>0.180</td>
<td>0.009</td>
<td>0.008</td>
<td>0.025</td>
<td>0.031</td>
<td>0.022</td>
</tr>
<tr>
<td>0.18</td>
<td>1.16</td>
<td>0.26</td>
<td>0.014</td>
<td>0.010</td>
<td>0.120</td>
<td>0.150</td>
<td>0.320</td>
<td>0.031</td>
<td>0.027</td>
<td>0.040</td>
<td>0.042</td>
<td>0.037</td>
</tr>
</tbody>
</table>

Table 2. Mechanical Properties of Hot-Rolled Sheet’s Steel S355J2+N of nominal thickness of 30 mm and 40 mm.

<table>
<thead>
<tr>
<th>Yield strength, Rc, MPa</th>
<th>Tensile strength, Rm, MPa</th>
<th>Total Elongation, А, %</th>
<th>Impact test*, K, J</th>
</tr>
</thead>
<tbody>
<tr>
<td>345 - 430</td>
<td>470 - 630</td>
<td>min 20 - 22 %</td>
<td>min 27 *</td>
</tr>
</tbody>
</table>

* test piece with V-figurative notch; T=−20°C
B became more efficient with the change of the initial conditions and the introduction of an automatically applied optimization program.

**Testing**

After rolling, 40 specimens were machined for standard mechanical testing - 20 to test Regime A and 20 to test Regime B. 10 specimens of each group were set to reach final thickness of 30 mm, while another 10 were envisaged to reach thickness of 40 mm. The data referring to the mechanical (tensile strength, yield strength) and plastic (elongation) behavior of the final product as well as the impact energy required is summarized in Fig. 2.

![Comparative analysis of mechanical properties](image)

Fig. 2. Comparative analysis of the mechanical properties of hot-rolled plate/sheets obtained by strain-speed-temperature Regimes A and B; a) a plate/sheet of a final thickness of 30 mm; b) a plate/sheet of a final thickness of 40 mm.
RESULTS AND DISCUSSION

The data presented in Fig. 2 show that the final products obtained in case of Regime B application have improved mechanical behavior in correspondence with standard EN 10025-2:2004, whereas the plates obtained by using Regime A cannot satisfy the requirements of this standard.

This means that the rolling process provided by Regime A is unstable in comparison to that of Regime B. It is worth noting that the rolling process there is controlled, which results in essential improvement of all mechanical properties and their steady reproduction.

The mechanical testing results subjected to a standard analysis have their usual standard presentation as that shown in Fig. 2. But these results can be presented in a completely different way as that illustrated by Figs. 3a and 3b. The latter visualize the Energy-Stress Constructions-Spaces MNLQQ,M\(1\),N\(1\),L\(1\) for 30 mm and 40 mm plates/sheets (obtained under Regime B including an automatic application of the optimization procedure mentioned above). They are built by using the final mechanical rolled-plate characteristics - the yield strengths, \(R_y\), the ultimate tensile strengths, \(R_m\) and the impact tests absorbed energies, \(K\). (The elongations after fracture are included in similar Constructions-Spaces shown in Fig. 5.) These Constructions-Spaces provide additional information on the rolling technology and the energy-mechanical properties of the finished/final products. The complicated three-dimensional Energy-Stress Surface MNLQ in Figs. 3a and 3b shows that although the minimum values of the yield and the tensile strengths are above the minimum set by the standard, it is worth looking for further improvement of the speed-temperature-deformation regime of rolling that will make this surface smoother, and hence further (even higher) stabilization of the technology and the energy-mechanical properties of the finished/final product. At present Surface MNLQ looks smoother for 30 mm plates/sheets than that for 40 mm ones.

Figs. 4a and 4b illustrate the complex pyramidal Spaces STUT\(_1\),S\(_1\),P built in correspondence with:

- the straight lines PU and S\(_1\)T\(_1\) refer to the average values of the yield and tensile strengths, respectively on the ground of 10 tests carried out for each thickness;
- the broken line ST refer to the average energy of the impact tests and the stresses \((R_{m,av} - R_{c,av})/2\) (on the ground of the same 10 tests).

It is easy to build a line corresponding to the average value of the stresses using the broken line ST. Thus the visualization of the pyramidal Spaces STUT\(_1\),S\(_1\),P makes it possible to predict the dispersion of all stresses within the range encompassing the yield and the ten-

Fig. 3. Energy-Stress Constructions-Spaces MNLQQ,M\(1\),N\(1\),L\(1\) expressing the mechanical behaviour of: a) 30 mm plates/sheets; and b) 40 mm plates/sheets.
sile strengths. This in turn provides some preliminary comparisons with the exploitation stress requirements.

The Energy-Stress-Elongation Construction-Space MVZQQ₁M₁V₁Z₁, obtained on the ground of the data presented in Fig. 3, is illustrated in Fig. 5. It includes the elongation after fracture, plotted for all stresses of broken line NL, which moves the line NL to its new position, i.e. to broken line VZ. The Construction-Space MVZQQ₁M₁V₁Z₁ includes all energy, stress and elongation characteristics of the final product and can be used as an instrument for a general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour, including plasticity, under exploitation conditions [3, 4]. The transition from Space MNLQQ₁M₁N₁L₁ to Space MVZQQ₁M₁V₁Z₁ can be done through Stress-Elongation Area NVZL, plotted in Fig. 5.

CONCLUSIONS

The technological process of production of hot-rolled steel plates/sheets of steel S355J2 + N has been investigated aiming at improvement of the mechanical characteristics of the final product. Two different regimes of normalization rolling have been studied (carrying out 20 experiments per regime) – the basic Regime A and a newly designed Regime B (including an automatically applied optimization procedure). Regime B is found to be the more efficient one.

Using standard test data characterizing the mechanical (tensile strength, yield strength) and the plastic (elongation) behavior of the final product, as well as the impact energy providing information about the impact strength, some Energy-Stress and Energy-Stress-Elongation Constructions-Spaces are built. They can be used as an instrument for a general evaluation of the applied rolling technology and for prediction of steel-sheet mechanical behaviour under exploitation conditions. The transition from one space to the other can be done through a specific stress-elongation area including the elongation after fracture.

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REFERENCES