OPTIMIZATION OF CONTINUOUS ANNEALING PROCESSES ON HOT-DIP PROCESS SIMULATOR

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Abstract

In May of 2006, United States Steel Košice (USSK) at its Research and Development Center (USSE) commissioned the latest version of a Hot-Dip Process Simulator (HDPS) of Generation IV produced by Iwatani-Surtec-Rhesca. This unique unit provides a realistic simulation of continuous annealing processes on a laboratory scale. It is the first simulator with enhanced hybrid humidification system, smart drive unit, mass adaptive heater control, controlled cooling and fast cooling capabilities. It also features process gas heating system, dual monitor display function and continuous data backup. It was constructed to support product development and process optimization, as well as to allow better serving customers and enhance USSK research capacities. This paper describes the capability of an HDPS to develop and evaluate product and process improvements, metallurgical properties for new steels and other experiments. The HDPS eliminates costly production trials and provides opportunity to conduct trials on samples and experimental steel. It allows for technical assistance for solving facility-process problems at any continuous annealing line of the USSK. The primary use of the HDPS has been to determine the effects of process variables on the annealing process and on the continuously annealed strips final properties.

Key words: Hot Dip Process Simulator, continuous annealing, simulation, modelling, optimization

1. DESCRIPTION OF HDPS

The U. S. Steel Košice HDPS was designed to meet or exceed the capabilities of any of the U. S. Steel Košice continuous annealing line (CAL) currently in operation. It is capable of producing a steel sample with a thermal history that matches any CAL design. While annealing, all important functions of the production process such as thermal treatment, soaking, cooling can be simulated in a real annealing atmosphere on a laboratory scale with the help of a command based program structure. The consumption of operating materials is extremely small compared with mini or commercial lines. Also, a wide choice of innovative thermal treatments can be performed on the HDPS that cannot be performed on commercial lines.

Figure 1 provides a schematic diagram and picture of the main sections of the simulator. The HDPS is a vertical system that consists of the driving mechanism at the top of the simulator, upper chamber in the middle section and lower chamber at the base. The steel sample is hung on the drive rod through the sample entry/cooling chamber and transferred up and down through the processing sections. Below this chamber is an IR furnace of 54 kW with 9 quartz lamps on each side. They are separated vertically into 3 heating zones that are individually controlled and heat the steel sample through a transparent quartz tube. At the base of the upper chamber is an induction furnace. The upper chamber is separated from the lower chamber by an atmosphere-sealing gate valve which allows an evacuation of the upper chamber at the beginning of each test cycle. The lower chamber consists of a zinc pot that allows zinc coating capability. Currently, the HDPS of USSK does not have the zinc coating.
option, however, the HDPS is designed for its easier future upgrade for this galvanizing capability. Also, inbuilt there is a dual-color pyrometer for a temperature control.

![Fig. 1. Schematic and photograph of HDPS.](image1)

Another functional unit that belongs to the HDPS is a gas mixing cabinet where the process gases, N\(_2\), H\(_2\), CO\(_2\), He, are mixed and then fed into the process chambers. The gas flows/volumes as well as the mixing ratio are set at the PC and made available by Thermo Mass Flow Controllers. If necessary, the gases may be humidified in a heated water bath, so called Hybrid Humidification System, which is placed between the main unit and the gas mixing cabinet. It allows very precise setting and control of process gases dew points as well as fast dew point changes and dew point detection inside the process chamber.

Inbuilt to operations, there is a computer control cabinet and a cooling system. The control system has several functions, such as preparing the simulation by adjusting all necessary parameters, performing the simulation process, monitoring the process, online visualization, displaying and editing the results and archiving files. An easy-to-use editor enables the simulations to be programmed by using short command words.

The total working volume of controlled atmosphere in the simulator is approximately 35 liters. The HDPS monitors many parameters such as the temperatures, gas flows, power settings, positioning sensors, dew points and pressures. The data collection interval of these parameters can be as low as 20 milliseconds. Some of the relevant performance capabilities of the USSK HDPS are in Table 1. Figure 2 is a picture of an HDPS sample.
Table 1. Capabilities of the USSK Research HDPS.

<table>
<thead>
<tr>
<th>Sample size</th>
<th>120 mm x 200 mm, max 130 mm x 220mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge range</td>
<td>0.18 mm - 3.0 mm</td>
</tr>
<tr>
<td>IR furnace</td>
<td>max 1100 °C</td>
</tr>
<tr>
<td>Uniform area</td>
<td>90 x 90 mm</td>
</tr>
<tr>
<td>Heating rate</td>
<td>max 50 °C/s</td>
</tr>
<tr>
<td>Cooling rate</td>
<td>max 200 °C/s</td>
</tr>
<tr>
<td>Dew point control</td>
<td>-60 °C → +50 °C</td>
</tr>
<tr>
<td>Withdraw speed</td>
<td>0,1 – 1300 mm/s</td>
</tr>
<tr>
<td>Acceleration</td>
<td>20 m/s²</td>
</tr>
</tbody>
</table>

2. EXPERIMENTAL PREPARATION

Each experimental project on the HDPS involves certain procedures prior to the final simulation. Typically, extra steel samples are prepared for thermal cycle tuning. It ensures that the thermal profile that is achieved by the steel sample processed on the HDPS matches the temperature targets, heating and cooling rates which were determined by the parameters from the CAL design. This requires calculations based on the commercial line parameters. During the tuning, the three thermocouples are used, Figure 3, in order to precisely measure the temperature in the uniform area and to help balance the three zones of the IR furnace. The tuning also involves managing temperature overshoots and offsets. For this, the optimization cycle is first performed. It is basically the self learning (autotuning) infrared heater control optimization software which allows convenient and accurate heater power adaptation to cope with changing masses and reflectivity of the sample. The result is optimized temperature distribution and excellent temperature gradients with the temperature difference from the target temperature of maximum +/- 7°C. The manual tuning of the process controller can be performed, too, by adjusting the proportional and integral settings within the program. Once the experimental cycles are tuned the final simulation may begin.

Prior to the final simulations, the samples are cleaned with aceton. Following cleaning, either one or three control thermocouples with a thin ceramic sheath are spot welded to the uniform area of the sample. Figure 3 presents the sample prepared for the simulation process. The sample is attached to the drive rod through the entry /cooling chamber which is than
closed and a vacuum is created to 0.14 torr to evacuate air. The chamber is then pressurized with nitrogen and the annealing cycle begins with the intended nitrogen/hydrogen concentrations.

3. EXPERIMENTS AND IMPLEMENTATIONS

3.1. Sheets for galvanizing

During the initial start up of the HDPS, efforts were made to exactly duplicate the thermal profile and mechanical properties of a standard sheets for galvanizing produced at USSK on continuous galvanizing line (CGL). Series of optimization and simulation tests were conducted and showed the mechanical properties only varied by a slight amount which was easily accounted for by inaccurate pyrometrical measurements of annealing temperature on the real line.

Due to start up of the new continuous galvanizing line no. 3 (CGL3) at USSK, the first major experimental project on the HDPS involved development of the thermal cycles for the CGL3. Number of grades at various thicknesses were subject to the study. The processing parameters included variations of different annealing temperatures, heating and cooling rates and their optimization for the real production cycles. Figure 4 presents an example annealing cycle of the sheet for galvanizing of the thickness of 1.0 mm. The line speed of 165 mpm was simulated for maximum annealing temperature of 830°C. Soaking section is followed by the fast cooling section where the cooling rate of 79 °C/s was required. For such a rate the cooling capacity of the inert gas helium has to be utilized. By modelling and consequent tuning and optimization the thermal cycle in the right picture was achieved on the HDPS. It is apparent that the HDPS heating profile is very similar to the required CGL heating profile.

![Fig. 4. Required CGL heating profile (left) compared to the profile achieved by simulation on the HDPS (right) of GI steel at 165 mpm.](image)

3.2. Tin sheets

Continuous annealing process of this product is very fast, using line speed of even 400 mpm, depending on the strip profile and final grade. In order to achieve the highest productivity it is not possible to make big changes in the technological process during the regular production. Therefore, the HDPS was used to simulate real process on the laboratory scale. The grade of 0.19 mm in thickness was processed, see Figure 5. Effect of a low annealing speed of 1 m/s, soaking time longer than 1 minute, annealing temperature above $A_{c1}$ and fast cooling on mechanical properties and recrystallization structure was studied.
Fig. 5. Required CAL heating profile (left) compared to the profile achieved by simulation on the HDPS (right) of tin steel at 360 m/min.

3.3. Electrical Steel

The continuous annealing process of this product is specific by using two atmospheres during the process, wet and dry atmosphere. Also, thermal treatment of some grades requires annealing temperatures as high as 1100 °C. Figure 6 shows an example heat treatment of this product where annealing temperature of 1060°C, line speed of 50 mpm and the dew points of +30 and -40°C were simulated. It was observed, when simulating on the HDPS, that the change of dew points from +30 down to -40°C can be performed in 25 seconds. This technical work was performed in order to support the development work of the new grade of electrical steels.

Fig. 6. Required CAL heating profile (left) with the dew points compared to the profile achieved by simulation on the HDPS (right) of DN steel at 50 mpm.
4. CONCLUSIONS

The HDPS provides the capability to improve and further develop product and process know-how, metallurgical properties for new steels, as well as provide technical assistance. With the HDPS, USSK Research has expanded its research capabilities for processing steel, from casting steel to annealing it on a small scale. The HDPS proves itself to be a very useful laboratory tool which significantly eliminates costly production trials and allows for experiments that cannot be performed on production units. Being able to simulate and optimize process with regard to the final properties of the product as well as production costs is a big advantage in today's industry.