

Advances in Industrial Tribology

Proceedings of the International
Conference on Industrial Tribology
December 2-5, 1997, Calcutta, India

Editor
J Bhatia



Twenty five years of
tribology in India



TRIBOLOGY SOCIETY OF INDIA

Advances in
INDUSTRIAL TRIBOLOGY

Advances in INDUSTRIAL TRIBOLOGY

Editor

J. BHATIA

Managing Director
Balmer Lawrie & Fuchs Ltd
Mumbai



Tata McGraw-Hill Publishing Company Limited
New Delhi

McGraw-Hill Offices

New Delhi New York St Louis San Francisco Auckland Bogotá Caracas
Lisbon London Madrid Mexico City Milan Montreal
San Juan Singapore Sydney Tokyo Toronto



**INTERNATIONAL CONFERENCE ON
INDUSTRIAL TRIBOLOGY**

December 2-5, 1997
Calcutta, India.

Organised by

Balmer Lawrie & Co. Ltd.

&

Balmer Lawrie-Fuchs Ltd.

Under the aegis of



Tribology Society of India



ADVISORY COMMITTEE

Dr. C.V. Chandrasekharan

M.D., Balmer Lawrie & Co. Ltd. & Chairman, Balmer Lawrie - Fuchs Ltd.
(Chairman)

T.S.R. Prasada Rao

Director,
Indian Institute of Petroleum

D.V. Singh

Vice Chairman,
All India Council for
Technical Education

A.K. Bhatnagar

Executive Director,
Indian Oil Corporation Ltd.

S.K. Bhattacharya

Director, RDCIS
Steel Authority of India Ltd.

N. Guha

Vice Chairman & M.D.
IFB Agro Industries Ltd.

V.R. Sharma

President
Bhushan Steel & Strips Ltd.

R.S. Guha

Director (Petroleum)
IBP Co. Ltd.

S. Behuria

Executive Director (Sales)
Bharat Petroleum Corpn. Ltd.

K.K. Dhingra

Executive Director
Petroleum Conservation
Research Association

S.P. Chaudhary

General Manager (L&S)
Hindustan Petroleum Corpn. Ltd.

P. Jagannathan

General Manager (R&D)
Bharat Heavy Electricals Ltd.

P.K. Basu

Dy. General Manager (Lubes)
Indian Oil Corporation Ltd.

Sudhir Singhal

President TSI

ORGANISING COMMITTEE

- V.N. Sharma (Organising Secretary)
- S.B. Chakravarty, P.K. Bishnoi, P. Radhakrishnan, R. Kannan (Balmer Lawrie & Co. Ltd.)
- S. Mahanti, Kamala Maheshwari, S.C. Saha (Balmer Lawrie-Fuchs Ltd.)

EDITORIAL BOARD

EDITOR & CHAIRMAN OF TECHNICAL COMMITTEE

Dr. J. Bhatia
Balmer Lawrie - Fuchs Ltd., Mumbai.

SECTION EDITORS & SESSION ORGANISERS

- | | |
|--------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. WEAR MECHANISMS & MODELLING: | Dr. A. Sethuramiah Indian Institute of Technology, New Delhi |
| 2. SURFACE ENGINEERING & TRIBOLOGICAL MATERIALS: | Mr. K. Balasubramaniam Fidelity Industries Ltd., Madras. |
| 3. BEARINGS: | Dr. D.V. Singh All India Council for Technical Education, New Delhi. Dr. Har Prashad Bharat Heavy Electricals Ltd., Hyderabad. |
| 4. AUTOMOTIVE LUBRICANTS: | Mr. Sudhir Singhal Indian Institute of Petroleum, Dehradun. |
| 5. METAL WORKING OPERATIONS & LUBRICANTS: | Mr. Sudhaker Jha Steel Authority of India Ltd., Ranchi. |
| 6. TESTING & ANALYTICAL TECHNIQUES IN TRIBOLOGY: | Mr. A.K. Mehta Indian Oil Corporation Ltd., Faridabad. |
| 7. LUBRICANT ADDITIVES: | Dr. S.P. Srivastava Indian Oil Corporation Ltd., Faridabad. |
| 8. CONDITION MONITORING & SIMULATION: | Mr. C. Mishra The Tata Iron & Steel Company Ltd., Jamshedpur. |
| 9. INDUSTRIAL LUBRICANTS & GREASES: | Dr. J. Bhatia Balmer Lawrie - Fuchs Ltd., Mumbai. |
| 10. ENVIRONMENTAL & RURAL ENGINEERING: | Dr. S. Chattopadhyay Balmer Lawrie & Co. Ltd., Calcutta. |

EDITORIAL COORDINATOR

Kamala D. Maheshwari
Balmer Lawrie - Fuchs Ltd., Mumbai.

Foreword

Publication of this important volume of proceedings of ICIT 97 marks the completion of twenty-five eventful years of tribology in India. It is indeed a privilege to be associated with this work, which represents state-of-the-art theoretical and experimental studies being carried out in the inter-disciplinary field of industrial tribology in different parts of the globe. The response to the call for papers for ICIT 97 was overwhelming and the task of selecting a final compendium a daunting responsibility. Fortunately, I was able to draw upon the resources of a highly experienced editorial team, each member of which was a specialist in the chosen field, thereby reducing my personal effort to that of supporting the section editors for maximum synergy (and minimum friction!). This volume has also benefitted from contributions from a number of internationally renowned tribologists and professional technocrats who readily came forward with their special papers on our request. More than anything else, this is all a fitting tribute to the silver jubilee year of an applied science which is beginning to find its justifiable place on the industrial map of our developing country.

On behalf of the editorial committee, I take this opportunity to thank all our contributors, including those whose papers could not be accommodated, for enriching our level of awareness and understanding of this complex science. It is to be hoped that the reader of this compendium will also find it an equally rewarding and enriching experience.

J. BHATIA

Editor & Chairman of the Technical Committee

From the Organising Secretary

The World Conference on Industrial Tribology held in New Delhi in 1972 marked a significant milestone in the development of the Science of Tribology in India. Since then, National level conferences have been held every alternate year to provide a forum for exchanging new ideas and sharing valuable experiences with a view to maximising the benefits from the advances in Tribology to industry as well as research and academic institutions. The pioneering efforts, starting with the 1972 Conference, resulted in the formation of the Tribology Society of India (TSI). The Tribology Society of India is now celebrating 25 years of Tribology in India with the International Conference on Industrial Tribology (ICIT-97) being held at Calcutta.

The theme of the Conference—*War Against Wear*—was chosen considering its particular relevance to the stage of economic and technological development that our part of the world is in today. It is hoped that the theme would underline the gravity and urgency of the need to adopt sound tribological principles and practices.

ICIT-97 is being organised by Balmer Lawrie & Co. Ltd. and Balmer Lawrie -Fuchs Ltd. under the aegis of TSI. On behalf of the organisers I thank the Executive Committee of TSI for granting us the privilege and opportunity.

ICIT-97 is the result of inspired team effort. Apart from numerous colleagues from Balmer Lawrie, Balmer Lawrie - Fuchs and the Executive Committee of TSI, I am grateful to tribologists and other professionals who have contributed to this venture. I would like to thank the Patrons and the Advisory Committee members for their valuable encouragement and guidance, as also the sponsors, donors and others who have contributed to support the Conference.

V. N. SHARMA
General Manager (G&L)
Balmer Lawrie & Co. Ltd.
Calcutta, India

Contents

| | |
|--------------------------------------|-----|
| <i>Organisers</i> | v |
| <i>Advisory Committee</i> | vi |
| <i>Organising Committee</i> | vi |
| <i>Editorial Board</i> | vii |
| <i>Foreword</i> | ix |
| <i>From the Organising Secretary</i> | xi |

SECTION 1: Wear Mechanisms & Modelling 1

1. Aluminium Alloy Hard Particle Composites: Potential Wear Resistant Materials
S. Das, B.K. Prasad, O.P. Modi, A.K. Jha, R. Dasgupta and A.H. Yegneswaran 3
2. Wear Characteristics and Machinability of Hyper-Eutectic Aluminium-Silicon Alloy
S.N. Thakur, S.N. Prasad and Ashok Mishra 16
3. A Fractal Analysis of Adhesion and Friction at the Contact between Rough Surfaces
S.K. Roy Choudhury and P. Sahoo 26
4. Mechanical Properties of Sputtered Multilayer Coatings
J.M. Castanho, A.S. Ramos and M.T. Vieira 39

SECTION 2: Surface Engineering & Tribological Materials 47

5. Tribological Behaviour of Nitrogen Implanted Al-Alloys
L. Gulzman, A. Miotello, M. Adami, E. Voltolini and F. Ferrari 49
6. Sliding Wear Behaviour of a Zinc-Based Alloy Compared with a Leaded-Tin Bronze
J.P. Pandey and B.K. Prasad 59
7. Influence of Short Fibre Reinforcement on Tribo-characteristics of High Performance Polymer Composites
Jayashree Bijwe, J. Indumathi, J. Rajesh and S.S. Chauhan 67
8. Diamond and Diamond-like Carbon Coatings for Various Applications
A.K. Dua, V.C. George, D.D. Pruthi, C.G.S. Pillai, P. Raj, D.S. Patil, K. Ramachandran and N. Venkataramani 75
9. Mechanical & Tribological Properties of Discontinuous Glass Fibre Reinforced Polypropylene Composites
H.S. Hebbar, Braham Prakash and R.K. Mital 81

| | | |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 10. | Tribological Performance of Molybdenum Disulphide Films <i>A.K. Kohli and Braham Prakash</i> | 88 |
| 11. | Theoretical Modelling of Surface Contact for Honed Surfaces <i>Rajesh Kumar, Braham Prakash and A. Sethuramiah</i> | 100 |
| 12. | Analysis of Abrasive Wear Behaviour of Redmud Filled PVC <i>Navin Chand and S.A.R. Hashmi</i> | 108 |
| SECTION 3: Bearings | | 113 |
| 13. | Rolling Element Bearings Temperature Prediction <i>Y.R. Reddy, D.P. Vakharia, K. Athre and S. Biswas</i> | 115 |
| 14. | Accurate Prediction of Performance Parameters of Rolling/Sliding Thermal EHL Line Contacts <i>M.K. Ghosh and R.K. Pandey</i> | 121 |
| 15. | Non-linear Analysis of Electromagnetic Bearings Using Finite Element Method <i>K.P. Nair, P.G. Alexander and Syam Sunder</i> | 130 |
| 16. | Effective Stiffness of Cylindrical and Elliptical Journal Bearings by Electrical Analogy—An Approach <i>Har Prashad</i> | 138 |
| 17. | Possibility of Replacement of Babbit Lining by Polymer Layer in Large Thrust Bearings—An Experimental Study <i>T.R. Choudhary, Om Prakash, G. Venkat Rao and A. Sethuramiah</i> | 143 |
| 18. | Dynamic Modelling of Large Tilting Pad Journal Bearings including Thermal and Elastic Effects <i>D.S.K. Reddy, S. Swarnamani and B.S. Prabhu</i> | 156 |
| 19. | Dynamic Performance Characteristics of Hydrostatic/Hybrid Journal Bearing with Non-Newtonian Lubricants <i>S.C. Jain, R. Sinhasan, Staish C. Sharma and P.L. Shah</i> | 167 |
| 20. | An Analytical Approach for Journal Bearing Design <i>H. Hirani, T.V.V.L.N. Rao, K. Athre and S. Biswas</i> | 172 |
| 21. | Performance of Multirecess Hybrid Journal Bearing Operating in Turbulent Regime <i>Satish C. Jain, Satish C. Sharma and A. Jagtap</i> | 178 |
| 22. | An Approximate Thermal Analysis of Engine Bearing <i>H. Hirani, K. Athre and S. Biswas</i> | 186 |
| 23. | Performance Characteristics of Floating Bush Bearings in Turbulent Regimes Using Non-linear Turbulent Lubrication Theory <i>S.C. Soni and M.K. Jain</i> | 194 |
| 24. | Use of Enveloping and <i>SEETM</i> (Special Emitted Energy) Technology of Detecting Rotational Impact Signals <i>D.K. Sen</i> | 203 |

SECTION 4: Automotive Lubricants 215

25. A Laboratory Technique for Evaluation of Automotive Gear Oils of API GL-4 Level
R.P.S. Bisht and Sudhir Singhal 217
26. Approaches for Characterisation of Running-In
M.R. Tyagi, V.R.K. Sastry, M. Abraham and S. Singhal 226

SECTION 5: Metalworking Operations & Lubricants 235

27. Monitoring of Process Indicators for Assessment of Tribology in Machining Processes
Z.A. Zoya and R. Krishnamurthy 237
28. Influence of Artificial Neural Network Parameters for an Effective Condition Monitoring of Tool Status
S. Kumudha, Y.G. Srinivasa and R. Krishnamurthy 246
29. Reduction in Wear of Work Rolls by Improved Thermal Condition during Hot Rolling of Plate
A.K. Marik, P. Pathak, P.K. Prusty, G.M.D. Murty and S. Jha 254
30. Plasma Aided Hot Machining of Difficult-to-Machine Materials
A.K. Roy, M. Singh, A.K. Bhakat, T.D. Chatterjee, S. Jha and S.K. Bhattacharyya 261
31. Low Evaporating and Low Misting Cutting Fluids
Dietrich Hoerner 269
32. Evaluation and Design of Steel Cold Rolling Oils
Umesh Srivastava, C.B. Semwal, K.C. Jayaprakash, S.P. Dubey, V. Martin and A.K. Mehta 282
33. Boundary Lubrication Studies in Plastic Deformation through New Laboratory Technique
R.K. Banerjee, C.R. Jagga and A. Sethuramiah 295
34. Steel Cold Rolling Oils, Background and Latest Developments in European Rolling Mills
A. Mascaró and X. Gaillard 305

SECTION 6: Testing & Analytical Techniques in Tribology 317

35. Fatigue Wear Modelling in Sliding and Rolling/Sliding Contacts
S.K. Karmakar and A. Sethuramiah 319
36. An Example of a Tribology Laboratory in Lubricants & Petroleum Industry—Mechanical Testing and Surface Analysis
F. Espinoux and B. Constans 326
37. Reciprocating High Temperature - High Pressure Water Tribometer
A.K. Kohli, P.K. Limaye and R.G. Agarwal 335

| | | |
|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| SECTION 7: Lubricant Additives | | 343 |
| 38. | Effect of Viscosity Modifiers on Viscometric and Wear Performance of Lubricants <i>A.V. Pantar and P. Ghosh</i> | 345 |
| 39. | A Study on the Comparative Evaluation of Tribological Properties of Formamidino Thiocarbamides and Their Mo-S Complexes as Potential EP Additives <i>V.K. Verma, R. Singh, A. Bhattacharya, A.K. Tripathi and N.S. Mishra</i> | 353 |
| 40. | Organo-Sulphur EP Additives—Structure and Tribological Performance Relationships <i>D.K. Tuli, H. Bhatia, R. Sarin, M.M. Rai, S. Ghosh and A.K. Bhatnagar</i> | 361 |
| 41. | Chemisorbed Reaction Films of Derivatives of Methyl Ricinoleate and Their Friction and Wear Characteristics <i>O.N. Anand, R.B. Choudhary and R.P.S. Bisht</i> | 369 |
| SECTION 8: Condition Monitoring & Simulation | | 379 |
| 42. | Condition Monitoring of Airbus A-300 CF 6-50C Engines through SOAP Analysis <i>S.K. Ghorai and J.S. Tomar</i> | 381 |
| 43. | Condition Assessment of Coal-feed Bunkers and Life Improvement Study <i>J.P. Pandey, R.S. Solanki, B.K. Saxena and S.P. Mukherjee</i> | 388 |
| 44. | Oil Contamination Monitoring and Control of Hydraulic Equipment <i>V.P. Moudgil and K.U. Rao</i> | 396 |
| 45. | Condition Monitoring of Rotating Machinery Using Expert Systems <i>B.S. Prabhu and M. Sarath Kumar</i> | 403 |
| 46. | Role of Oil in the Performance of Heavy Duty Gear Box Used in Coal Pulveriser <i>N. Santanam</i> | 412 |
| 47. | Benefits of Condition Based Maintenance—A Case Study from Opencast Mines <i>B. Akala, M.I. Alam and A.K. Singh</i> | 422 |
| SECTION 9: Industrial Lubricants & Greases | | 431 |
| 48. | Ti-Complex Grease: A Versatile Grease for Industry <i>Anoop Kumar, S.C. Nagar, E. Sayanna, K.P. Naithani, M.M. Rai and A.K. Bhatnagar</i> | 433 |
| 49. | Tribochemistry and EP Activity Assessment of Some Polyurea Greases <i>T. Singh and M.F. Sait</i> | 443 |
| 50. | Evaluation of Refrigerant Lubricants through Diagraph Matrix Analysis <i>A.R. Ansari, O.P. Gandhi and A.D. Telang</i> | 452 |
| 51. | Tribological Characteristics of Compounded Oils Containing Tallow <i>Mahendra Pal</i> | 463 |

| | | |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| SECTION 10: Environmental & Rural Engineering | | 471 |
| 52. | Lubricants and the Environment—A Review <i>W.J. Bartz</i> | 473 |
| 53. | Effect of Hardfacing on the Wear Properties of Steels Used in Agricultural Components <i>R. Dasgupta, B.K. Prasad, A.K. Jha, O.P. Modi, S. Das and A.H. Yegneswaran</i> | 483 |
| 54. | Tribology for Rural India <i>R.A. Rao</i> | 491 |
| 55. | Environment Adapted Lubricants Part - I: An Overview <i>M. Pal and Sudhir Singhal</i> | 494 |
| 56. | Water Based Functional Fluids—Economical and Ecofriendly Alternative <i>M.C. Dwivedi</i> | 502 |
| 57. | Effect of Degraded Fat in Performance of Cold Rolling Oils <i>N. Datta, S. Murli, M.L. Das, N. Pandey, R.R. Bhaskar and S. Chattopadhyay</i> | 503 |
| SECTION 11: Special Topics | | 513 |
| 58. | Toward Modeling of Chemical Boundary Lubrication <i>Kenneth C. Ludema</i> | 515 |
| 59. | Sliding Wear—A Review of Generalities and Challenges <i>S.K. Biswas</i> | 536 |
| 60. | The Tribological Mechanisms of Coated Surfaces <i>Kenneth Holmberg, Allan Matthews and Helena Ronkainen</i> | 585 |
| 61. | The World Lubricants Market <i>Manfred Fuchs</i> | 605 |
| 62. | Tribology in India, Waking Up to New Realities <i>A.K. Bhatnagar, S.S.V. Ramakumar, D.K. Tuli and V. Martin</i> | 624 |
| 63. | Lubricants for the Next Century <i>Theo Mang</i> | 639 |
| 64. | Recent Trends in Automotive Lubrication and Maintenance <i>D.L. Surbey</i> | 654 |
| 65. | Tribology in Power Sector and Associated Tribological Issues <i>K.V.V. Gopalakrishna</i> | 671 |
| 66. | Testing Extreme Pressure and Antiwear Performance of Crankcase and Gearbox Lubricants <i>A.F. Alliston-Greiner, A.G. Plint and M.A. Plint</i> | 672 |
| | <i>Author Index</i> | 687 |