OPTIMIZED INDUCTION HEATING TECHNIQUES IMPROVE MANUFACTURING PROCESSES

Tata Steel is using multiphysics simulation to explore methods for optimizing induction heating during the manufacturing of steel wire.

BY ALEXANDRA FOLEY

In the steel industry, induction heating is quickly becoming a widely used technique for manufacturing a variety of metal products including blooms, billets, slabs, and many types of cables, wires, and ropes. This process offers faster and more precise heating control, uses less energy, and is more environmentally friendly than many other heating methods. Additionally, there is a decreased labor cost, the equipment is easy to maintain, and it offers better quality assurance and reliability.

However, predicting the electromagnetic, thermal, and metallurgic phenomena that come into play during the heating process is challenging. Using multiphysics simulation software, Tata Steel, one of the top ten steel companies worldwide, is exploring ways to optimize induction heating techniques in order to improve the quality of the final product, as well as to increase the energy efficiency and cost effectiveness of their production processes.

SIMULATING INDUCTION HEATING OF WIRES

At Tata Steel, Research and Design Engineer Ishant Jain is using COMSOL Multiphysics® to simulate the induction heating of Tata's high carbon wire rods, strands, and ropes. "Numerical simulations of temperature distribution are highly beneficial for designing induction heating systems," describes Jain. "Choosing the correct shape and distribution of the heating coil and adjusting the electric current can greatly affect the quality of the manufactured product, and simulation can help to optimize this process to achieve the highest-quality results."

Jain developed a model of Tata's furnace system for producing structural rope, a wire that consists of six carbon wires helically spun around a steel core (see Figure 1). These ropes are manufactured from individual wires, which are made by drawing the end of a rolled rod through a tapered hole.

"In order to stabilize deformation and elongation while the wires are

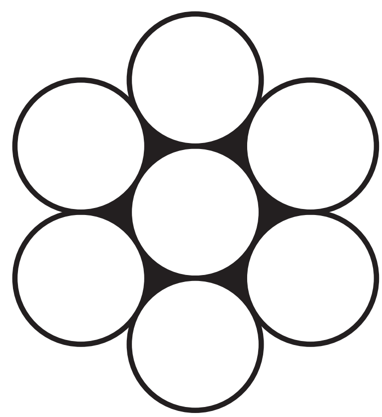

FIGURE 1. Wire strand (rope).

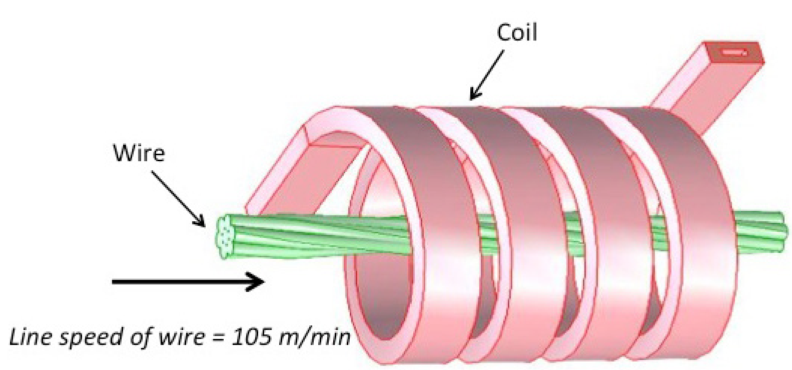

FIGURE 2. Geometry used for the simulation of the induction heating of structural rope in a heating furnace (geometry created in the COMSOL® software). The coil has a rectangular cross section and a water jacket for cooling.

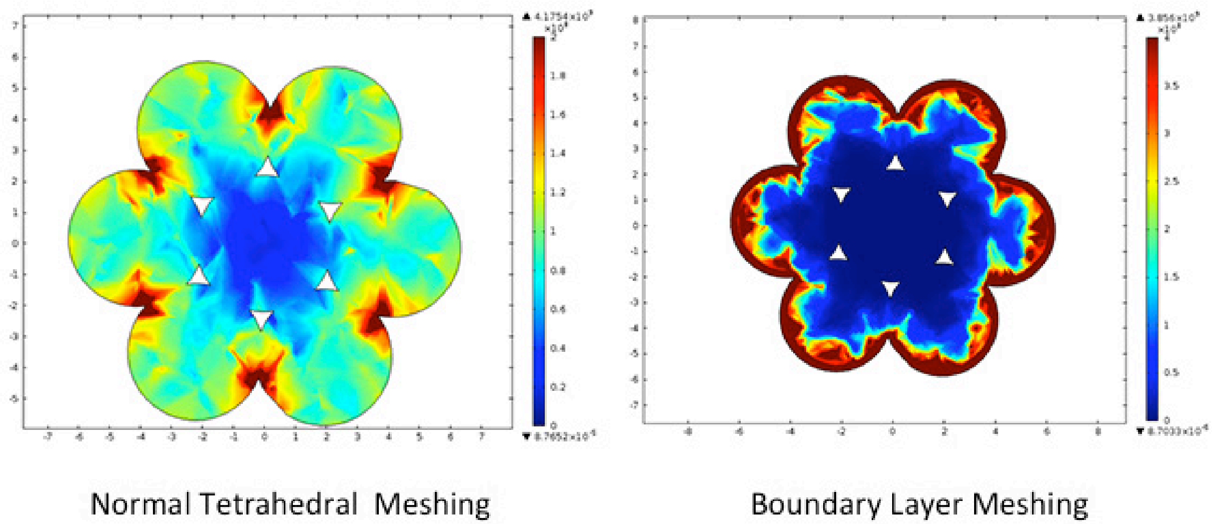

FIGURE 3. Simulation results show the current density norm distribution (skin effect) captured by a tetrahedral (left) and boundary layer mesh (right).

in use, ropes and strands are typically pre-loaded to about 55 percent of their breaking strength to increase the ultimate tensile strength (UTS) of the wire," says Jain. "After pre-loading is complete, deformation becomes linear and predictable, allowing the wires to be used for construction purposes."

This is achieved by stretching and heating the wire while passing it through a coil carrying alternating current (see Figure 2). The magnitude of the alternating current and the distribution of the induced magnetic field inside the wire can be used to precisely and accurately control the temperature of the wire as it passes through the furnace.

One of the aspects that make modeling this process so challenging is the extreme changes that occur in the temperature of the heated material. "The temperature changes within the wire are so drastic that we had to implement nonlinear temperature-dependent material properties in order to accurately model the system," says Jain. "By developing this model, we want to verify that under the current operating conditions, we are heating the wire correctly in order to achieve the desired mechanical properties. Additionally, we are looking to optimize the operating parameters of the furnace for the production of different types of wires so that the desired mechanical properties for a particular application can be achieved."

SKIN EFFECT AND FURNACE DESIGN

In order to ensure that the correct heating is achieved within the wire, only a small temperature gradient between the surface of the wire and the wire's center is permitted. However, this is complicated by a phenomenon known as the skin effect. Alternating currents tend to be unequally distributed within a conductor so that the current density is highest near the surface of the conductor, and decreases closer to the center. "Understanding how the skin effect influences heating within the wire was one of our key areas of study," says Jain.

In the manufacturing of the structural rope with a radius of 6 mm, the skin depth is predicted to be about 0.03 mm. "We wanted to implement a computationally efficient simulation that would allow us to visualize the induced current profile over the surface of the wire while also letting us quickly obtain answers and easily revisit and modify our design," describes Jain. "A typical tetrahedral mesh wouldn't have allowed us to investigate what happens at skin depth without increasing the mesh density significantly. Instead, we implemented boundary layer meshing, which helped us to refine the calculation while keeping the model at a reasonable size." The results for both the tetrahedral meshing and boundary layer meshing are shown in Figure 3.

Once the mesh was refined, the furnace could then be modeled in full. "We modeled the complete furnace

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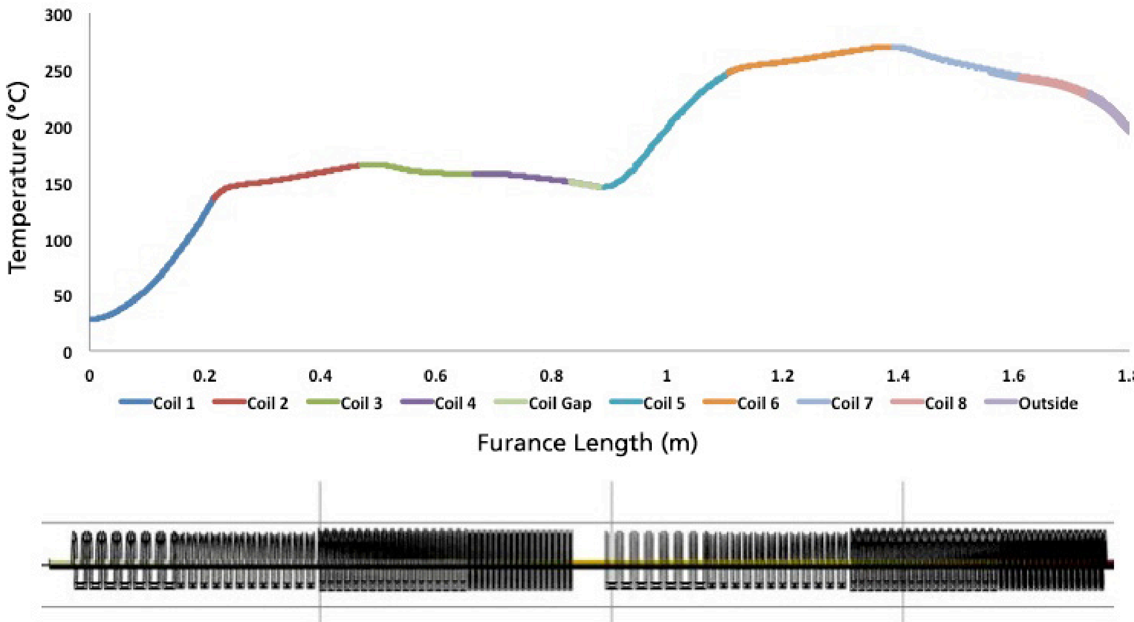

FIGURE 4. Surface temperature variation within the furnace for a 12 mm diameter wire. The line speed is 105 m/min. Along coils 1 and 5, a sudden rise in temperature can be seen due to the increased cross-sectional area of the individual coil. A small drop in temperature can be seen around .8 m, when there is a gap of 15 mm between the two furnaces, and around 1.4 m, where there is a decrease in the cross-sectional area of the coil and the wire approaches the end of the furnace.

as a 2D axisymmetric model, with the helical structural rope represented as a cylinder having the same power consumption per unit volume," describes Jain. "This approach reduced the complexity of the simulation and allowed us to model the variation in the wire's surface temperature along the entire length of the furnace (see Figure 4)." The model was validated against experimental results from an in-house developed pilot line furnace, and showed good agreement.

Currently, the induction heating furnace at Tata Steel contains 104 coils, with areas of tighter and looser coil density, as shown in Figure 4. Jain's current work is to understand how the different coil winding densities or cross-sectional areas can affect the heating of the wire. "The furnace is divided into areas where the coils windings are dense and areas where the coil windings are spread apart in order to ensure that the temperature in the center of the coil increases along with the surface temperature," explains Jain. "Using our model, we can determine if the furnace is designed according to a coil configuration specifically optimized for constructing structural rope, and eventually optimize the furnace parameters for the production of all different types of products."

THE FUTURE OF INDUCTION HEATING TECHNIQUES

Tata Steel is constantly improving their range of products in order to meet industry demands such as lighter, stronger components for the automobile industry, and wire ropes for the oil and gas industry that can withstand harsher environments. "Simulation allows us to stay on top of market demands and ensures that we are continuously delivering high-performance products to our customers," says Jain. Using the model produced in this study, Tata Steel will continue to deliver on this mission by manufacturing higher quality products at lower costs and with improved energy efficiency. "In the past, simulation was a sort of black box that we couldn't adapt to our design needs," describes Jain. "One of the unique features of COMSOL is that we can implement boundary conditions, material properties, and study parameters based on our requirements. Using the results obtained in this preliminary study will help us to further improve the products that we deliver to our customers." ■

Ishant Jain presenting his work at the COMSOL Conference 2013 held in Bangalore, India.