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Hongchun Li
University of Wollongong

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A Study on Wear and Surface Roughness of Work Roll in Cold Rolling

A thesis submitted to fulfill the requirements
for the award of the degree

Doctor of Philosophy

from

University of Wollongong

by

Hongchun Li

BEng

School of Mechanical, Materials and Mechatronic Engineering

Faculty of Engineering

2008

DECLARATION

This is to certify that the work presented in this thesis was carried out by the author in the school of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Australia, and has not been submitted for a degree to any other university or institute.

HONGCHUN LI

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ABSTRACT

The objective of this study is to improve our understanding of the evolution and tribological behaviour of work roll surfaces in cold rolling because surface deterioration affects the quality of products and the efficiency of production. The cost of rolls is almost 25% of the cost of cold steel production. An experimental Lateral Set-testing (LST) mini-mill was developed to make use of the Gleeble 3500 thermo-mechanical simulator functions to evaluate, for the first time, the roll material surface features, surface roughness, fast Fourier transform (FFT) and Power Spectral Density (PSD) of frequency distribution, after single and multi-pass rolling.

A low carbon-steel was prepared for the paired disc and then experiments on disc-to-disc wear were carried out to test surface deterioration and friction.

In the laboratory, material imitating an industrial roll was manufactured. One batch contained 4%Cr and another contained 4%Cr plus approximately 0.1% Ti. These materials were compared against each other in the LST and disc-to-disc experiments.

Experiments considered a series of parameters, including strip reduction, speed, and lubrication, while the disc-to-disc experiments considered duration of wear, forward and backward slip and load amplitude. The surfaces of the LST roller and disc were evaluated by surface technologies such as Atomic Force Microscope (AFM), Scanning Electron Microscope (SEM), and surface profile-meters. Transmission Electron Microscope (TEM) and X-ray diffraction

were helpful when analysing features of the roll microstructure that affects the wear properties.

Test results from the mini-mill reveal that dominant waviness of the surface roughness still exists on the surface after a single pass of rolling and a 30.5% reduction is a critical reduction level that has a significant influence on the density of power spectrum. A rougher work piece results in a larger power spectrum of the surface profile. It has found that the PSD altitude of the roller surface is significantly affected axially but is more sensitive to its original surface roughness circumferentially. It is distributed in an inverse order to the surface roughness in a high frequency domain. The addition of Ti alters surface deterioration. Lubrication has a significant effect on surfaces containing either 4Cr% or 4%Cr+Ti, affecting surface roughness of rollers containing 4%Cr more significantly.

In the disc-to-disc tests, more material was removed in the first 60 minutes from the disc containing Ti than the disc containing only 4%Cr. In general, roll material with 4%Cr+Ti reveals to have better anti-abrasive properties than the roll with only 4%Cr, while lubrication significantly reduced the wear rate and amount of material removed from both materials. The speed of the disc influences the weight loss, ie, the higher the speed the greater the amount of material removed. The slip rate also affects roll wear and weight loss because as the speed increases, so do the slip and loss of weight.

The coefficients of friction are between 0.35~0.75 when the contact was dry and 0.06~0.11 when lubrication was applied. Adhesive friction dominated the dry

contact while a mixed lubrication regime features friction behaviour when emulsion lubrication was applied. A backward slip of 2% and a forward slip of 1.5% resulted in a different coefficient of friction in dry contact mode although the corresponding torques were similar.

The torque and coefficient of friction are found to increase with disc speed in dry contact condition.

Lubrication alters the friction of both materials. The coefficient of friction decreases with speed on the disc with added Ti but the effect of load is in the opposite trend, while the disc with 4%Cr was less influenced by speed. The coefficient of friction is more sensitive to load at higher speeds on the disc with 4%Cr than at slower speeds on the disc with Ti added.

This indicates that the addition of Ti enhances the tribological behaviour of rollers because the disc with Ti additive is characterised by carbonitrides precipitated in a refined tempered martensitic matrix. Coarse carbides characterise the 4%Cr disc materials.

Surface defects of the work rolls, including banding, spalling, marking and welding in a cold strip plant, were investigated. It was found that early failures principally resulted from operational factors and roll material off-specification micro-structure defects rather than wear.

It is recommended that different grades materials of the roll and strip with different roughness and hardness to be tested and studied on the evolution and tribological behaviour of roll surfaces in the future.

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NOMENCLATURE

ACF	auto-correlation function
AFM	Atomic Force Microscope
f	frequency
FEM	Finite Element Method
LST	Lateral-setting test
L	length
l_{x0} and l_{y0}	integrated width and depth
N	number of data points
P	power
PSD	Power Spectrum Density
LCS	low carbon steel
R	roll radius
EAB	Electronic Analytical Balance
Ra	Roughness Average
R_{ku}	kurtosis
R_{max}	maximum roughness
R_q	root mean square roughness
R_{sk}	skewness
Rz	average maximum height
SEM	Scanning Electron Microscopy

W	Roll speed in rpm
SPM	Scanning Probe Microscopy
FFT	Fast Fourier Transform
τ	shear strength
ε	percentage reduction, %
ε and $\dot{\varepsilon}$	strain and strain rate
μ	coefficient of friction
v	rolling velocity
σ	Strength (MPa)
TEM	transmission electron microscopy
EDX	energy-dispersive X-ray

LIST OF PUBLICATIONS DURING THE PHD COURSE

1. **Hongchun Li**, Zhengyi Jiang, Kiet A. Tieu, Weihua Sun, Analysis of premature failure of work rolls in a cold strip plant, *Wear* 263 (2007) 1442–1446.
2. **Hongchun Li**, Zhengyi Jiang, Kiet A. Tieu, Weihua Sun, Surface Roughness and Wear of Work Roll Containing Ti in Cold Strip Rolling. *Advanced Materials Research*, Vol. 32 (2008), pp 157-160.
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4. **Hongchun Li**, Weihua Sun, A. K. Tieu, Z. Y. Jiang, A Microscopic Examination on Work Roll Wearing Behaviour by Disc-to-Disc experiments in Cold Rolling of Steel, in M. Pietrzyk et al: *Proceedings of Metal Forming 2008*, Krakow, Sept 24-28, 2008.
5. Weihua Sun, **Hongchun Li**, A. K. Tieu, Z. Y. Jiang, Experimental study on deformation behavior of oxide scale during hot rolling of steel, in M. Pietrzyk et al: *Proceedings of Metal Forming 2008*, Krakow, Sept 24-28, 2008.
6. **Hongchun Li**, Chunguang Meng, Weihua Sun, Bob de Jong, A Mill Configured for a Thermo-mechanical Simulating Test system. US Patent, Application Number: 12017998. Receipt Date: 22-JAN-2008