PART 3 – WEAR (continued)

Predicting and analysing wear

Efforts in these directions are showing some success. Archard’s equation (7) is a basic technique that is used quite often for predicting and analysing wear – but applies only to bearings, gears, and other sliding systems, and not to rolling systems.

\[ V = KWL / H \]

Where

\[ V = \text{Volume of wear, cubic inches} \]
\[ W = \text{normal load, pounds} \]
\[ L = \text{sliding distance, feet} \]
\[ H = \text{penetration hardness of the softer material in the pair, psi} \]
\[ K = \text{wear coefficient} \]

The equation predicts that wear is a linear function of sliding distance and load, which agrees with general experience. It enables the hardness characteristics of materials in one system to be compared to those in a control system. Instead of having to run a test system for a given time in order to determine the wear rate, designers and failure analysts can apply data from empirical studies on the control system to the equation.

For example, if several types of materials were being considered for use in a bearing, each type could be evaluated on a standard wear tester to determine a wear coefficient. The wear coefficient is then useful for estimating service life under a given loading and amount of sliding. The degree of tolerable wear must be determined; and from there, predictions on component service life can be made, using Archard’s equation.

The equation, however, has many limitations. For example, it does not account for material properties other than hardness and does not predict phenomena such as initial rapid wear during “wear-in”, and the dramatic increase in wear rate with a relatively small increase in load. Also, it does not account for the effect of speed, lubrication, or contact pressure* on sliding systems.

In addition, hardness is not a universal criterion for wear rate. When a metal is work hardened, for example, the improvement in wear is negligible. Hardening steel by heat treatment, e.g., by induction heating, flame hardening, or laser treatment – improves wear resistance, but not as significantly as changing to another material, such as chromium plating or tungsten carbide.

An example of where a harder material has replaced a softer material: the heavily loaded bearings supporting the control surfaces of aircraft. Bearings for the flaps, tail section, and some linkages in the airframe are now being constructed of beryllium copper, which is not only harder, but also more corrosion-resistant than are traditional aluminium bronze bearings.

*Some standardized contact pressure data have been compiled in the ASME Wear Control Handbook, 1980.
Frictional heating, or heat from other sources, can change the hardness of a sliding surface with unpredictable wear results. Thus, using wear coefficients obtained by wear tests or from handbooks can cause misleading results unless the limitations of Archard’s Equation are recognised.

But, even with these limitations, the formula is useful if the other influencing effects are recognised, and if experimentally derived data are judiciously applied to compensate for limitations.

![Wear Rate vs Hardness Graph](image)

*Fig: 1 – Effect of hardness on wear resistance of various metals and alloys.*

**Type of wear**

Wear is often difficult to classify; yet identifying the type of wear that is occurring is a key factor in wear control. A great deal of experience is generally required to analyse surface topography created by wear, and to determine if wear is being produced by a chance encounter or by recurring contact.

Several recognised types of wear can be found in machinery:

- abrasive wear
- adhesive wear
- erosion
- fretting
- contact fatigue
- corrosive wear

Those that **can** be described by Archard’s equation are abrasive and adhesive wear; and those that **cannot** are erosion, fretting, contact fatigue, and corrosive wear. Each type has a different mechanism, cause and effect.

Once the type of wear has been identified, and the cause pinpointed, control methods can then be implemented. These methods can involve:

- lubrication technology
- materials substitution
- load reduction
- removal of impact conditions
Abrasive wear

In machinery, wear occurs most frequently as an abrasive process. We have pointed out that contacting surfaces really touch at only a few high points – there are no atomically flat engineering surfaces! The high contact stresses developed at these small contact areas cause localised plastic deformation. However, since the surfaces are moving tangentially, this deformation results in microscopic grooves. The movement of the asperity over the opposing surface resembles the action of a blunt tool with a negative rake angle trying to cut a surface. In fact, abrasive wear is much like material removal by grinding. The scratch pattern produced by abrasive wear is shown in Fig. 2. Abrasive wear can be caused by hard particles caught between sliding surfaces or by dragging metal parts over soil, concrete, or other rough areas. In cases such as these, and especially if the abrasive particles are sharp, an occasional particle will become lodged so that it cuts the surface much like a sharp tool. The result is curled, chip like wear debris.

Referring again to our mining industry example, we can picture a dragline bucket being worn by sliding contact as it is pulled through soil and rocks. When abrasion is severe enough to scrape holes through the bucket, field repair often requires welding plates over worn areas.

Abrasive wear also occurs under lubricated conditions – especially during boundary lubrication.

Adhesive wear

Adhesive wear entails metal transfer, which, to some extent, is a part of all wear. Even under lubricated conditions, metal transfer is possible on a very limited scale. Minor adhesive wear can be seen, for example, as a slight discoloration of a shaft that runs in a bronze journal bearing.

*Fig. 2 - Photomicrograph of surface features caused by abrasive wear
Where metal transfers from one sliding surface to another in visible lumps, adhesive wear predominates. An example of adhesive wear is shown below (fig 3.)*

*Fig. 3 - Photomicrograph of scar from adhesive wear.*
Metal transfer in adhesive wear does not occur as chunks plucked out of one surface and attached to the other during cold welding. Rather, it most often occurs as a build-up or agglomeration of small particles released from one surface and transferred to the other surface in layers. The built-up edge on a cutting tool is an example of adhesive wear.

Under lubricated conditions, interruption of the lubricant film causing metal-to-metal contact can produce metal transfer, adhesion, and surface damage. Piston ring scuffing is an example of adhesive wear during lubrication. The metal transfer that results causes deep scratching and surface damage, leading to loss of compression. Aluminium in the pistons is particularly sensitive to this process because it resists the formation of effective boundary lubrication films.

**Polymers**

In some applications, polymeric materials can be used in place of metals. For example, they are being used increasingly as piston rings in dry gas compressors where metal particle contamination cannot be tolerated. Any number of low speed, low load devices are also using polymer gears, bearings and sliding surfaces. Polymers are also appearing in medical applications where stainless steel sockets for hip joint prostheses are now being replaced by ultra-high density polyethylene.

Polymers offer a number of advantages over metals. For example, they generally cost less to produce, weigh less, resist corrosion, and distribute the load – thus resisting wear more effectively than metals because they have better elastic deformation properties under contact pressure.

On the other hand, adhesive wear is usually more prevalent in polymers than in lubricated metal systems. Also, polymeric materials have limited load-bearing capacity; and their low thermal conductivity and elastic modulus causes them to over-heat and deform. These limitations thus tend to restrict their use – for the time being – to lighter weight, more controlled applications. However, the wear resistance and strength of polymers can be enhanced by adding ceramic or graphite fibres as reinforcements. In fact, composites of polymers, metal fibres and minerals are now being used to fabricate such components as brakes.

**Erosion**

Erosive wear results from particle impingement or cavitation shocks against a surface, but not from the trapping of loose particles between sliding contact surfaces. Wear of a dragline bucket pulled through gravel is abrasive; but wear of an impeller moving through a slurry is erosive.

There are three types of erosion – recognition of each is important for determining appropriate erosion control:

- **Solid particle erosion** – surface wear by impingement of particles carried by a gas or fluid. *Example:* wear of helicopter blade leading edges in dusty environments.
- **Liquid drop erosion** – surface wear by impingement of liquid drops.
  Example: wear of centrifugal gas compressor blades by condensate droplets.
- **Cavitation erosion** – surface wear in a flowing liquid by the generation and implosive collapse of gas bubbles.
  *Examples:* Cavitation erosion of a ship’s propellers, and of components in fluid pumps.

Erosion is particularly insidious because it tends to concentrate its effect, and can cause damage quickly with little warning – *i.e.* a hole punched through the elbow of a pipe carrying a slurry or gas suspension of particles.

Erosion is difficult to predict, and therefore, difficult to control. Because it is not as pervasive as abrasion, and more confined to specific situations, it has not received the amount of scientific enquiry as has abrasive wear. Since fewer studies have been undertaken to identify erosion causes and control methods, less general application experience is available to draw on.
However, limited testing of material hardness has been conducted. Results reveal that when steels of various hardness levels are tested in an erosion tester using silica as an eroder, their wear rate is not influenced by their hardness. A comparison of the effects of hardness on erosion (Fig. 4) with the effects of hardness on other types of wear (Fig 1) illustrates the difference in material behaviour.

Fig. 4 – Effect of steel hardness on erosion rate. Eroding medium: Sand

Thus, the traditional methods of hardening materials by heat treatment or by adding hard particles to the microstructure also do not affect erosion resistance. On the contrary, the more homogeneous a material is, the better the erosion resistance.

The angle at which particles approach a surface is also important for wear control since there is a “critical impingement angle” at which the maximum erosion rate occurs. In addition, the critical angle changes with velocity for some materials making prediction of erosion severity difficult.

Though particle size and velocity will influence erosion rates, materials show varying sensitivity to these parameters. For example, ductile materials have a different critical impingement angle from brittle materials.

When corrosive conditions are present, a combined erosion-corrosion wear process will occur. In this case, the protective surface reaction products from corrosion are removed by erosion, thereby accelerating both processes and producing a very rapid material loss. This condition creates severe problems that are particularly evident in coal gasification and liquefaction plants. The critical problems arising here have added further incentive for developing more refined erosion control strategies. Work in erosion control is progressing, much of it directed toward identifying materials that will effectively withstand erosive environments.

References

Fig. 5 – Erosion ripple pattern caused by sand impinging at a low angle on a rod from a sandblasting unit.