COMPARISON OF EXPERIMENTAL RESULTS OBTAINED BY LABORATORY HOT ROLLING AND ON SIMULATOR OF THERMOMECHANICAL CYCLES

ABSTRACT

The aim was to compare two different ways of the physical simulation of the controlled rolling and cooling of the case-hardening steel 16MnCrS5. We used the results obtained by hot rolling in the laboratory mill TANDEM (VŠB-TU Ostrava) and simulation of analogous modes of processing on the unique simulator of thermomechanical cycles (COMTES FHT a.s.), the principle of which is based on the alternating pressure and tensile deformation. The required forming temperatures were obtained by the resistive heating, the temperature was measured by thermocouples welded on the surface of the testing sample. The maximum speed of the piston is 500 mm s⁻¹. Two ways of the thermomechanical treatment were simulated – either the cooling in the free air from the finish rolling temperature was realized, or a complex mode including the accelerated water spray cooling to the coiling temperature was applied, combined with subsequent retarded cooling of the coil in the Garret coilers, installed in the continuous small section mill at Třinecké Železárny a.s. The rolled down products with thickness 6.4 mm and the specimens with initial dimensions ∅6×11 mm formed on the simulator were subjected to tensile tests and the metallographic evaluation of microstructural characteristics. The structure of specimens from the simulator featured a larger heterogeneity and a complicated transition area from the testing part to the clamping heads. This found its reflection also in the mechanical properties, which in the case of the analogous rolling showed a comparable yield point though, but substantially lower strength and - vice versa - higher elongation at the room temperature. These differences are caused to a great extent by the different shape and size of specimens for the tensile test (in the case of the cylindrical specimens formed on the simulator, the part of the specimen subsequently subjected to the tensile test had the diameter only 4 mm and length 4 mm).

KEYWORDS: simulator of thermomechanical cycles, laboratory hot rolling, mechanical properties

1. INTRODUCTION

The introduction of new facilities into operation has to be accompanied by implementation of the starting tests and experiments. For the reason of downtimes and financial losses it is without any perspective to carry out these experiments directly in operational conditions. Therefore it is effective to utilize the experimental laboratory equipment, simulating in a simplified way the real operational conditions of rolling. For this purpose a wide offer of laboratory rolling mills, dilatometers and plastometers of various types exists [1].
2. SIMULATION IN THE LABORATORY MILL TANDEM

A large experimental programme of the laboratory simulation of the finish rolling in the continuous small section mill at Třinecké železárny a.s. was implemented [2], the main aim of which was to define the influence of the finish rolling temperature and cooling in the Garret coilers on the microstructure and mechanical properties of the investigated steel 16MnCrS5, the chemical composition of which was as follows: 0.182 C – 1.22 Mn – 0.30 Si – 0.021P – 0.028 S – 1.09 Cr – 0.035 Al (wt. %).

The specimens with thickness 16 mm were heated in the electric resistance furnace to temperature 1100 °C and then rolled in both two-high mill stands of the laboratory rolling mill Tandem [3]. The semi-finished product with thickness 10 mm, the primary casting structure of which was refined by the repeated static recrystallization, was gained by two reversible roughing passes. The free cooling down of the rolled stock to the chosen finish rolling temperature 870 °C at an average cooling rate of 4.5 °C / s followed, and afterwards two consecutive finishing reductions to the final thickness 6.4 mm were made. The surface temperature of the sample was measured in the course of rolling and/or cooling, by means of portable pyrometers and the high speed temperature scanners [4].

3. SIMULATION ON SIMULATOR OF THERMOMECHANICAL CYCLES

The simulation of the laboratory thermomechanical treatment was carried out on the physical simulator, based on the servo-hydraulic testing equipment MTS 810 with the uni-axial load of testing specimens by tensile and pressure [5]. The required forming temperatures are achieved by resistance heating of the test specimens, temperatures are measured by thermocouples welded on the surface of the specimen. The testing machine is able to develop the maximum force 250 kN and the maximum speed of piston reaches 500 mm s⁻¹. The forming force is scanned by the dynamometer between the crossbeam and top jaw, the deformation (displacement of the piston) by the scanner LVDT. The chart of the specimen is shown in Fig. 1.

Fig. 1. Test specimen ∅ 6 x 11 mm for simulations of forming

In the modelled case the increase in the heating speed to the forming temperature and the increase in the after-cooling speed following the forming in the region below 200 °C was performed, i.e. safely after realization of the phase transformations. The non-homogeneity of the temperature field was documented by the multi-channel measurement of temperature in different distances from the regulating thermocouple. The displacement of the piston during the simulation of rolling was programmed in such a way that the logarithmic deformation due to decrease in thickness of the rolled stock corresponded to the logarithmic deformation of the test specimen in the place of the regulating thermocouple in the direction of the axis of the testing machine. In the first step of tuning of deformation parameters, the amount of deformation was estimated as the ration of the piston displacement to the initial length of the specimen body (11 mm).
Based on the photos of the deformed specimen in various time in the progression of the simulation, the relative deformation in the place of the regulating thermocouple was determined, as well as the correction of the piston displacement for achievement of the requested local deformation \( \text{(Fig. 2)} \). The strain rate was derived from the revolutions of the rolls of the rolling mill stand, the friction was neglected.

4. DISCUSSION OF RESULTS

Two ways of cooling of the final rolled product were chosen for comparison:
- specimens marked (1) – cooling in the free air to the room temperature;
- specimens marked (2) – accelerated cooling by water sprays to 780 °C (lasting 10 s), then slowed-down cooling in the furnace heated to 600 °C; after 10 minutes the rolled product was taken out from the furnace and cooled in the free air to the room temperature; this mode simulated the cooling of the material in the Garret coiler \( \text{[6]} \).

In Figs. 3, 4 the selected variables registered during hot rolling in the laboratory mill Tandem (specimens marked as HR) and during deformation on the simulator of thermomechanical cycles (specimens marked as TC) are shown. The same deformation and temperature conditions during the thermomechanical treatment of all specimens on both equipment were maintained with a high accuracy.

4.1 Analyses of mechanical properties

The values of yield stress \( R_{p0.2} [\text{MPa}] \), tensile strength \( R_m [\text{MPa}] \) and elongation \( A_5 [%] \) in the longitudinal direction were evaluated. The dimensions of the rolled products made it possible to manufacture the test specimens utilizing the whole thickness of the strip, with the width 12.5 mm and the measured length 55 mm. By contrast, in the case of the cylindrical specimens formed on the simulator of thermomechanical cycles the test part of the specimen for the tensile test had the diameter only 4 mm and the length only 4 mm. The obtained results are summarized in Table 1.
Table 1: Comparison of mechanical properties of specimens after rolling and on simulator of thermomechanical cycles

<table>
<thead>
<tr>
<th>specimen</th>
<th>$R_{p0.2}$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_5$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>rolled product</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR 1– air</td>
<td>477</td>
<td>792</td>
<td>16,0</td>
</tr>
<tr>
<td>simulator TC 1</td>
<td>491</td>
<td>933</td>
<td>13,97</td>
</tr>
<tr>
<td>rolled product</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR 2 – coiler</td>
<td>355</td>
<td>540</td>
<td>24,4</td>
</tr>
<tr>
<td>simulator TC 2</td>
<td>378</td>
<td>658</td>
<td>18,53</td>
</tr>
</tbody>
</table>

In the case of yield stress a relatively good accordance of results obtained by rolling and on the simulator may be observed, even though in the case of the specimen TC 1 a considerable deviation was achieved by the repeated measurements. Strength found on the rolled products was in all cases lower than in the case of specimens from the simulator – the deviations amounted on average 18 to 22 %, whereas a greater discrepancy was observed in the case of specimens that were cooled in a more complicated (slowed-down) way. It is worth the attention that a small scatter of the strength properties of rolled products was found.

The measured values of plastic properties after treatment on the simulator of thermomechanical cycles are methodically considerably lower than after the analogical rolling – after the cooling in the air by ca 37 % and after the simulation of the accelerated water spray cooling and the function of the Garret coiler by ca 50 %. This fact may be explained by a larger total structural heterogeneity of the specimens and by a various shape and size of the specimens for the tensile test.

4.2 Structural analyses

The dilatometric comparison of both applied cooling modes was performed on the small prisms with dimensions 10 x 10 x 70 mm. The spread of the resistance heated specimen in the middle of its length was measured – see Fig. 5, where $\Delta l$ [µm] is a difference between the final and initial length. During cooling in the free air (1) the transformation in the temperature range that is typical for bainite takes place, during the slowed-down cooling by charging into the furnace (2) the transformation into ferrite and pearlite takes place.

The knowledge mentioned above corresponded with the information gained by metallographic analyses of particular specimens. The rolled products were investigated in the longitudinal direction, in the vertical section in the middle of width of the product, namely in the core area. In the case of cooling in the free air (specimen HR 1.9) the structure is created by the hardening phases, ferritic grains and islands of pearlite (Fig. 6), in the case of specimen HR 2.7 after the slowed-down cooling in the furnace the structure is created by ferrite and pearlite (Fig. 7) and it features a distinct banding in the rolling direction. The specimen surface was mildly decarburized. The specimen structure from the simulator distinguishes itself by a greater heterogeneity and a more complicated transition from the test part into the clamping heads – see Fig. 8 for example.
The deformed specimen TC 1.1 features the uniform structure in the central deformed part (influence of recrystallization), a relatively coarse-grained structure in the threaded clamping heads (influence of high-temperature heating) and the noticeable transition areas between these parts, with the characteristic ferritic network. The deformed area of the specimen from the simulator features coarser formations and a lesser portion of ferrite than in the case of the analogical rolled product 1.9 – compare with Fig. 6. In both cases the structure is created by the identical phases.

After the slowed-down cooling of specimen TC 2.1 from
the simulator, the prevailing ferritic-pearlitic structure is observed (Fig. 9), which is, however – compared to the rolled product 2.7 – with coarser grains and without banding that is typical for the rolled state.

5. SUMMARY

The structure and mechanical properties of specimens from the low-alloyed case-hardening steel 16MnCrS5 were compared, after their thermomechanical treatment on the simulator of thermo-mechanical cycles, or in the two-stand laboratory rolling mill. The specimen properties were essentially affected by their final cooling – in the free air, or slowed-down with simulation of terms in the Garret coilers for steel bars.

Due to the character of the material stress (by alternating pressure and tensile), the structure of specimens from the simulator features a greater heterogeneity and a more complicated transition from the test part into the clamping heads. Notwithstanding, in principle the accordance in character of the microstructure after rolling and after application of the simulator was achieved, at least as far as the phase composition is concerned. However, microstructures from the simulator were a bit more coarse-grained and, of course, without banding caused by the longitudinal rolling.

The determined differences in mechanical properties of both types of specimens were caused mainly by the very small dimensions of pieces for the tensile test at the room temperature, which were manufactured for forming on the simulator. In this respect, a better accordance of the mechanical properties between the rolled products and the analogical specimens after torsion tests was reached. These tests were performed at an order of magnitude lower strain rate though, but they made it possible the tensile tests with fairly large specimens [7].

The experiments confirmed a possibility to investigate effectively the deformation behaviour and structure-forming processes by means of the plastometer with the alternating deformation by pressure and tensile. Nevertheless, the subsequent studying the mechanical properties of the specimens, gained in such a way, is burdened with scatter of data due to very small dimensions of the test pieces.

ACKNOWLEDGEMENT

The research was realized within the project MSM6198910015, supported by the Ministry of Education, Youth and Sports of the Czech Republic.

REFERENCES