Use of COMSOL® AC/DC Module to Model a EM Sensor Deployed to Monitor Steel Transformation

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Abstract

Real-time microstructure monitoring is important during the cooling process for hot-rolled strip steel production, as the microstructure formed determines the mechanical properties required by customers. The materials magnetic and electric properties, relative permeability and resistivity respectively, are related to the steel microstructure and hence changes in these can be used to characterise the phase transformation during steel strip cooling. Electromagnetic (EM) sensors have been extensively used to characterise steel at room temperature and different approaches have been used to quantify the relationship between EM sensor signal and microstructure, including empirical and FE modelling approaches. A new EM sensor system, using EMspecTM technology, has been developed that can monitor microstructure at elevated temperatures (below the Curie temperature of approx. 760°C) in the production environment taking advantage of the system being non-contact, inexpensive, having a fast response and being unaffected by water and the surrounding high temperature environment. To fully exploit this system there is a need to able to quantitatively relate the signal to the microstructure taking into account the high temperature characteristics of the material and industrial sensor design, which has not been previously reported.

In this paper, a 3D FE model for the commercial electromagnetic sensor system using EMspecTM technology, has been developed using the AC/DC module in COMSOL Multiphysics®. The physics of magnetic fields was used in the model and the multi-turn coil feature was assigned to the exciting and sensing coils. In addition coil geometry analysis and frequency domain (375-48000 Hz) were assigned to the study. The steel sample geometry was layered by using swept and boundary layers in the mesh process, which was found to be required to allow the skin depth to be solved when considering the high permeability and high resistivity of the steel, for example in the elevated temperature scenarios. Experimental measurements using the commercial sensor and steel samples during cooling were carried out to validate the modelling approach, with excellent agreement being obtained for the sensor signal at different frequencies. An auxiliary sweep was also used in the study to help model convergence at low frequency. The output from the model of a plot of temperature-permeability/resistivity-sensor signal can now be used to obtained permeability at any (known) temperature (and hence resistivity) from the sensor signal, which can then be used to determine the microstructure (phase fraction), mimicking the real-time monitoring of phase transformation of steel products. The challenges overcome were in the validation of the room temperature sensor model taking

into account the sensor design and in-built signal processing and then specifically in the model configuration and optimisation to correctly represent high permeability/resistivity samples considering a range of operating frequencies, which required use of the COMSOL Multiphysics® software features of AC/DC module, boundary layer mesh, parametric and auxiliary sweep in study.