

**FILM FORMING CHARACTERISTICS AND TRIBOLOGICAL
BEHAVIOUR OF EMULSIONS DURING COLD ROLLING OF
STEEL STRIP**

By

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



Indian Institute of Technology, Delhi

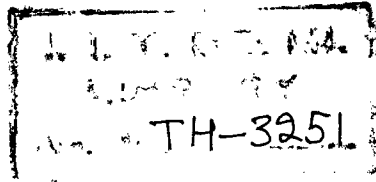
June, 2005

1. Lubricants
2. Lubrication - mechanism

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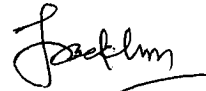
CERTIFICATE

This is to certify that the thesis entitled "**Film Forming Characteristics and Tribological Behavior of Emulsions during Cold Rolling of Steel Strip**" being submitted by Shri Sheo Pujan Dubey to the **Indian Institute of Technology, Delhi**, for the award of the Degree of Doctor of Philosophy is a record of bonafide research work carried by him under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard for the Doctor of Philosophy Degree.

The results contained in this thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.



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ACKNOWLEDGEMENT

I express my heartfelt gratitude to Prof. G S Sekhon and Prof. K S Shishodia for their valuable guidance, inspiration and encouragement throughout the period of my PhD work.

I am equally thankful to Dr G K Sharma, Dy. General Manager, R&D Center, Indian Oil Corporation, Faridabad for his help, guidance and support.

My sincere thanks go to professors of different departments of IIT Delhi, who taught me the background courses for the present doctoral work.

I am extremely grateful to the management of Indian oil corporation Ltd. (IOCL), R&D Center, for allowing me to do part time PhD at IIT Delhi and providing financial support, study leave and experimental facilities.

I am thankful to the staff and officers of different departments of R&D center, IOCL, Faridabad, who helped carry out the experiments on different test rigs. My deeply felt gratitude goes to Shri R Mahapatra, Shri S P Singh, Shri Amrik Singh and Shri Sanjay Sharma of Department of Tribology-II of IOCL, R&D Center, Faridabad, who readily extended help whenever needed.

My deep sense of gratitude goes to Dr B Basu, Dy. General Manager, Department of Information Systems, IOCL, R&D Center, Faridabad, who was very helpful during the development of the artificial neural network model.

I am sincerely thankful to M/s Lubrizol Corporation, USA for their help in determination of droplet size of samples of emulsion.

Finally I express my indebtedness to my wife, Smt Shiv Kumari Dubey, son Shri Mukesh Kumar Dubey and other family members for their love, affection and support during the present study.


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ABSTRACT

- ❖ Friction in the roll bite is an important factor affecting the cold rolling process. Control of friction at the roll/work interface is achieved mainly through proper choice of the lubricant. Oil-in-water (O/W) emulsions are used with the twin objectives of cooling and providing sufficient amount of lubrication in the roll/ strip contact zone.

- ❖ The oil-in-water emulsion is essentially a two-phase heterogeneous mixture of oil and water, in which the oil remains as the dispersed phase and water the continuous phase. The oil phase contains the base oil, emulsifiers, lubrication additives and other ingredients. O/W emulsions used in steel cold rolling generally contain oil between 2.5% to 5.0% by volume.

- ❖ The mechanism of lubrication through emulsion has not been adequately understood. Existing explanations of the phenomenon are based on the so-called plate-out and dynamic concentration theories. Some investigators have observed a positive correlation between droplet size and film thickness, some others have found speed and droplet size as being responsible for the size of film thickness, and still others have shown that the film forming ability of lean emulsions is extremely low and practically independent of temperature.

- ❖ The role of emulsion stability, saponification (SAP) value and nature of emulsifier in the lubricating action of O/W emulsions has been studied in the past.
- ❖ Except a few, most of the researchers have used specially formulated O/W emulsions (non-commercial formulations) during their investigations.
- ❖ The experimental studies on a wide variety of test rigs including Elasto-Hydrodynamic (EHD) interferometry and experimental rolling mill have led to the development of theories and mathematical models for the prediction of film thickness between emulsion-lubricated contacts. Yet, tribologists in the industry still prefer to rely on experience and rules of thumb.
- ❖ Available studies on the behavior of commercial O/W emulsions used in industries are quite scarce. Such investigations will be valuable for both the oil formulator and industrial user. Topic of research may include the followings:
 - I. Effect of chemical composition of commercial O/W emulsions on their physico-chemical properties especially the emulsion stability value (ESV), saponification value, droplet size and film thickness.
 - II. Film forming and lubricating characteristics of different generations of commercial rolling oil (O/W emulsions).
 - III. Evaluation of the tribological performance of O/W emulsions in an experimental steel cold rolling mill under simulated industrial

conditions. The performance under both boundary and hydrodynamic lubrication conditions may be studied.

IV. Development of an artificial neural network (ANN) model for predicting the performance of commercial O/W emulsions.

- ❖ The objectives of the present study are as follows:
 - To carry out an experimental investigation of the film forming characteristics of selected commercial oil-in-water emulsions used in Indian industry.
 - To evaluate the tribological behavior of the above oil-in-water emulsions under different processing conditions with the help of an experimental rolling mill.
 - To develop an ANN model for predicting the effect of physico-chemical properties and tribological parameters of the foregoing oil-in-water emulsions during cold rolling of steel strips.

- ❖ The thesis contains an introduction, a literature review, a summary of the background material, a description of the experimental investigations and the findings, estimation of coefficient of friction, a presentation of the proposed artificial neural network model and an epilogue. The above contents have been arranged in seven chapters.

- ❖ In the Introductory chapter—I background of the study, scope and objectives of the present investigations have been mentioned.

❖ The literature review (Chapter–II) deals with previous studies on cold rolling oils, emulsion technology, film forming characteristics including viscosity, droplet size and concentration based theory, plate out theory, dynamic concentration theory and tribological behavior. The literature survey leads to the following conclusions:

- Film forming behavior of O/W emulsions used for cold rolling of steel strips continues to be a topic of considerable research interest in view of its practical importance.
- Comparative study of the tribological behavior of commercial O/W emulsions is important to industry.
- Researchers have expressed diverse views on film forming and lubricating characteristics of O/W emulsions. For example Wilson considers the droplet size of oil and speed of rolling as important factors in film forming and lubrication whereas Guzman and John emphasize the role of chemistry related factors such as emulsion stability, saponification value, nature of emulsifier and other additives on the performance of O/W emulsions. Vergne et al hold the view that film-forming ability of lean emulsions is extremely low and practically independent of temperature.
- Several analytical models of tribological behavior of emulsions during rolling of metallic strip are available in the published literature. It would be interesting to assess their relevance to industry.
- During the literature search, the author has observed that investigators have used either specially formulated rolling oils or

those which were easily available to them. Very few have used commercial rolling oils. Studies on the film forming characteristics and tribological behavior of emulsions based on successive generations of commercial rolling oils of proven industrial performance would be valuable.

- Lean O/W emulsions (i.e. those in which oil concentration varies from 2.5 to 5.0%) are often used in commercial steel cold rolling mill. However the ability of lean O/W emulsions to form films on steel strip is low. The question arises whether different emulsifiers and chemical additives do significantly affect the performance of O/W emulsions.

- ❖ Chapter III gives a summary of the background material relevant to the present work. Topics covered include modeling of the strip rolling process including equations of equilibrium, elastic stress-strain relations, plastic stress-strain relations, equation of heat transfer, analysis of roll deformation and computation of coefficient of friction. Test methods for determination of the saponification value, Kinematic viscosity, density, flash point, acid number, emulsion stability are also mentioned. Also outlined are the experimental techniques for determination of film thickness, droplet size and mechanical properties of strip materials. This chapter also contains a brief of description of artificial neural networks.

- ❖ Three rolling oils have been selected for the present investigation on the lubricating action and tribological behavior of O/W emulsions. They are

commercial rolling oils used in Indian industry. Their physico-chemical properties along with results of emulsion stability value, droplet size, film thickness and saponification value are given in chapter IV. Tribological behavior of the selected oils has been studied by conducting experiments on a 2- High experimental rolling mill. Nature of oil film and film strength have also been studied by IR (Infrared) spectroscopy and Falex Pin and Vee blocks test rig. Experimental results have been presented and discussed in this Chapter.

- ❖ Procedure for estimation of coefficient of friction, using a commercial software, has been mentioned in chapter V. Salient features of mathematical model, computational details for coefficient of friction, computed results and discussion on findings are mentioned in this chapter
- ❖ An O/W emulsion having larger droplet size, higher saponification value, higher film strength and lesser emulsion stability produces higher film thickness and lower co-efficient of friction. The results obtained on the experimental test rig correlate with those of industrial rolling mill. The results also match the findings of other researchers. However there was significant difference between the results found from the experimental rolling mill and the film thickness obtained on an ultra thin film EHD test rig.
- ❖ A neural network model has been described in chapter VI. It is based on the experimental results obtained from a 2-Hi experimental rolling mill using three different rolling oils, two different concentrations (2.5 % and

5.0%) and three different speeds (100, 350, 500 m/min). Oil concentration, emulsion stability value, saponification value, speed, percent reduction and droplet size are considered as the input parameters and the coefficient of friction as the output parameter. The predicted and actual values of co-efficient of friction are in good agreement.

- ❖ The conclusions of the present investigation are summarized below.
 - In the present investigation, three commercial rolling oils (O/W emulsion) used in Indian industry, have been studied
 - Lubrication mechanism of an O/W emulsion has been analyzed on the basis of its SAP value, emulsion stability value, droplet size and film thickness. The emulsifier and other chemical ingredients used in the formulation of rolling oil have a major effect on the above parameters.
 - Film thickness is not the sole determinant of the lubricating property of a given O/W emulsion. It also depends upon the nature of the film and its strength. In fact O/W emulsions producing a smaller film thickness can perform better if the nature and the strength of the film are superior to those of an oil that forms a thicker film.
 - An O/W rolling oil emulsion having higher SAP value, lower emulsion stability value, larger droplet size and higher film strength produces larger film thickness and lower coefficient of friction. The above findings correlate well with industrial experience. An oil that produces lower friction in the roll bite of an experimental rolling mill, exhibits similar performance in an actual industrial rolling mill too.

- Film thickness measurements on an ultra thin film EHD interferometry test rig have poor correlation with results obtained on an experimental and industrial rolling mill. For example an oil having moderate droplet size, SAP value, film strength and emulsion stability value may produce a thin film during experiments on an EHD interferometry test rig. But this result is not the correct indicator of its actual tribological performance in an experimental or industrial rolling mill.
- The lubrication and tribological behavior of an O/W emulsion can be understood properly if the role of SAP value, droplet size, film strength and emulsion stability is studied by conducting performance tests on an experimental or industrial rolling mill.
- ANN model can be used to predict the performance of an O/W emulsions for a particular type of mill and strip material. Variables such as SAP value, droplet size, emulsion stability value, concentration of oil, percent reduction and rolling mill speed form the inputs of the model. Output of the model is co-efficient of friction.

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