Mathematical Modelling of an Annealing Furnace

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Abstract

The metal coating line at New Zealand Steel relies on a large electric radiant furnace to heat steel strip before hot-dip galvanising in a continuous process. The temperature evolution of the strip inside the furnace is vital in ensuring the specified mechanical properties are achieved for a range of steel products. Ductile products require high temperatures sufficient to cause recrystallisation of the steel microstructure, while stronger products must be heated without causing recrystallisation. Strip dimensions and desired properties are changed often and irregularly during operation, and these changes and associated furnace control actions cause changes in furnace and strip temperatures and rate of heat transfer over several different time scales.

Accurate control of temperature is difficult because temperature measurement devices are strongly affected by reflected radiation in the furnace cavity. The furnace is often operating during transient temperature conditions, as control actions take effect very slowly compared to the the rate of change of operational targets. Understanding of the transient behaviour of this system of interrelated, nonlinear variables can be improved using modelling to calculate furnace and strip temperatures as a result of control actions in real time, which cannot otherwise be measured or predicted.

It is shown that a three-dimensional model is capable of accurately calculating furnace temperatures changing over both time and location, requiring minimal simplification of the physical system, but is computationally expensive. Radiative heat exchange in the furnace cavity causes significantly increased temperature along the edges of the steel strip, which can cause reject product due to localised softening. It was found that furnace thermocouples are strongly affected by reflected radiation, so that furnace wall temperatures be may significantly hotter than measured.

A simplified, coupled temperature-metallurgical model was shown to accurately calculate both furnace and strip temperatures and metallurgical changes, while the 3D model provides understanding of effects not explicitly modelled in the simplified model. The simplified model is used for optimisation of furnace operational parameters, to improve plant throughput and energy efficiency while maintaining desired metallurgical properties, which is demonstrated by application to common products at NZ Steel.

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List of Abbreviations

GJC	Gas Jet Cooler
HR	Hot rolled (steel)
L1	‘Land 1’ Pyrometer (Furnace Zone 13)
MCL	Metal Coating Line
MISG	Mathematics in Industry Study Group
NZS	New Zealand Steel
PID	Proportional Integral Derivative (Control)
RX	Recrystallisation (of Steel Microstructure)
UTS	Upper Tensile Strength (MPa)
UYS	Upper Yield Strength (MPa)
WR	Warm rolled (steel)

Model Designations

F3DC	Full 3D Comsol
RDHT	Reduced Dimensionality Heat Transfer
RDHT-CM	RDHT - Coupled Metallurgical