Selection and Use of WEAR TESTS for CERAMICS

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C. S. Yust and R. G. Bayer, editors

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Foreword

This symposium on Selection and Use of Wear Test Systems for Ceramics was presented at Cincinnati, Ohio, 13 May 1987. It was sponsored by ASTM Committee G–2 on Wear and Erosion. C. S. Yust, Oak Ridge National Laboratory, Oak Ridge, TN and R. G. Bayer, IBM Corp., Endicott, NY, served as symposium chairmen and as the editors of this publication.

Contents

Introduction

In the relatively recent past, ceramics were considered to be materials of limited technical use, principally utilized for their thermal and electrical properties. The demand for high temperature structural materials and the resultant improvement in the microstructures and mechanical properties of ceramics has led to serious consideration of these materials as machine components, particularly as wear resistant components. Consequently, wear performance data for ceramics are suddenly in demand, but relatively little reliable information is presently available to satisfy the need. Many investigators presently interested in ceramic wear studies are primarily concerned with the collection of performance data for materials selection and design, while others seek improved wear performance through an extended understanding of ceramic wear mechanisms. In either case, the investigator is often uncertain about the optimal procedures for wear testing of ceramics. This volume is intended to provide the desired information.

Wear or wear resistance is not a material property, but is best viewed as a system response. The tribo-system which governs this response is composed of the materials in contact, the environment surrounding the contact (gaseous, particulate, thermal), the type of relative motion (rolling, sliding, impact), the loading, and the geometry of the interface. These parameters affect both the mode of wear and the magnitude of the wear rate. It is not unusual to find different wear resistance rankings for the same materials in different tests. While a large number of specific wear modes can be identified, they are frequently classified roughly and broadly as adhesive, abrasive, and fatigue.

Because of these system related factors, wear testing is a complex subject and can be approached from several different aspects. ASTM Committee G2 on Wear and Erosion has addressed the field in terms of materials, sponsoring several symposia and Special Technical Publications (STP) on the subject. Prior STPs have included: *The Selection and Use of Wear Tests for Metals* (*ASTM STP 615*); *Wear Tests for Plastics: Selection and Use* (*ASTM STP 701*); and *Selection of the Wear Tests for Coatings* (*ASTM STP 769*). This current STP is the fourth in this series and is based on a symposium held May 13, 1987 in Cincinnati, Ohio on the subject of wear testing of ceramics. The majority of the papers presented at that symposium are contained in this STP.

In the first paper, "Considerations in Ceramic Friction and Wear Measurements," R. S. Gates, J. P. Yellets, D. E. Deckman, and S. M. Hsu review several of the pertinent factors which should be considered in the development of a wear test. Their discussion focuses on the testing of ceramics; however, the general theme is applicable to any material. L. Fiderer, in his paper, "Unique Friction and Wear Tester for Fundamental Tribological Research," particularizes some of these considerations in the development of a tester for high temperature applications of ceramics. G. J. Tennenhouse considers another application, tool wear, in a similar manner in his paper, "Pin-On-Disk Wear Tests for Evaluating Ceramic Cutting Tool Materials." The subject of testing of ceramics for rolling element bearing application is treated in the paper "Systematic Testing of Ceramic Rolling Bearing Elements," by L. D. Wedeven, R. A. Pallini, and C. G. Hingley. These authors emphasize the need for a hierarchy of tests for full evaluation of wear properties. W. Wei, K. Beaty, S. Vinyard, and J. Lankford in their paper, "Friction and Wear Testing of Ion Beam Modified Ceramics for High Temperature Low Heat Rejection Diesel Engines," extend this theme further and illustrate the need for using different wear tests for complete tribological evaluation and selection. Finally, M. G. Gee discusses a meeting in the United Kingdom on standardization of wear test methods for ceramics, cermets and coatings.

These papers, as well as the majority of the papers in the previous STPs on wear testing, point to the same major requirement, namely the need to effectively simulate the intended application in the wear test. This is an essential ingredient in any wear test program. However, while essential, the practice is somewhere between an art and a science. It is the editors' hope that the papers presented in this STP, in conjunction with those presented in the earlier STP volumes, can aid in this area. It is interesting to note that while these works were organized by materials, they also reflect applications. This is because the unique properties of the various material categories make them more suitable for some applications than for others.

Since the specific papers of this STP deal mainly with the specific subject of wear testing of ceramics, it is appropriate that some of the basic properties of ceramics and the relationship of those properties to their wear behavior be briefly reviewed. This will provide a basis for a better understanding of the papers which follow.

Much has been written recently about wear mechanisms in metals, and there is no need to restate that information in detail. Many of the primary mechanisms applicable to the wear of metals seem also to be applicable to ceramics. The principal distinguishing feature between the two material categories is in their response to loadings. Ceramics have a propensity for fracture. This characteristic of ceramics is also a major issue in evaluating the wear behavior of this class of materials. Several material approaches to alleviate the fracture problem in ceramics are under study, including: (a) refining of the microstructure to reduce the residual flaw content; (b) modification of the microstructure to minimize the initiation and/or propagation of fractures; and (c) designing to minimize the onset of fracture.

Despite the significant improvements being made, the question of initiation and propagation of fracture in ceramics continues to be a major consideration in the use of these materials. In wear testing, too, the role of fracture and the possibility of inducing fracture prematurely through test system design or operation remains a concern.

Consider first the inherent properties of ceramics which contribute to their reputation as fracture sensitive, "brittle" bodies. In many ceramics, strength testing at room temperature, and often at elevated temperatures, results in sudden fracture without any prior indication of failure such as the yield behavior observed in metals. One fundamental basis for this behavior is the fact that dislocations and slip systems in multi-atom ceramic lattices are more complex than in single atom metal lattices, and require higher forces for activation. The added complexity of structure also limits the number of available slip systems and may make a general shape change of the lattice of individual grains, a requirement for plastic deformation of a polycrystalline mass, impossible. [1]

An additional microstructural consideration derives from an often cited advantage of ceramics, very high melting points. This property, however, dictates the preparation of polycrystalline bodies by consolidation of powder masses, rather than by the familiar melting and casting techniques utilized for metals. The inability of ceramics to readily deform would also prohibit the use of the mechanical processing steps generally applied to metals to optimize bulk properties, even if the melting and casting of ceramics could be conveniently achieved. While other sophisticated techniques for the preparation of bulk ceramics exist, in general, powder consolidation by sintering or hot pressing is the principal means of preparation of ceramic bodies [2]. As a result, the microstructure of the body formed is very sensitive to the powder consolidation process since it is that process which determines the residual flaw content in the product. Both the inherent properties and the microstructure of the ceramic under test can contribute to the wear response.

A further aspect of wear testing which deserves special attention in the case of ceramics is that of the test geometry, in particular the initial area of contact. Although a compendium of wear test devices has been prepared which lists several hundred wear test machines, most wear test systems are some variation of about a half dozen types [3]. One of the more critical distinctions among the several types of test systems is the area of the contact surface and the constancy of the contact area, which in turn determine the magnitude and form of the stress field generated in the region of contact. The specifics of the stress field are very significant in the case of ceramics because of the possible induction of fracture by large, local tensile stress components. Consider the pin-on-disc wear test, a frequently used test arrangement. The pin tip is often prepared as a spherical surface to avoid alignment difficulties between the pin and the disc surface. The spherical tip forms a small area of initial contact, typically of the order of 100 microns in diameter in ceramics, and components of the associated Hertzian stress field can be very large in magnitude. In particular, the surface tensile stress at the edge of the contact may be made sufficiently large to initiate surface fractures [4]. Similar stress states may be generated in other test geometries. The block on ring test, for example, may begin with a flat block applied to the circular ring surface resulting in an initially linear contact with relatively large local stress values. Even in nominal flat-on-flat arrangements an initially incomplete contact of the surfaces may yield locally increased stress fields. It is evident that the stress states developed at the wear test surface in all test geometries should be carefully evaluated and the magnitude of local stresses estimated. In practice, wear under stress conditions which avoid fracture initiation will be the desired wear mode for ceramic materials. The paper by Gates et al in this volume discusses this issue and provides data on the comparison of stress effects in metals and ceramics.

The parameters of the wear test are a third category of elements to be considered in assessing the relationship between properties and the wear testing of ceramics. These parameters include the applied load, type and velocity of motion, the ambient temperature, the test atmosphere, the test duration, and the surface condition of the test specimens. The load, of course, determines stresses generated in the test bodies by acting on the test configuration, and the same considerations regarding localized stress levels apply with respect to selection of load as were cited in the discussion of test geometry. The ambient temperature, however, may modify the properties of the ceramic, making plastic deformation more possible as the temperature is increased thereby diminishing the potential for fracture [5]. As velocity increases, there will be local temperature elevations at the wear interface, especially in poorly lubricated or unlubricated surfaces [6]. Large localized temperature increases at high velocities may, however, induce fracture by thermal shock if the temperature excursions occur over very short time intervals. Test duration determines the total number of cycles of stress imposed, in test arrangements in which stress is a variable with time. Under conditions for which lattice damage can occur, the accumulation of that damage over time can lead to fracture initiation and significant wear.

As has been previously noted, the microstructure has a significant relationship to the wear response, and ideally should be dense, and free of cracks, voids, and inclusions which may serve as stress concentrators. The actual test specimens may not meet this ideal standard, but at least should be well characterized. The surface condition can also be important and special surface preparation techniques may be required for specific applications. Most ceramic surface preparation processes involve cutting and grinding and the resulting surfaces contain residual flaws, usually micropits and microfractures [7]. These micro-scale defects can serve as nucleating sites for premature fracture, consequently surface condition should also be well characterized.

Finally, a feature of wear testing which deserves more attention than it has received is the dynamic behavior of the wear test device. All dynamic mechanical systems experience some measure of vibration originating in the motion of individual system components. The point of concern for wear testing is the extent to which the vibratory motion of the system is translated into fluctuating stresses applied to the wear test interface. Each test system requires an individual analysis for active vibrational modes, and interpretation of the vibrational effects as stress effects on the test. The problem is complicated by the fact that some of the vibrational content may originate at the test interface, especially in the case of unlubricated motion. Only limited efforts have been made to date to incorporate such analyses into wear testing procedures and to analyze the resultant stress effects on the wear process. Because subtle stress effects may be of consequence for fracture propagation in ceramics, the evaluation of system dynamic effects is a challenge which remains to be met in ceramic wear testing.

The papers in this STP discuss wear testing for several varied applications. The intent is to show current practice and the devices used in different applications areas. Many of the points introduced in these opening comments are considered in detail in the following pages, and these remarks are only intended to stimulate further reading of this volume. Significant progress has been made in development of wear testing of ceramics, but many avenues for improvement remain to be explored.

C. S. Yust
Metals and Ceramics Div.,
Oak Ridge National Laboratory,
Oak Ridge, TN 37831;
Symposium chairman and co-editor

R. G. Bayer
IBM Corp., Endicott, NY 13760;
Symposium co-chairman and
co-editor

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