Optimized Heating Process with Uniform Coating

Optimizing the Ruukki Metals color coating process increases product throughput and help achieve higher and uniform quality.

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When coating rolled metal with paint, it's important that the coating be applied such that it's not discolored or damaged through; for example, overheating or even boiling, which can cause pitting. The process must also result in an end product with good weather resistance and a long service life. Another goal is to eliminate waste and increase process throughput and production rate. With these aspects in mind, I recently created a model in COMSOL Multiphysics to assist in the optimal running of the heating/paint-drying oven for surface-coated roofing, façade, and panel materials.

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Rautaruukki Oyj supplies metal-based components and systems to the construction and mechanical engineering industries. It has operations in approximately 30 countries, and annual sales in 2011 were almost 3 billion Euros. At one of the divisions, Ruukki Metals Oy in Hämeenlinna, we manufacture weather-resistant steel raw material for roofing and other building parts as well as for the domestic appliance industry. Other Ruukki Metals products include wear-resistant steels for applications such as excavator buckets, cutting edges for earthmoving machines, wearing parts for mining machines, concrete mixers and wood-processing machines. In addition, our high-strength steels are used in various vehicles, transportation equipment, tipper bodies, lifting equipment booms and containers.

Coating Roofing Sheet Metal

One application for our products is the manufacture of sheet metal for roofing, and here building contractors and owners are particularly concerned about having the proper color (shade, gloss, reproducibility) as well as a long-lasting product. Our color-coating process for roofing sheet metal takes place on a system that is equipped with two ovens with several oven zones (Figure 1). Currently, steel sheets move through this at a rate of 45 to 90 meters/minute. The metal strip entering the process already has a coating of a zinc alloy on top of which the paint is applied.

The settings for the oven — temperature at various stages and the speed of the material through the oven — vary considerably depending on the base material, its composition and thickness, and the paint (Figure 2). We had been searching for a tool to help us quickly determine and enter the proper settings. Earlier, I created a theoretical model based on a differential equation to calculate the thermal curves during the drying process. However, it could not properly estimate internal heat transfer, and only through separate calculations could I estimate the time it takes to achieve a steady temperature difference in the oven.

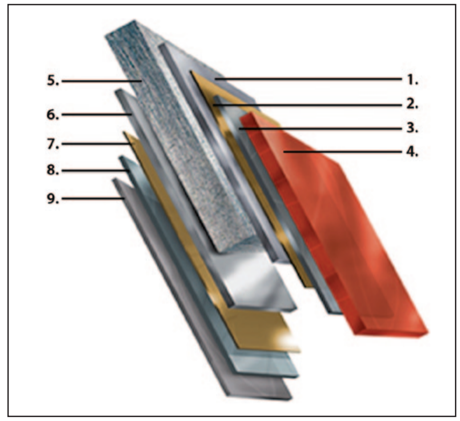

Figure 2: The layers in a typical roofing sheet: 1. Zinc layer 2. Passivation layer 3. Primer 4. Coating 5. Steel sheet 6. Zinc layer 7. Passivation layer 8. Primer 9. Protective paint coat.

I first used COMSOL Multiphysics to determine the heat conductivity of the paint during the drying process in a 3D model. I then used it to model the whole oven drying process. From a geometry standpoint it's a simple model, but even so, the physics in the multiple layers we are investigating can become quite complex because we are modeling heat transfer, a liquid-to-vapor phase change (moisture being driven out) and a liquid-to-solid phase change (paint pigments turning to a solid, and this without any change in color or other properties). To find the process settings, the model calculates the heat distribution on both sides of the zinc-coated steel as a function of time; we want to know the temperature distribution of the metal strip that is coated with several

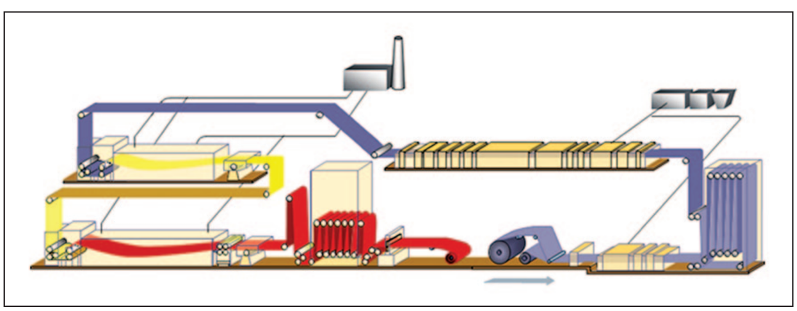

Figure 1: Outline depiction of the color coating process. The coating is applied where the strip is a yellow color, while the oven zones are where the strip is a red color.

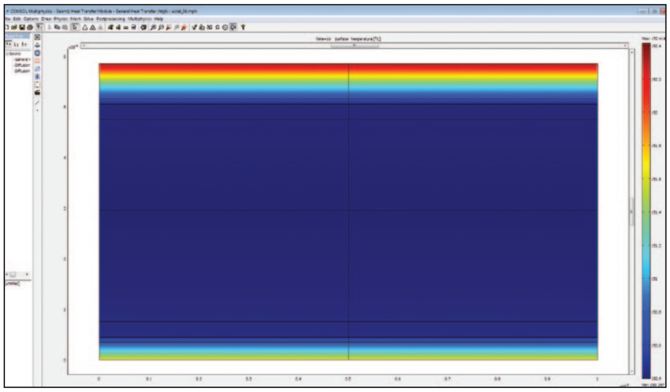

Figure 3: Temperature profile over the thickness of the material after 10 s of drying.

“We are now investigating the possibility to automate the process and integrate it directly with the process machinery, without the need for an operator to enter them manually.”

layers of paint (Figure 3). With the model, we are also trying to discover why some coatings are sensitive to boiling, yellowing and other defects. In addition, we can identify and confirm new critical parameters in the stoving process.

Making Life Easy for Operators

When the coating process is running, operators must change these settings for each new material or coating, which happens frequently. Changing the dimensions and other material properties such as density, solvent properties and diffusivity parameters of the paint can be time-consuming and prone to error, where at least 43 input values must be included. We need these settings for the COMSOL model and use MATLAB to create a user interface for the COMSOL simulation (Figure 4).

The operators can use entry boxes and pull-down menus in the user interface to describe the type of materials, their thicknesses and other inputs specified in the production planning. The application then searches a centralized database that contains the properties of these materials and then inserts them in the model. After the model runs, it displays the results in a form that shows the operators exactly which parameters must be changed and by what values.

With the model, it is possible to determine critical parameters in the stoving process such as the maximum possible heating rate, Biot number (which compares heat conduction inside a body to heat convection away from its surface) and the maximum temperature differential between the strip and the steel. We can estimate the performance of systems with varying layer thicknesses, specific heat, heat conductivity, density and solvent parameters. Analyses make it possible to fine-tune oven setups and provide feedback to paint manufacturers, which sometimes have to modify the properties of their paint.

With the model, I can calculate the temperature distribution (from the top to the bottom) of the coated material in 0.1- to 0.2-second intervals. It can also determine the temperature distribution of any layer, even those with thicknesses of just several micrometers. In addition, it’s possible to test new coatings in the model and compare results to previous coatings to determine if it is possible to run the process without any defects.

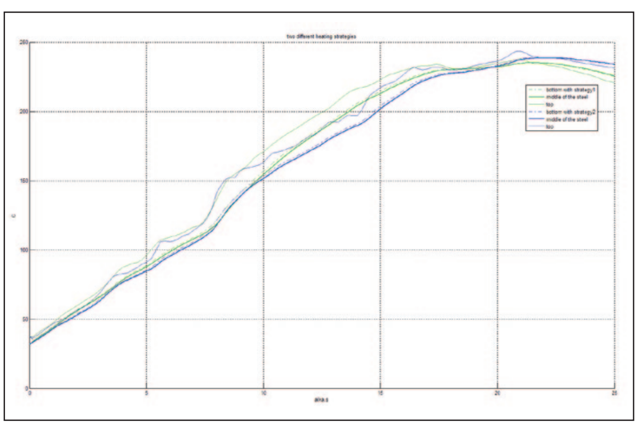

Figure 4: Temperature (in °C) in the middle (thick lines), top (thin lines) and bottom (dashed lines) surfaces of the material over time (in seconds) as calculated using COMSOL Multiphysics. The green lines were calculated using normal process inputs, while the blue lines were calculated using adjusted inputs.

Uniformly High Quality

From an operating standpoint, we also get a number of benefits. We run the machines in multiple shifts, and different operators have their own preferences of how to best run the machines. As a result, there was an interest in achieving a higher degree of product uniformity and assuring the same high quality over each shift. With this software, all the operators use the same optimized set of parameters for each grade, which leads to repeatability and high quality. Further, it takes less time to change the process for a new grade, so more product can be produced. There are also energy savings because we optimize use of the power-hungry ovens.

The optimization of the process can be taken yet a step further. We are now investigating the possibility to automate the process and integrate it directly with the process machinery, without the need for an operator to enter them manually. ■

About the Author

Mika Judin has been employed with Rautaruukki Oyj since 1999, and his primary task is to tune existing mathematical models and create new ones for a variety of lines including cold rolling mills, tempering mills and galvanizing lines. He has a degree from the University of Oulu’s Department of Process Engineering and also a MSc in Chemical Engineering.