Overview

There is always an effort to increase the performance of mechanical systems. This has resulted in the components of the systems being subjected to higher stresses or aggressive environments and lead to the development of high performance materials. In this succession, ceramic materials have shown a great promise because of their high melting point, strength such as modulus of elasticity and hardness, and inertness to common atmospheres. The main drawback of these materials is the lack of ductility and fracture toughness, and poor thermal conductivity. Thus it is natural to think of the coatings of these materials over metals which compensate these materials for these drawbacks by providing the substrates with good toughness and high heat transfer characteristics. While coated systems enable the scientist to tailor the structures for specific applications, they introduce other complications because of porosity, dendritic grain structure, residual stresses, and interface shear stresses.

The understanding of the tribological behavior of even monolithic materials has been slow to evolve because of the complications from the interaction of sliding surfaces with their environment. Because of the later development of coated systems, it is not surprising that the tribological behavior of these has been of considerable interest. The latter has transpired because of the beneficial use of these coatings in advanced systems such as adiabatic diesel engine, coal fired engine, and gas turbine because higher operating temperatures provide higher thermal efficiency. These systems are subjected to a variety of tribological conditions which involve adhesion, abrasion, erosion, fretting, and others. Because of their high hardness, hard ceramic coatings in general exhibit high abrasion resistance. In the other modes of wear, problems often arise because of spalling of the coating due to the high shear stress induced between the coating and the substrate from high contact stresses and differential expansion resulting from localized temperature rise.

Purpose

This symposium was sponsored towards meeting the objectives of the ASTM G2 Committee, in particular the promotion of knowledge, stimulation of research, and the development of standards. The objective of this symposium was to provide a forum for the presentation of new research work related to the tribological behavior of hard coatings of the materials such as diamond, the carbides, nitrides and oxides of the elements and alloys, and explore the possibility of standards development activity based on this symposium.

ASTM has sponsored several symposia related to tribology. Of direct interest to the readers of this STP are the publications *ASTM STP 1010, Selection and Use of Wear Tests for Ceramics,* 1988 (Yust/Bayer, Eds.), *ASTM STP 1167, Wear Testing of Advanced Materials,* 1992 (Divakar/Blau, Eds.), and the *Tribology of Composite Materials,* 1991 (Rohatgi/Blau/Yust, Eds.).

Overview of Papers

The symposium was held on 7 December 1994 at Phoenix, Arizona. It was contributed by seven authors from USA and two from abroad, and one paper was not presented. It included papers on adhesive wear, abrasion, and fretting behaviors of the different kinds of coatings. The following is an overview of each paper.

The introduction to the symposium was provided by the opening paper by K. Budinski which reviewed the different surface treatment and coating processes such as plating, diffusion treatment, physical and chemical vapor deposition, ion implantation, thermal spray coatings, selective hardening, hardfacing, and the like. An overview of the wear processes was then presented to serve as a background information for the engineers in industry. It was followed by a discussion of the processes that were suited for different wear situations.

The next paper by Blau et al. discussed the development of self-lubricating ceramic coatings based on titanium nitride and MoS_2 and prepared by special chemical vapor deposition methods. The sliding of these coatings against silicon nitride counterfaces in the temperature range 20 to 700°C in air showed that the coefficient of friction was low (0.07 to 0.20) on initial sliding but varied considerably later on. It was particularly high at 400°C because of the changes occurring on the surface and the wear debris at this temperature. Further work is needed to study these changes and to explore the potential of these coatings for practical applications.

The paper by Bahadur and Yang studied the effect of laser surface melting on the detonation gun sprayed (W, Ti) C-Ni and WC-Co coatings on 1044 steel and Ti-6Aℓ-4V substrates. The study showed the variation in structure and hardness through the coating thickness because of laser treatment. Since laser treatment generated a lot of porosity, the use of these coatings in dynamic applications is questionable. The coefficient of friction and wear test data on these coatings is presented and the wear mechanisms are studied.

The paper by Vingsbo el al. reported the fretting results on three kinds of hard coatings: TiN and diamond-like carbon on steel substrates, and polycrystalline diamond on steel substrate. The displacement amplitudes selected in these experiments covered the partial slip regime and the lower part of the gross slip regime. Fretting maps were developed and the fretting mechanisms explained.

The paper by Mohrbacher et al. presented a conceptual framework for modeling laboratory fretting testing and applied the concepts to PVD TiN and CVD diamond coatings. The influence of the fretting conditions on the mechanical contact response as well as the materials modification induced in the contact zone are analyzed. The effects of third bodies, tribochemical reactions, and residual stress on the friction and wear behavior are also discussed.

The paper by Kennedy and Agarwala investigated whether thermally stable compounds such as oxides could be used as high temperature vapor phase ceramic lubricants. Towards this effort, they measured thermodynamic interactions between ceramics and the vapor phase of low sublimation temperature materials. They obtained thermodynamic data such as heat of adsorption, packing density, and reversibility of adsorption and related these data to the wear characteristics of these materials.

The paper by Ramalingam and Zheng studied the problem of hard coatings on light alloys which arises because the modulus of elasticity of the substrate is much lower than that of the coating. Loading in such a system produces differential displacements in the coating and the substrate thereby promoting debonding of the coating which contributes to severe wear. Using the displacement formulation solution approach, the authors have demonstrated that the film stresses can be managed to prevent coating failure by changing the coating material, contact condition, coating thickness, and film deposition conditions.

In the next paper Ruff studied the elastic, plastic, and cracking properties of the plasma sprayed coatings of ZrO_2, ZrO_2-metal composite, and Ni-NiO composite. In this study, from the continuous load versus nanoindentation depth data, material hardness, and elastic modulus are analyzed and the results for different indenter shapes compared. From the instrumented scratch test, the critical loads for severe cracking damage are also determined. The mechanisms responsible for damage in the above processes are then explained.

The last paper by Li and Qunji discussed the preparation of a coating by a high temperature synthesis process. The coating is prepared using a number of reactants such as CrO_3, Cr_2O_3, Al and C which comprise 98% of the total material. The resulting coating consisted of mainly Cr_7C_3, Cr, Cr_3C_2 and Al as revealed by X-ray diffraction. The coating deposited by this process on a steel substrate was found to have better adhesion and abrasion resistance than the Cr_7C_3 coating prepared by the chemical vapor deposition process.

As may be seen from the above, the papers covered a broad scope and were highly informative. The editor believes that this book will be a valuable and useful reference for both the scientists and engineers. Finally, the symposium chairman gratefully acknowledges the expert contributions of authors and reviewers. He would also like to express his deep appreciation for the help and cooperation of the ASTM staff in making this STP possible.

Shyam Bahadur

Professor, Mechanical Engineering Department, Iowa State University, Ames, IA 50011; symposium chairman and editor