Thermal Analysis of Lubricating Film Formation in Inlet Zone in Cold Rolling of Metallic Strips

by

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Submitted

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Certificate

This is to certify that the thesis titled "**Thermal Analysis of Lubricating Film Formation in Inlet Zone in Cold Rolling of Metallic Strips**" being submitted by **Mr. Prahlad Singh** (2004AMZ8001) to the **Indian Institute of Technology Delhi**, New Delhi, India, for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him under our guidance and fulfilled the requirements for the submission of this thesis. As per our awareness the results contained in this thesis have not been submitted in part or in full to any other university or institute for award of any degree or diploma.

We also certify that Mr. Prahlad Singh has pursued the prescribed course of research at Indian Institute of Technology Delhi as a part time student.

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Abstract

In cold rolling process, the energy for the deformation of the strip is transmitted by the rolls through the interfacial friction force. The presence of an effective lubricant film thickness between contact surfaces in the cold strip rolling operation increases the forming limit, reduces the roll wear, and improves the surface quality of the products. Existence of too thick lubricating film produces matt surface due to insufficient constraint by the rolls, while too thin lubricating film might allow direct metal-to-metal contact leading to rapid roll wear, strip surface scoring and other defects. Therefore, a better understanding of the lubrication mechanism in terms of operating parameters for maintaining an optimum lubricating film thickness at the strip-roll interface can promote efficient production with better surface quality of the strips. Formations of hydrodynamic lubricating film at the rolls-strip interfaces mainly take place in the inlet zone, while the work zone governs the friction force and pressure engendered in effecting the deformation. One of the mechanisms still to be simulated relatively in depth in the lubrication of cold strip rolling is the starvation where the amount of available lubricant happens to be insufficient to completely fill the inlet zone. Starvation generally occurs due to excessive roll speed and high lubricant's viscosity, or due to the limited supply of lubricant. Under starved conditions, the minimum film thickness goes down much below than the one exists with the fully flooded condition. It is worth mentioning here that design methodologies for the lubricated strip-roll interfaces developed over the years are primarily under the assumption of fully flooded conditions. Even the advance design procedures of the lubricated interface in cold strip rolling are mainly based on isothermal hydrodynamic lubrication models which do not incorporate the role of viscous shear heating in the lubricant. Hence, it is vital task to study the performance characteristics (mainly minimum film thickness) of the lubricated inlet

zone of roll-strip interface by incorporating the combined effects of starvation and viscous shear heating of the lubricant considering smooth and rough contacts. An effort has been done in this thesis to address the above concerns.

The primary objective of this thesis is to do thermohydrodynamic lubrication analysis of fully flooded and starved smooth and rough inlet zones in cold rolling process for the development of empirical relations for predictions of isothermal and thermal minimum film thickness and maximum film temperature rise. However, the limited objective of the thesis is to correlate the results obtained by applying minimum film thickness relations (developed based on the lubricating oil) with the minimum film thickness results achieved by the prior researchers using emulsions. Numerical studies have been done for the fully flooded and starved thermohydrodynamic lubrication (THL) of inlet zones of rolls-strip interfaces operating at range of material parameter (G = 5 to 11), reduction ratio (R_D= 0.05 to 0.15), slip (S goes up to 0.20), starvation distance ($|X_{starved}|$=1.25 to 10), surface roughness (σ = 0.75 to 2.2.5 μm), and thermal loading parameter (Q= 3 to 340). In order to have reasonable accuracy in numerical results with less computational cost, the Lobatto quadrature technique as developed by Elrod and Brewe [75] has been used for mathematical modeling and evaluation of interface performance parameters for smooth interface. However, thermal model proposed by Chang and Farnum [77] has been employed for rough lubricated interface. Results computed based on the proposed models are validated against the experimental and theoretical results available in the open literature. Significant reductions in minimum film thickness and maximum film temperature are obtained with respect to fully flooded conditions in presence of starvation. Based on the results embodied in this thesis, empirical relations have been developed for the prediction of dimensionless isothermal and thermal minimum film thickness and dimensionless maximum film temperature rise for fully flooded as well as for the starved conditions. It is believed that empirical relations proposed in this thesis may be of worth to design and maintenance engineers of cold rolling industries.

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