

Mechanical Wear Fundamentals and Testing

Second Edition, Revised and Expanded

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Terminology and Classifications

1.1. WEAR, FRICTION, AND LUBRICATION

A number of different definitions, which have varying degrees of completeness, rigor, and formalism, can be found for wear (1–6). However, for engineering purposes, the following definition is adequate and contains the essential elements. Wear is progressive damage to a surface caused by relative motion with respect to another substance. It is significant to consider what is implied and excluded by this. One key point is that wear is damage and it is not limited to loss of material from a surface. However, loss of material is definitely one way in which a part can experience wear. Another way included in this definition is by movement of material without loss of mass. An example of this would be the change in the geometry or dimension of a part as the result of plastic deformation, such as from repeated hammering. There is also a third mode implied, which is damage to a surface that does not result in mass loss or in dimensional changes. An example of this might be the development of a network of cracks in a surface. This type of damage might be of significance in applications where maintaining optical transparency is a prime engineering concern. Lens and aircraft windows are examples where this is an appropriate definition for wear. As will be shown in subsequent sections, the significant point is that wear is not simply limited to loss of material, which is often implied in some, particularly older, definitions of wear. While wear is not limited to loss of material, wear damage, if allowed to progress without limit, will result in material loss. The newer and more inclusive definitions of wear are very natural to the design or device engineer, who thinks of wear in terms of a progressive change to a part that adversely affects its performance. The focus is on adverse change, which simply may be translated as damage, not necessarily loss of material. The implications of this generalization will be further explored in the discussion of wear measures.

Older definitions of wear and application oriented definitions often define wear in terms of limited contact situations, such as sliding or rolling contact between solid bodies. However, the definition of wear given does not have such limitations. It includes contact situations involving sliding, rolling, and impact between solid bodies, as well as contact situations between a solid surface and a moving fluid or a stream of liquid or solid particles. The wear in these latter situations is normally referred to as some form of erosion, such as cavitation, slurry, or solid particle erosion.

At least in the context of engineering application and design, these considerations essentially indicate what wear is. A brief consideration as to what it is not is of importance

as well. Engineers, designers, and the users frequently use the phrase “it’s worn out.” Basically, this means that as a result of use, it no longer works the way it should or it is broken. In this context, the part or device may no longer function because it has experienced severe corrosion or because a part is broken into two pieces. In terms of the definitions for wear, these two failures would not be considered wear failures nor would the two mechanisms, that is, corrosion and fracture, be considered wear. Corrosion is not a form of wear because it is not caused by relative motion. Brittle and fatigue fracture in the sense referred to above are not considered forms of wear because they are more a body phenomenon rather than a surface phenomenon and relative motion and contact are not required for these mechanisms to occur.

While corrosion and fracture, per se, are not forms of wear, corrosion and fracture phenomena are definitely elements in wear. This is because in a wearing situation, there can be corrosive and fracture elements contributing to the damage that results from the relative motion. An illustration of this point is sliding, rolling, and impact situations in which material is lost as a result of the formation and propagation of cracks near the surface. In such situations, fatigue and brittle fracture mechanisms are generally involved in the wear. In addition to be involved in the wear, corrosion and fracture, per se, can be influenced by wear. An example of wear being a factor in fracture of a part is a situation where the wear scar might act as a stress concentration location to initiate fracture or where fracture results from the propagation of a crack formed in the wearing process. An example of a situation where both types of relationships can occur is wear situations involving the pumping of slurries. In such situations, wear behavior involves both chemical and mechanical factors and the severity of the corrosion can be influenced by the wear. These interactions and involvement of fracture and corrosion phenomena in wear will be further discussed and illustrated in subsequent chapters.

While illustrated by corrosion and fracture, the important point is that all failures of devices or life-limiting aspects associated with use or exposure are not the result of wear and wear processes. To be considered wear failures, there generally has to be some surface, mechanical, and relative motion aspects involved. However, as will be shown, wear mechanisms involve a very large number of physical and chemical phenomena including those involved in fracture and corrosion.

In view of these considerations, another way of defining wear for engineering use is that wear is damage to a surface resulting from mechanical interaction with another surface, body or fluid, which moves relative to it. Generally, the concern with wear is that ultimately this damage will become so large that it will interfere with the proper functioning of the device. While not the subject of this book, it is interesting to note that machining and polishing are forms of wear. As such, there is a positive side to wear and wear phenomena.

In situations involving sliding or rolling contact, a companion term with wear is friction. Friction is the force that occurs at the interface between two contacting bodies and opposes relative motion between those bodies. It is tangential to the interface and its direction is opposite to the motion or the incipient motion. Generally, the magnitude of the friction force is described in terms of a coefficient of friction, μ , which is the ratio of the friction force, F , to the normal force, N , pressing the two bodies together

$$\mu = \frac{F}{N} \quad (1.1)$$

Distinction is frequently made between the friction force that must be overcome to initiate sliding and that which must be overcome to maintain a constant relative speed.

The coefficient associated with the former is usually designated the static coefficient of friction, μ_s , and the latter the dynamic or kinetic coefficient of friction, μ_k . A frequently encountered impression is that the two terms, wear and friction, are almost synonymous in the sense that high friction equates to a high wear rate or poor wear behavior. The complimentary point of view is that low friction equates to a low wear rate or good wear behavior. As a generality, this is an erroneous concept. While there are common elements in wear and friction phenomena, as well as interrelationships between the two, that simple type of correlation is frequently violated. This point will become clear as the mechanisms for wear and friction, as well as design relationships, are presented and discussed. However, the point can be illustrated by the following observation. Teflon is noted for its ability to provide a low coefficient of friction at a sliding interface, for example, a dry steel/Teflon system typically has a value of $\mu \leq 0.1$. However, the wear of the system is generally higher than can be achieved with a lubricated hardened steel pair, where $\mu \approx 0.2$.

Another element that can be considered in differentiating between friction and wear is energy dissipation. Friction is associated with the total energy loss in a sliding system. The principal form of that energy loss is heat, which accounts for almost all of the energy loss (7–9). The energy associated with the movement or damage of the material at the surface, which is wear, is normally negligibly small in comparison to the heat energy.

Often in rolling situations, an additional term, related to friction, is used. This is traction. Traction is defined as a physical process in which a tangential force is transmitted across the interface between two bodies through dry friction or an intervening fluid film, resulting in motion, stoppage, or the transmission of power. The ratio of the tangential force transmitted, T , and the normal force, N , is called the coefficient of traction, μ_T

$$\mu_T = T/N \quad (1.2)$$

The coefficient of traction is equal to or less than the coefficient of friction. In rolling situations, the amount of traction occurring can often be a significant factor in wear behavior. In sliding situations, the coefficient of traction equals the coefficient of friction.

There are two other terms, lubrication and lubricant, which are related to friction and wear behavior and that need to be defined. One is lubrication. Lubrication may be defined as any technique for: (a) lowering friction, (b) lowering wear, or (c) lowering both. A lubricant is a material that, when introduced to the interface, performs one of those functions. Understood in this manner, any substance, solid, liquid, or gas, may be a lubricant; lubricants are not just liquid petroleum-based materials. It should be recognized that some materials may act as a friction reducer and a wear riser in some situations, as well as the converse. Different types of lubrication and lubricants are discussed in later sections and reasons for this apparent anomaly are pointed out. This is also a further illustration of the distinction between friction and wear.

1.2. WEAR CLASSIFICATIONS

There are three apparent ways in which wear may be classified. One is in terms of the appearance of the wear scar. A second way is in terms of the physical mechanism that removes the material or causes the damage. The third is in terms of the conditions surrounding the wear situation. Examples of terms in the first category are pitted, spalled, scratched, polished, crazed, fretted, gouged, and scuffed. Terms like adhesion, abrasion, delamination, oxidative are examples of the second type of classification. Phrases are

commonly used for the third method of classification. Examples of this are lubricated wear, unlubricated wear, metal-to-metal sliding wear, rolling wear, high stress sliding wear, and high temperature metallic wear. All three methods of classification are useful to the engineer but in different ways. Classification in terms of appearance aids in the comparison of one wear situation with another. In this manner, it helps the engineer extrapolate experience gained in one wear situation to a newer one. It also aids in recognizing changes in the wear situation, such as differences in the wear situation at different locations on a part or at different portions of the operation cycle of a device. It is reasonable that if the wear looks different, different ways of controlling it or predicting it are required; if similar in appearance, the approaches used should also be similar.

Some of these aspects can be illustrated by considering the wear of gears. Scuffing is a term used to characterize the appearance of a wear scar produced as a result of sliding with poor or no lubrication in metal-to-metal systems. With gears, different portions of the tooth experience different types of relative motion. If designed and fabricated properly, near the pitch line it should be pure rolling. As you move further out, sliding occurs. If scuffing features are observed at the pitch line, it can be inferred that sliding is occurring, pointing to a possible contour or alignment problem. In a lubricated situation, there may be little evidence of wear near the tip. However, if evidence of scuffing wear is found to occur with time or with different operating conditions, it suggests a possible lubrication problem. Increased scuffing in such a case could be the result of lubricant degradation or loss, or the use of the wrong lubricant for the different condition. These observations would guide engineering action to resolve the problems.

The usefulness of classification by physical mechanism would be in guiding the engineer in using the correct models to project or predict wear life and to identify the significance of design parameters that can be controlled or modified. Given that the mechanism for wear is known, the engineer can then identify the dependency of such parameters as load, geometry, speed, and environment.

From a designer's viewpoint, the third type of classification is the most desirable and potentially the most useful. It describes a wear situation in terms of the macroscopic conditions that are dealt with in design. The implication is that given such a description, a very specific set of design rules, recommendations, equations, etc., can be identified and used.

While wear is generally described in terms of these three classifications, there is no uniform system in place at the present time. In addition, the same term might be used in the context of more than one classification concept. For example, the term scuffing is used in several ways. One author may use this term simply to describe the physical appearance. Another author may use this term to indicate that the wear mechanism is adhesive wear. A third may use it to indicate wear under sliding conditions. This leads to another point that needs to be recognized with respect to these classifications.

While relationships exist between these classifications, the classifications are not equivalent nor are the interrelationships necessarily simple, direct, unique, or complete. A common error is to assume that a category in one is uniquely associated with ones in the other two, such as unlubricated metal-to-metal sliding is always associated with a scuffing appearance and adhesive wear. Basically, this is because there are numerous ways by which materials can wear and the way it wears is influenced by a wide number of factors. With the present state of knowledge within tribology, complete correlation between operating conditions, wear mechanisms, and appearance generally are not possible, particularly in relationship to practical engineering situations. Because of the complex nature of wear behavior, it has even been argued that it may never be possible or even practical to establish complete relations of this type (10,11). While this is the

case, analytical relationships of more limited scope can be used effectively in engineering (12,13).

All three of types of classifications are used in this book, since individually they are of use to the designer and any one classification method is not sufficient to provide an adequate description in engineering situations.

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