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Abrasive Wear		

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Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

- 1. Scope**—An enormous economic loss, as well as a waste of natural resources, is incurred world-wide as a result of wear of components and tools. Any effort expended in an attempt to reduce this loss is indeed worthwhile. The purpose of this SAE Information Report is to present the current state of knowledge of abrasive wear. This report, therefore, covers wear, or the undesired removal of metal by mechanical action, caused by abrasive particles in contact with the surface. It does not concern metal-to-metal wear or wear in the presence of an abrasive free lubricant.

Abrasive wear occurs when hard particles, such as rocks, sand, or fragments of certain hard metals, slide or roll under pressure across a surface. This action tends to cut grooves across the metal surface, much like a cutting tool.

Abrasive wear is of considerable importance in any part moving in relation to an abrasive. Tools in contact with the ground, such as plows, cultivators, scraper and bulldozer blades, are intended to operate in abrasives. Machines for processing ores such as crushers and for grinding of natural minerals such as ball mills are also subjected to abrasive wear. Contact with abrasives by many other machinery components may not be a normal circumstance, but, since it may inadvertently occur, must be considered.

Increased hardness usually increases wear resistance but also increases brittleness, which can cause fracture of the tool in rocky soils. Thus, the selection of a suitable material for use in a variety of abrasive conditions is necessarily a compromise between wear and brittle fracture resistance.

This report presents present day information on the fundamentals, testing methods and specific solutions for abrasive wear problems. The limited information reflects the current lack of knowledge on this subject. However, it is a starting point. Further work is necessary to develop general design information.

Abrasive Wear—The removal of material from a surface by mechanical action of abrasive (hard) particles in contact with the surface.

Classifications—The following are arbitrary classifications of abrasive wear based on observed conditions(1):¹

1. Numbers in parentheses designate References—see Section 2.1, Applicable Publications.

Gouging Abrasion—The result of this type of abrasive wear is the removal of large particles from a metal surface. Worn surfaces show heavy gouges.

High Stress Grinding Abrasion—This type of abrasive wear occurs during the progressive fragmentation or grinding of the abrasive which was initially of small size and takes place on the surfaces employed to grind the abrasive. The wear is believed to be caused by concentrated compressive stress at the point of abrasive contact and to result from plastic flowing and fatiguing of ductile constituents and cracking of hard constituents of the metal surface. The use of the words "high stress" in this classification is intended to imply that the crushing strength of the abrasive is exceeded.

Low Stress Scratching Abrasion or Erosion—The result of this type of abrasive wear is scratching of the metal surface, and the scratches are usually minute. The stress imposed on the abrasive particle does not exceed the crushing strength of the abrasive.

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3. **Fundamentals of Abrasive Wear Phenomena**—The action of a hard particle on a surface under the influence of a force which is oblique to the surface is generally referred to as abrasive wear. The interaction between the particle (of high crushing strength), and the surface is very much like the interaction between a cutting tool and a work-piece in machining. In the case of a ductile material, a continuous particle is removed from the surface by each cutting abrasive particle. In the case of a brittle material, many particles are removed during a single encounter by an abrasive particle. The parameters, which are important in metal cutting, should also be important in abrasive wear. However, as in machine shop grinding, it is difficult to state precisely the geometry of the cutting faces of the abrasive particle due to their random shape. This is a statistics problem.

Abrasive wear differs from adhesive wear (2, 3, 4) which occurs between two surfaces. In adhesive wear, the contacting asperities on adjacent surfaces weld, and the resulting interaction can lead to the removal of material from the surfaces. However, in the case of abrasive wear, material is removed from the surfaces, as indicated above, by the cutting action of abrasive particles. The hardness of the abrasive particle must exceed that of the abraded surface in order for cutting to occur. In the case when the crushing strength of the abrasive is exceeded, the method of material removal may be somewhat different than by the simple cutting action.

- 3.1 **Mechanisms of Abrasive Wear**—The force component which is normal to the surface and is acting on the hard particle causes penetration of the surface by the particle. That force component which is parallel to the surface causes relative tangential motion to occur between the particle and the surface. This results in shearing, plowing, or chipping of the surface which leaves the surface grooved. For ductile surfaces and hard particles which have sharp edged faces shearing occurs. This shearing is in the form of a continuous metal-cutting-like chip which removes material from the surface. Particles which have smooth edged or rounded faces tend to merely plow a ductile surface. During plowing, the surface material is pushed transversely to the direction of the particle motion to form a groove. Most of the displaced material piles up along the groove edges rather than being removed from the surface. In the case of a brittle material, the groove is formed by crack propagation and subsequent chipping out of surface material.

The severity of the wear by this mechanism for a given material and abrasive will greatly depend on the magnitude of the acting forces. When the forces are low (low stress), the wear rate per abrasive particle will also be low. In this case, this mechanism is sometimes referred to as scratching when fixed particles or loose particles are involved. In the machine shop, this type of abrasion is referred to as polishing. It is referred to as erosion when flowing loose particles are attacking a single surface. During erosion, the overall wear rate can be high if the flow rate of the abrasive particles is high. When the magnitude of the acting forces is higher, the wear rate per abrasive particle will be higher, and the mechanism is referred to as gouging when either fixed particles or loose particles are involved. When loose particles are present between two sliding surfaces (entrapped loose particles), this type of abrasion is referred to as lapping in the machine shop. This lapping or three body loose particle wear is less efficient than two body fixed particle wear because the loose particles tend to roll without cutting about 90% of the time (5). If the stress applied to the abrasive is so high as to exceed its crushing strength, then this type of abrasion is referred to as grinding abrasion. Here the abrasive is being ground up and was initially of a small size. This high stress grinding abrasion should not be confused with machine shop grinding which is classified as gouging abrasion.

When crushing of the abrasive occurs as in grinding abrasion, the mechanism of material removal may be somewhat different from the simple cutting mechanism. The abrasive may have little opportunity to roll or cut before crushing occurs, and the major effect on the abraded surface would then be due to the concentrated compressive stress at the point of abrasive contact. For a surface of ductile material, the surface will be displaced plastically by the abrasive in the manner of an indentation hardness impression. With many closely spaced impressions, the displaced material may flow back and forth, to fail eventually by fatigue. There is also the possibility of some cutting action by the rupturing abrasive with the cutting force being supplied by the elastic energy stored in the compressed abrasive particle. For a surface of a hard material, little plastic displacement will occur. Wear in this situation may occur as a result of brittle cracking (chipping) of the surface material. There is also the possibility of subsurface cracking due to fatigue under repeated stressing, as occurs in the spalling of ball bearing races.

3.2 Analytical Approaches to Abrasive Wear—The same underlying ideas are involved in all types of abrasive wear, except perhaps when the abrasive particle is crushed. Penetration of the surface and subsequent grooving of the surface by the abrasive particle occurs. When the abrasive is crushed, grooving of the surface may not occur, however penetration of the surface does occur. The appearance of the wear fragments and wear surface will vary depending on the ductility of the surface material and on the configuration of the particle.

The means by which the force is applied to the abrasive particle can be divided into two categories:

1. The direct mechanical application of force by the surfaces in the case of entrapped loose particles or by the abrasive bond and the surface in the case of fixed abrasives.
2. The kinetic application of force resulting from the kinetic energy of a flowing abrasive particle as it encounters a surface.

The first category of force application is experienced in gouging abrasion, grinding abrasion and scratching abrasion. The second category is experienced in erosion abrasion, and pertains to the handling of the abrasives in pneumatic or liquid systems, sand blasting or dust erosion of compressor blades in gas turbines. The second category of force application is probably not as common as the first. However, it will be considered here, since a fair amount of analytical work has been carried out for this case. There is a distinctly different analytical expression for abrasive wear for each category of force application. These analytical expressions will now be discussed.

3.2.1 THEORY OF ABRASIVE WEAR WITH DIRECT MECHANICAL APPLICATION OF FORCE TO ABRASIVE PARTICLE—A number of authors have investigated this type of wear (5–12). There is general agreement among authors that simplified theory results in the following expression for volume wear rate per unit length of sliding (q):

$$q = \frac{dQ}{d\ell} \propto \frac{W}{p} \quad (\text{Eq. 1})$$