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Process-structure-microstructure relationship in hot strip rolling of steels using statistical data mining

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Abstract

Mathematical models have been widely used for prediction of microstructure and mechanical properties in hot rolling of strip. To accurately predict these characteristics, it is necessary to create models that can replicate thermomechanical state of material and its evolution during processing. This paper presents development of a hybrid model that uses mills setting and real time plant data such as chemical composition; forces and temperatures; and integrates them with empirical relationships of material evolution to predict quality attributes. This information is combined with non-linear statistical data mining models to create on-line tool that predicts properties of individual coil. Case study from Steel Plant is presented that illustrates implementation, calibration and validation of this model across different materials grades.

Keywords: Hot rolling; Strips; Material evolution; Statistical data mining; Microstructure

1. Introduction

Manufacturing processes like hot rolling of coils represent a complex engineered system as they involve a series of steps through different machines which the material has to undergo before it is converted into a final product. For example, in hot rolling of steel, steel is melted with different alloying elements like Si, V, Cr, Mo etc. and

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poured into a continuous caster which has different strands and is formed into a slab. This slab then goes through a series of roughing passes, intermediate passes and finishing passes through a hot rolling mill.

Accurate prediction of dimensions and material properties in the hot rolled steel product requires modeling of the mechanical behavior of the material during rolling, microstructural evolution in the roll bite and in the inter stand region, and phase transformation during controlled cooling after rolling.

With significant progress been made in recent years in modeling of microstructural evolution, mathematical models are gaining acceptance as powerful tools for conducting off-line analysis of metal flow and metallurgical changes during rolling. For example, Shivpuri et al. (1997, 1999) developed an integrated framework for hot rolling of bars (ROLPAS) which can predict the microstructural evolution during the rolling and also the profile of the bar being rolled. Similarly, AIST (Integ) developed model for prediction of microstructure and mechanical properties during the rolling of sheets. These models are off-line, computationally very expensive, need to be tuned for different mill and are deterministic in nature.

Recently, hybrid models that combine the usefulness of both the statistical and FEM models are being tried in the prediction of properties of hot rolling (Kusiak, 2002; Hodgson, 1992; Yoshie, 1992). Notable among these is the model by Danieli Automation called DANIELI – CQE (Mukhopadhyay, 2010) that is an online model for prediction of UTS, YS and elongation.

The aim of this research is to come up with a model that not only takes the metal flow, temperature distribution, microstructural evolution etc. into account, but also the actual variation in the hot rolling mill. Such a model should be able to calculate the properties of the rolled coils in real time and be able to tune itself as the rolling process continues. This paper presents the development of such a hybrid model (MICROL) that uses the real time plant data such as chemical composition; forces and temperatures from HSM; reduction schedule etc; and integrates them with the empirical relationships to predict the quality attributes as well as microstructural features.

Nomenclature

h_2	exit thickness at a given pass
h_1	entry thickness of the strip
R	roll radius
N	roll peripheral speed, rpm
Q	activation energy for plastic deformation determined by experiments for different materials
R	universal gas constant, 8.314 J/mole/K
T	temperature in K
C, α, n	Material constants
K	curve fit constant
v	strip speed
T_1, T_2	strip surface temperature between the cooling
a, b	exponent of strip speed and thickness
c, d	exponent of surface temperature and flow rate.
t	reheat time (s),
D^m	Grain size at time t
D_0	Initial Grain size.

2. Background

The hybrid mode MICROL described in this study was developed for a steel plant. This is a 2000 mm (78.74") wide continuous mill. It has three 100 ton/hr continuous pusher type reheat furnaces, five 4-high roughing stands, seven 4-high finishing stands and three pneumatic coilers. The roughing mill has one vertical stand for slab control and sizing, one 2-high stand and four 4-high universal stands with edgers and roller tables with hydraulically operated side guards. The finishing mill has seven stands in tandem with hydraulic automatic gauge control in the last 4 stands.