MODELLING STRUCTURE DEVELOPMENT WITH HIGH GRADIENT OF THE CHANGES IN PHYSICAL PARAMETERS

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ABSTRACT

The contemporary development of technological processes for the production of modern multiphase materials can be characterized by the need for precise control of their technological parameters. The design of modern technological processes which allow sophisticated structures to be obtained cannot be carried out on real production equipment for technical as well as economical reasons. Therefore, new processes and test devices are continuously being developed to make it possible to simulate and model material treatment on small specimens with precise control and monitoring of process parameters. A simulator for modelling thermomechanical processes has been developed at the University of West Bohemia.

Key Words: physical modelling, multiphase steels, thermomechanical simulator,

INTRODUCTION

Rising prices of raw materials and energy combined with the high workload of production devices make it generally impossible to test or optimize new manufacturing processes and material treatments directly under production conditions. Physical-material modelling of structural evolution is a very efficient way of developing and optimizing new procedures. Physical-material modelling represents the establishment of such an environment that resembles the real time conditions for material processing as closely as possible. The process conditions in forming technologies, thermomechanical treatment and potentially in heat treatment can be characterized by a series of selected parameters. In physical-material modelling it is necessary to know the effects of these parameters and to adjust the model parameters accordingly. With correctly selected parameters a good agreement between the modelled and the real process can be expected.

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THERMOMECHANICAL SIMULATOR

At present a new thermomechanical simulator is available in the FORTECH Research Centre at the University of West Bohemia in Pilsen. This simulator allows the exact temperature behaviour and some selected deformation parameters to be set so that they correspond to those of a real process or those that can be expected in a real process in the case of development of new technologies, materials or structures. This device allows sudden changes of both the temperature and the deformation parameters.

Thus the conditions of technological processes can be simulated exactly. The simulation of the deformation component can reach a speed of 3 ms\(^{-1}\) with the possibility of repeating several arbitrary, precisely driven deformation steps within a few seconds depending on the deformation regime. Concerning temperature behaviour, controlled changes of over 100\(^\circ\)C and 250\(^\circ\)C per second can be obtained during steel heating and cooling respectively. The self-evident is exact process monitoring guaranteed by the simulator’s built-in high precision sensors and can further be extended by attaching external monitoring devices to the control system. These include for instance an optical pyrometer with automatic emissivity correction or a high speed camera capable of capturing fast deformation processes in detail, which may help to analyze crack formation etc.

PHYSICAL-MATERIAL MODELLING

Physical-material modelling can be used not only for the development of new technologies but also for testing new materials such as low alloyed CMnSiNb TRIP steel (Table 1). TRIP steels are multiphase steels, which have so far been used mainly in the automotive industry. Their advantages are a good combination of strength and ductility. This material was treated using a regime which simulates normal rolling mill processing, to determine whether or not this innovative and economically beneficial material is suitable for treatment in a specific rolling mill and what material properties can be expected in the final product.

<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>Al</th>
<th>Nb</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.21</td>
<td>1.45</td>
<td>1.80</td>
<td>0.008</td>
<td>0.005</td>
<td>0.008</td>
<td>0.072</td>
<td>0.058</td>
<td>0.006</td>
<td>0.059</td>
<td>0.02</td>
<td>0.005</td>
<td>0.02</td>
</tr>
</tbody>
</table>

For the experiment, a regime was applied which simulated a rolling strategy for a rolling track with heating to 1050\(^\circ\)C and passing through twenty rolling mills in 2.8 s (Diagram 1). The tensile and compression strains represent the individual passes. During the design of this deformation regime time intervals between individual rolling mills were taken into account. The deformation took place during a temperature decrease within an interval from 1050\(^\circ\)C to 830\(^\circ\)C. During this deformation a true strain of 1.66 with various strain rates from 0.3 to 20 s\(^{-1}\) was reached. In the final part of the simulated regime the influence of various cooling
rates and isothermal holding times on the structure development were examined.

In the first simulated regime the deformation was followed by a 622 s slow cooling to room temperature. This slow cooling represents one of the real process alternatives. The final structure consisted of ferrite and bainite with a small amount of pearlite (Fig. 1). Pearlite is undesirable in TRIP structures because it decreases the carbon content in retained austenite thus decreasing its chemical stability. The ferrite volume fraction was 59% and the volume fraction of retained austenite measured via X-ray diffraction analysis reached 15%. The ferritic grain size was determined to be approximately 3.5 µm.

![Diagram 1. Temperature behaviour in regimes simulating the rolling mill process with various cooling strategies](image)

In the next step another strategy was examined, in which the same deformation regime was followed by cooling that was interrupted at 300°C. At this temperature a 600 s holding was carried out. This isothermal holding time is characteristic for TRIP steels and it serves to stabilize the retained austenite. Stabilized austenite

![Fig. 1. Regime with usual behaviour without holding](image)

![Fig. 2. Regime with shorter cooling and holding time at 300°C](image)
contributes to a good combination of strength and ductility in the structure during a following cold deformation. With this TMT strategy a ferrite-bainite structure with 58% of ferrite and 16% of retained austenite was achieved. The grain size remained unchanged. In comparison to the strategy without holding no pearlite was detected in the structure. Further, the time of cooling between the last deformation step and holding at 300°C was shortened to 33 s. This treatment resulted in a ferrite-bainite structure with large bainitic blocks (Fig. 2). Only laths of bainitic ferrite were observed in the structure and no polyhedral ferritic grains were detected. The structure contained 12% of retained austenite. The retained austenite occurred between the laths of bainitic ferrite.

Table 2: Mechanical properties after thermomechanical treatment simulating a rolling mill process

<table>
<thead>
<tr>
<th>Cooling time after deformation</th>
<th>TB [°C]</th>
<th>tB [s]</th>
<th>RA [%]</th>
<th>Rm [MPa]</th>
<th>A5mm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>830-200°C / 440 s without bainitic holding</td>
<td>300</td>
<td>600</td>
<td>15</td>
<td>835</td>
<td>25</td>
</tr>
<tr>
<td>830-300°C / 400 s</td>
<td>300</td>
<td>600</td>
<td>16</td>
<td>835</td>
<td>26</td>
</tr>
<tr>
<td>830-300°C / 33 s</td>
<td>300</td>
<td>600</td>
<td>12</td>
<td>1043</td>
<td>29</td>
</tr>
</tbody>
</table>

Mechanical tests were carried out on all the strategies used (Table 2). Because of the small amount of TMT material a mini-tensile test was used. The best results were achieved for the regime with fast cooling and with holding at 300°C. With this regime the tensile strength was determined to be 1043 MPa and ductility A5mm = 29%. Both strategies with longer cooling times gave rise to worse mechanical properties. The tensile strength was approximately 170 MPa lower with the same ductility.

CONCLUSION

The behaviour of low alloyed CMnSiNb steel under various treatment strategies was tested with the help of physical material modelling on the TMB simulator. The thermomechanical process consisted of thermal and deformation phases. The deformation regime ran at a high strain rate, which corresponds to the real conditions in a rolling mill. The thermal part simulated both the existing real conditions and the newly designed process with a controlled cooling profile. The results proved the high sensitivity of structural development to the changes of simulation parameters. The required structures were achieved through physical-material modelling on real material specimens, which allowed material and mechanical properties to be measured. The verified parameters of the thermomechanical process can be used for accelerated application of the innovative treatment of CMnSiNb steels with a tensile strength of over 1000 MPa and ductility A5mm = 29%.

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