Tribology Research in Australia

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Australia is a country where the ancient culture of the Aborigines coexists with a modern culture in a young future-orientated multicultural society. Subconsciously, perhaps, this immersion in a situation where ancient problems require innovative new solutions has stirred the creativity and imagination of many Australian researchers in tribology. When compared with other countries of a similar population size, the Australian contribution to tribology is substantial. In this paper major achievements of Australian tribologists are presented.

Keywords: tribology research, Australia

1. Introduction

Tribology is as old as human culture yet it is considered to be a science of the future. Australia is the home country of Anthony Michell, who developed pivoted pad thrust bearings and greatly contributed to the theory of hydrodynamic lubrication, and Francis Bowden, who developed much of the theory of friction and lubrication by adsorbed films. Melbourne was, for many years, the home of the Lubricants and Bearings Section at the Council for Scientific and Industrial Research, later converted to a Tribophysics Laboratory and managed by Francis Bowden and David Tabor. Despite the eventual disbandment of the Tribophysics Laboratory, research in tribology has continued in Australia and there are now numerous research groups working on many of the significant topics in tribology. When compared with other countries of a similar population size, the Australian contribution in tribology is notably large. Every four years, international tribology conferences, AUSTRIB series, are organized in Australia to share these local initiatives in tribology with the wider global research community. In this paper past and current tribological research in Australia is described.

2. Tribology Research in Australia –Past

Australia has a long history of its involvement in tribology. The first major scientific investigation into a tribological system in Australia is attributed to Anthony Michell who invented the tilting pad bearing. Michell had studied the applications of Reynolds’ theory of hydrodynamic lubrication to a pad thrust bearing and concluded that there must be a point or line where the hydrodynamic pressure would balance and allow the pad to be supported by a pivot. A pivoted pad would tilt independently to achieve the optimum slope ratio (ratio of inlet to outlet film thickness) as schematically illustrated in Figure 1. It can be seen from Figure 1 that optimal bearing friction and load capacity can be achieved at a specific value of the convergence ratio parameter ‘K’, i.e. at the optimum \( h_1/h_0 \) ratio. Under normal operating conditions bearing load and hence \( h_1/h_0 \) ratio can vary. As shown in Figure 1 load changes affect the \( h_1/h_0 \) ratio and hence the ‘K’ parameter value. With the changing load ‘K’ parameter is no longer at its optimal value resulting in lower load capacity and higher friction. This required a construction of large bearing containing multiple rotating plates. It is thus desirable to run the bearing at optimum \( h_1/h_0 \) ratio, i.e. maximum load capacity and minimum coefficient of friction. A pivot was a solution to this problem.

Michell performed detailed analytical work and presented his analysis in a learned German journal of Zeitschrift fur Mathematik und Physik\(^1\). This, perhaps, is the reason why his invention has found one of its first practical applications in the German U-boats. The Germans realized that Michell’s invention could be crucial to the development of the fuel efficient thrust bearings for the ship propeller shafts. In earlier designs, the propeller shaft simply abutted on to a stack of rotating plates, which groaned and smoked to accommodate the heavily loaded sliding motion. When...
the Royal Navy captured one of the German U-boats the navy engineers studied in great detail ship propeller thrust bearings. The bearings were much smaller than those traditionally used in the submarines. Hence, they allowed for significant savings of fuel because of reduced friction and lower noise emission since there was no longer any of the aforesaid groaning and squealing from tormented metal plates. Later, Michell designed pivoted pad bearings for pumps at Cohuna on the Murray River, Australia. In recent times, the Michell pivoted pad has been utilized in hydro-electric power schemes and many other applications.

Michell was also the inventor of crankless engine which could perform 10% better than the standard car engines today. This invention was not, however, implemented by car manufacturers due to the high cost of re-tooling and re-equipping. In 1950 Michel published a book on 'Lubrication - Its Principles and Practice'.

The contributions of Frank Philip Bowden, from Hobart in Tasmania, to tribology are well known. In the 1940s he established the Section of Tribophysics at the Council for Scientific and Industrial Research (CSIRO) in Melbourne. This was the place where much of the work on adhesive wear and the adsorption of fatty acids on metal surfaces was performed. This work has led to the development of effective lubricant additives and combinations of sliding metals to prevent scuffing and other forms of frictional seizure. In 1950 and 1964 Bowden published two famous books with David Tabor on ‘The Friction and Lubrication of Solids’ and ‘Friction and Lubrication’.

Predicting the temperature increase in friction contacts is a difficult task. A Sydney scientist John Conrad Jaeger solved this problem. Jaeger’s major contribution in tribology was the work on transient heat phenomena in sliding contact resulting in elegant equations for the flash temperature calculations presented in a widely cited paper.

Jaeger’s work on rock mechanics had a significant scientific impact and probably established him as one of the principal authorities on friction in rock at the time. While working on friction he made a number of important observations on the role of surface finish, on gouge formation, and on the stick-slip phenomenon. He published several books including ‘Conduction of Heat in Solids’ with Horatio Scott Carslaw.

3. Tribology Research in Australia -Present

Wear is difficult to observe directly. In the early 1980s, Peter Oxley and Mark Challen, from the University of New South Wales, developed a theory of wear based on the observation that a hard wedge drives a wave of highly deformed material across a counter surface. They reasoned that if it is not possible to view wearing surfaces directly then, at least, it should be possible to do that in cross section. This idea of application of cross section of sliding surfaces in wear studies was not new as it had been developed earlier by Bowden and Tabor, but was only put to a limited use.

Model developed by Oxley and Challen was based on a concept of the rigid prism forced into the softer material and then driven horizontally along the surface of the soft counterface, as schematically illustrated in Figure 2. A wedge of material from a softer counterface, accumulating in front of the prism, is being pushed by this prism, and remains at a constant size as it moves across the surface. This results in a layer of highly strained material on the counterface. Wear particles form when this wave of highly strained material eventually develops cracks. This theory explained the linkage between friction and wear in partially lubricated systems; the energy required to force the waves to move across the surface is the cause of frictional energy dissipation, i.e. much of the frictional energy in unlubricated sliding is dissipated in driving waves of deformed material across the surface.
Following the research initiated by Michell, Australian academics advanced the study of hydrodynamic lubrication. Notably, Eric Hahn, of the University of New South Wales, conducted extensive studies of ‘squeeze film bearings’ and achieved world-wide acclaim for this work. Squeeze film bearings use the viscous damping generated by reciprocating oil flow to attenuate vibrations. Hahn is also known for the work on stability and unbalance response of rotor bearing systems with hydrodynamic bearings, designs of squeeze film dampers for vibration attenuation and stabilisation of rotor bearing systems, cavitation, pressure feed and axial land profile effects and software development for evaluating vibration behaviour, etc., of practical turbomachinery, including misalignment and foundation effects.

Kiet Tieu, of the University of Wollongong, has completed extensive studies of pad bearings with effects such as deflection and heating included. He is also well known for his work on determination of friction coefficients during rolling of steels.

The practical application of tribology to solve urgent industrial problems has been actively promoted by Will Scott and Doug Hargreaves of Queensland University of Technology. Vital industries such as sugar cane processing and coal mining have presented a variety of problems such as the wear of sugar cane shredders and rail fatigue under extreme axle loads, that could only be solved with expertise in tribology. Scott and Hargreaves worked and found solutions to many practical problems, as for example:

• solid contamination control in power hydraulics,
• effect of anti-wear additives on the wear of hydrodynamic journal bearings,
• dragline lubrication, in particular open gear lubrication,
• effects of air entrainment on the performance of oil lubricated journal bearings,
• lubrication of human synovial joints,
• optimisation of wheel-rail lubrication,
• cavitation erosion,
• on-line tool wear identification,
• and many others.

At the CSIRO laboratories in Adelaide, Ian Sare and co-workers have studied abrasive wear under extreme loadings typical of minerals processing. There they developed the model of abrasive wear being controlled by the material response at very high strains, which is very different from the strains generated during the standardized hardness tests. This work has led to a better selection of materials for minerals crushers, rock hammers, etc.

The contribution of Tribology Laboratory, led by Gwidon Stachowiak at the University of Western Australia, has been in showing a direct link between the abrasive particle shape and wear. This relationship is illustrated in Figure 3. The researchers in this group have developed the techniques for numerical characterization of particle angularity and description of 3-D topography of engineering surfaces and wear particles. Currently, the research efforts are focused on the development of an automated system for classification of engineering surfaces and wear particles. The system, when fully developed, may find applications in machine condition monitoring, manufacturing and failure analysis. The group is also known for their work in bio-tribology, in particular the studies of wear in synovial joints and the development of techniques for early detection of osteoarthritis.
At the Tribology Laboratory, University of Western Australia, a technique called ‘Sealed Capsule Differential Scanning Calorimetry’, allowing accurate determination of the oxidation stability of mineral oils, has been developed. In industrial applications this technique can be used to determine the remaining useful life of a lubricant, i.e. to optimize the lubricant’s draining periods. This technique has also been used in the studies of vegetable oils. Sunflower oils were found to possess good oxidation resistance. The West Australian government is reportedly trying to promote the commercial use of eucalyptus oils beyond the traditional markets of cough mixtures. Amongst a large variety of vegetable oils eucalyptus oils have been mainly ignored.

Studies at the same Tribology Laboratory of University of Western Australia reveal that cineole (the main constituent of oil from mallee leaves) possesses good solvent properties and could be useful as an environmentally friendly, non-toxic, bio-degradable solvent. The widespread use of cineole as an industrial solvent would give sufficient commercial value to mallee trees and facilitate their large-scale planting. This would have an additional beneficial effect of preventing salinification of the soils in Australia.

About 20 years ago across the Australian industry wear was considered as something inevitable, i.e. that we have to live with it, and its cost was simply included, budgeted for, in the operating cost of the plant. Nowadays the perception of wear and tribological problems has dramatically changed. There is greater understanding across the industry of wear problems, wear resistant materials and lubrication practice. Proactive machine condition monitoring programs based on both oil and vibration analysis are now a standard practice across the industry.

Australian industry has also been involved in tribology research with work on abrasive wear and the wear of railway wheels performed at the former BHP Research laboratories in Melbourne. Similar research work on abrasive wear and rolling wear was performed by the then CRA Advanced Technology Centre, which later become the Rio Tinto Technical Services Perth, at Bentley Technology Park, Western Australia.

Australian activities in tribology are not only limited to its industrial applications. Bio-tribology, the tribology of the human body and other organisms, is also widely studied in Australia.

One form of arthritis, osteoarthritis, is believed to be characterized by extreme wear of the articular cartilage which means that the entire bearing surface of the synovial joint has begun to disintegrate. Information on how and why these joints are wearing out is important since it affects to a great extend the proper functioning of a synovial joint and the onset and progress of osteoarthritis. However, systematic experimental data on in vivo wear of human synovial joints is virtually impossible to obtain. To overcome this problem the studies were conducted at the University of Western Australia on cadaver sheep joints on a specially designed joint simulator in an oxygen-free sterile environment. The experiments conducted using the simulator revealed that the wear particles generated in the sheep joints subjected to wear are very similar to those observed in osteoarthritic human joints.

The relationship between the structure of orthopaedic cartilage and its lubrication properties was also investigated by researchers at the University of Western Australia and led to the discovery that the cartilage secretes fatty lubricants, i.e. surface active phospholipids, that aid the synovial fluid to achieve low friction.

Australia has always been active in promoting tribological research. It has been a host to a number of...
International Tribology Conferences - AUSTRIB series. Two books on experimental methods in tribology and wear have recently been published. A special contribution to tribology is the field of education with the popular textbook, Engineering Tribology, originating from the University of Western Australia. Courses in tribology are taught on regular bases at the University of Western Australia and Queensland University of Technology. The Royal Melbourne Institute of Technology is also involved in tribology, with investigations on the design and optimization of bearings. The quality of tribology courses in Australia is highly regarded, with many overseas students and also people from the industry participating in the courses.

A major part of Australian tribology research has been achieved by individual research workers often proceeding with only the minimum of institutional support. Given the small size of the Australian population and the tyranny of distance, the Australian contribution to tribology is very creditable.

4. Future Trends in Tribology in Australia

What is the future of tribology in Australia? The work on industrial applications of tribology will continue as Australia has a large sector of mineral processing industry where wear problems still present new challenges. Progress will be made in the area of development of expert systems for automated classification of wear particles and engineering surfaces. Australia's contribution to bio-tribology is well known. The work will continue on wear and lubrication of synovial joints aiming at better understanding and control of osteoarthritis. Understanding of wear and friction at nano level is problematic at the best. There are some early indicators that Australian tribologists are gradually getting involved in this field and start producing new exciting research discoveries. Tribology at nano scales in Australia has been actively promoted by Liangchi Zhang from the University of Sydney with his research interests focusing on better understanding of friction and wear on the atomic scale. Biodegradable lubricants may become a source of Australian innovation as zoologists and botanists locate plants with potentially useful lubricants or lubricant additives. The significance of bush onions or 'stink-weed' has yet to be investigated as this plant would appear to contain natural sulphur compounds. Sulphur compounds are the source of extreme pressure lubricant additives that prevent gear-wheels from seizing. Studies at the University of Western Australia revealed that cineole (the main constituent of oil from mallee leaves) possesses good solvent properties and could be useful as an environmentally friendly, non-toxic, bio-degradable solvent. The widespread use of cineole as an industrial solvent would give sufficient commercial value to mallee trees and facilitate their large-scale planting.

5. Summary

Reviewing the state of past and present tribology research, a pattern of eminent but isolated academics working at various locations in Australia emerges. Much frustration has been expressed concerning the lack of success in generating new industries in Australia from their work. However, the structure of international corporate and financial organizations may explain much of this difficulty. Given the small size of the Australian population and the tyranny of distance, the Australian contribution to tribology is very creditable.

This century will pose new challenges for humanity. Human population is still growing, environment is gradually being degraded and the natural resources, in particular oil reserves, dwindle. New technologies would need to be developed to keep the growing population alive and healthy while maintaining our standards of living and keeping our biosphere intact. These are major issues and tribology has an important role to play.

6. References