Strip Temperature in a metal coating line annealing furnace

New Zealand Steel

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New Zealand Steel (NZS) use a unique process to convert New Zealand iron-sand into steel sheet products at its Glenbrook mill near Auckland. Traditional galvanised steel (Galvsteel$^{\mathrm{TM}}$) and the new product Zincalume $^{\Lambda}$ are produced in arange of dimensions, grades and coating weights.

The steel strip is annealed prior to being coated, by heating to a predetermined temperature for a definite time. Annealing produces desirable changes in the crystalline structure of the steel, allowing NZS to tailor its strength and ductility. Strips of steel sheet are passed through a 150m long, 4.6 MW electric radiant furnace at speeds of up to 130 metres per minute in order to achieve the strip temperatures required for annealing, and subsequent coating. The temperature along the furnace is controlled by varying the power supplied to the heating elements and by use of cooling tubes. The cooling tubes are located in the last half of the furnace and consist of steel tubes through which ambient air is pumped. It is important that steel exit the furnace with the correct temperature for the coating that is applied at the exit point

The line speed through the furnace is reduced for strips of large thickness and width in order to achieve the required temperatures. At the beginning of the annealing-coating line there is an automatic welding process which welds the beginning of a new coil of steel sheet to the end of its predecessor, allowing the line to run continuously.

In each of the twenty zones of the furnace, there are thermocouples in steel tubes, which are used to measure furnace temperature. The thermocouple temperatures are compared with desired temperature set-points, and the heating elements are controlled accordingly. Steel strip temperature is also measured, using non-contact pyrometers at three positions in the furnace.

If there is no variation in strip dimensions and annealing settings then the line is able to run in a steady state, with the furnace temperatures remaining steady at the desired thermocouple settings. NZS have already developed a mathematical model of furnace and strip temperatures for this steady state operation. Challenges occur when there is variation in strip dimensions or annealing settings because the furnace-strip system has a large amount of thermal inertia. Consequently the line is in a transient state for up to 50% of its operation, with varying effects on quality control of the product.

Two improvements are planned for the line in the very near future; a 3 MW induction heater and a gas jet cooler. The induction heater is capable of heating the strip rapidly. The steel strip will pass directly from the induction heater into the radiant furnace. The extra heating power should allow the system to achieve greater line speeds for strips of large thickness and width. Further, with its more rapid response, the induction heater has the potential to reduce the time spent in transient modes of operation. In the gas jet cooler, which will replace part of the existing cooling zone, cooled furnace gas is blown directly onto the steel strip. The new cooler section is expected to respond more rapidly than the existing cooling tubes, giving more precise control of dipping temperatures.

NZS set the following tasks for the Study Group:

- Develop a mathematical model for transient furnace conditions.
- Investigate the accuracy of the existing steady state model.
- Predict transient strip temperatures for actual production schedules with changes in product dimension, steel grade and furnace temperature settings.
- Couple the temperature model to a metallurgical model.

The Group focussed first on modelling the temperature of the steel strip, and soon discovered that this can be accurately modelled as a function of time and just one spatial coordinate, the distance from the entry point of the furnace. Temperatures rapidly equilibrate across the thickness of the steel. Thermal diffusion along the strip was found to be negligible for the length of time that any part of the strip was in the furnace.

This strip model led to a steady state model for the furnace–strip system which took into account the power supplied by heating elements. The Group then compared this to NZS's steady state model. The models differ in that MISG's model allows for continuous changes in temperature along the length of the furnace while NZS's model is discrete, involving one value of strip temperature and one value of the furnace (wall) temperature for each of the furnace's twenty zones. Calculations indicated that the models were in good agreement, confirming the accuracy of the NZS steady-state model.

Next the Group studied the heating of the furnace walls and calculated that while it would take hundreds of hours for bulk changes to wall temperatures, the inner surfaces of the walls heat up rather quickly. They respond to radiation changes on a time scale of about one minute, and to a depth of only a few millimetres. This is too rapid to account for the observation that the furnace typically takes five minutes to equilibrate, so attention was then shifted to the steel hearth rolls (the rollers which carry the strip along the furnace), to see if they could be the main source of thermal inertia within the furnace. Preliminary calculations indicated that the hearth rolls do indeed respond to temperature changes on the correct time scale. A transient model for steel strip temperature was developed that included the hearth rolls.

During the meeting the Group realised the importance of view factors. These factors need to be calculated to accurately model the radiation exchange between the steel strip, heating elements, furnace walls, cooling tubes, hearth rolls and thermocouple tubes. This will improve the accuracy of the transient model for the temperature of the steel strip, by giving a more accurate understanding of the radiation environment that the steel strip is experiencing from moment to moment.

The thermocouple tubes house the thermocouples which are used to estimate the furnace temperature in each zone of the furnace. They play a vital role, as they are used to control the power fed to the heating elements. The temperature measured by the thermocouples is not the true furnace temperature, which is needed for accurate calculation of steel strip temperature, in both the transient and the steady-state models. A calculation of view factors for these tubes will give much better information on the true furnace temperature than is presently available.