Myth Buster Series: 1st of 4

Wear and hardness - does a harder surface actually give better wear resistance?

In the engineering industry, many components' surfaces are subjected to progressive deterioration caused either by wear or corrosion, which ultimately leads to the loss of plant operating efficiency and, at worst, equipment breakdown.

Wear is defined as the progressive loss of material from the operating surface of the component, occurring as a result of the surface rubbing against some other component. This includes any metal-to-metal, metal-to-solids and metal-to-fluid contact associated with the surfaces of components. The wear rate of a surface is determined by, but not limited to, factors such as load, velocity, temperature, materials, lubricant, etc. Through the proper selection of metals and/or surface treatments for specific wear applications, one can design a suitable wear solution for a specific type of material operating in that specific wear application.

It is known that due to their relatively low hardness, plain carbon steels generally exhibit poor resistance to wear and surface damage, but generally have very good toughness and ductility. By selecting an appropriate surface treatment(s) to increase the wear resistance of the surface of plain carbon steels, one can create a "composite material" that will lead to a wear-resistant surface without sacrificing the tough, ductile inner core. However, selecting the appropriate surface treatment is not at all simple. Careful consideration of the material, especially the hardness, tensile strength and toughness requirements, and the dominant wear mechanism(s) in the environment, should be considered. In order to convey the whole picture, this article will take the reader through the different wear mechanisms that can be encountered, and will discuss the role hardness plays in the wear of materials.

Hardness is the resistance of a material to plastic deformation, thus, the more difficult it is for a material to plastically deform while placed under load, the higher the hardness of that

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material will be. Hardness is directly related to the ultimate tensile strength of a material, but inversely related to the toughness and ductility of that material.

The bulk hardness of metals is frequently used as a guideline to the abrasive wear- resistance for the metals. In this case, abrasive wear-resistance is seen to increase along with the increase in hardness, as shown in Figure 1.

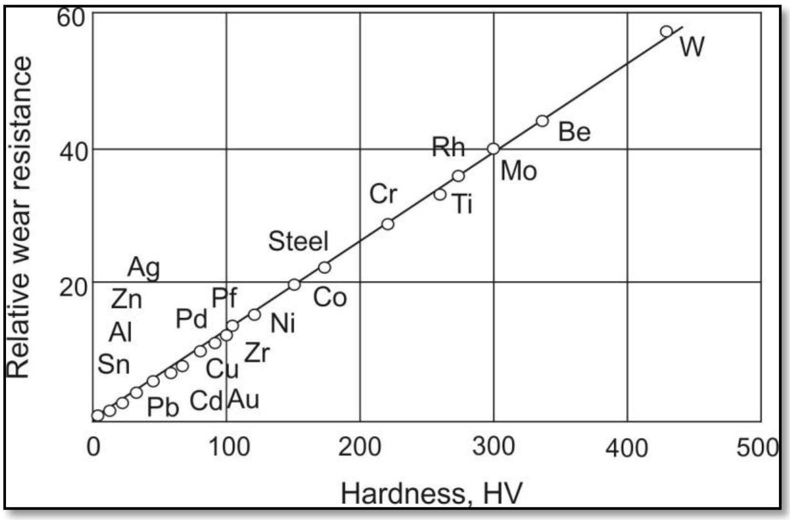

Figure1: Abrasive wear resistance as a function of hardness for annealed un-alloyed metals and steel.

Care should be exercised in extending the sample hardness correlation above to metals containing impurities or solutes, or to more complicated alloys. When considering different classes of materials the hardness versus wear-resistance will follow a trend similar to Figure 2.

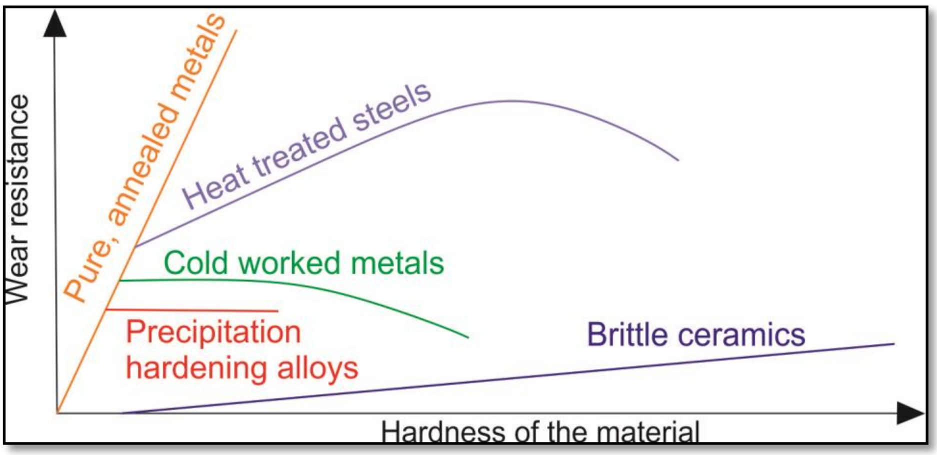

Figure 2: Wear resistance as a function of hardness for several classes of material.

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It is shown that for typical precipitation hardenable alloys, large increases in hardness do not necessarily provide equivalent increases in wear-resistance. The same trend can also be seen for cold-worked metals.

Generally, more than one wear mechanism can be encountered in a system. The dominance of one mechanism can be overridden by another. The result of one wear mechanism can also lead to the initiation of another wear mechanism. These factors combine to make wear a complex subject. In order to understand the role hardness plays in wear, it is important to consider the different wear mechanisms that can dominate an environment. The major wear mechanisms are:

1. Adhesive wear:

This type of wear is synonymous with galling, fretting, scuffing or surface fatigue, and is described as the interaction and adhesion between surface irregularities.

It is shown in Figure 3 that if the strength of the adhesion junction is more than that of either one of the materials, material transfer and the production of wear particles will occur. The interaction between the materials is complex due to high strain rates and temperatures being generated.

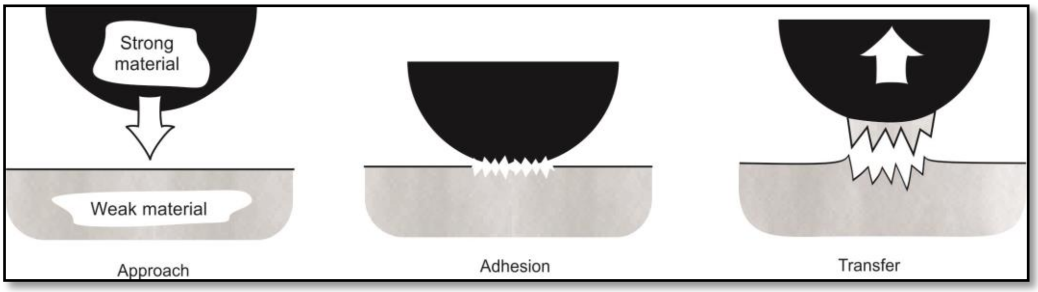

Figure 3: Schematic illustration of adhesive wear.

Adhesion in metals can be classified as mild or severe. Mild adhesion includes visible oxidation, wear of non-metallic debris, and low loads and velocities. Severe adhesion is characterized by damage to the oxide film so that there is direct interaction of the metal with the environment, larger wear particles, and higher loads and velocities.

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Adhesive wear generally occurs when inadequate lubrication leads to metal transfer.

Adhesive wear thus occurs due to the differences in hardness of the two interacting surfaces. In order to design for adhesive wear-resistance, dissimilar materials that are tribologically compatible will have to be considered, for instance:

- Soft bearing coatings allow for the embedding of abrasive particles and the deformation of bearing surface alignment - adequate lubrication is required. Typically one would apply an arc sprayed aluminium bronze coating for this purpose.
- Hard bearing coatings are highly resistant to adhesive wear and are used where embeddability, self-alignment and lubrication are not requirements. Plasma-sprayed molybdenum or Ni-Cr-B-Si blend coatings are typically applied for this purpose.

2. Abrasive wear:

This type of wear is also termed gouging, cutting or ploughing. It describes the process of hard particles or asperities ploughing or cutting through a softer body, leading to debris formation. Abrasive wear is either 2-body (particles constrained) or 3-body (particles not constrained), and any debris produced may be harder than the original material, contributing to the 3-body wear (Figure 4).

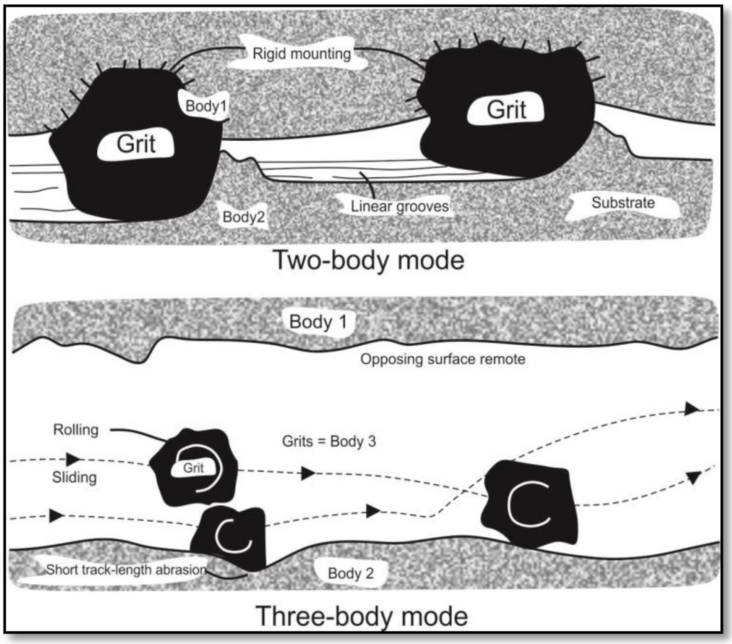

Figure 4: Schematic illustration of 2-body (top) and 3-body (bottom) abrasive wear.

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The important factors that should be considered when dealing with abrasive wear are:

- The relative hardness – this is the abrasive hardness / material hardness
- Size of the particles
- Angularity of the particles
- Load

Generally more than one wear mechanism can be encountered in a system. The dominance of one mechanism can be taken over by other wear mechanisms, and the products of one mechanism can lead to the initiation of another mechanism. These factors combine to make wear a complex subject.

The coating selection for this wear mechanism is based on the operating temperature and surface finish requirements. One would typically use the plasma and HVOF processes to apply a chrome oxide, chrome carbide or tungsten carbide coating.

3. Erosive wear:

Erosion is defined in the ASM Handbook of Thermal Spray Technology as damage to a surface when a gas or liquid, ordinarily carrying entrained particles, impacts on that surface with velocity. In other words, erosion has magnitude (the particles impacting on the surface) and velocity, with the particles impacting on the surface at different angles (angle of impingement).

If the angle of impingement is relatively small, the wear-producing mechanism closely resembles abrasion. When the angle of impingement is normal to the surface, material is displaced by plastic deformation, or dislodged by brittle failure. The effect of the angle of impingement is shown in Figure 5.

Figure 5 follows on next page/…

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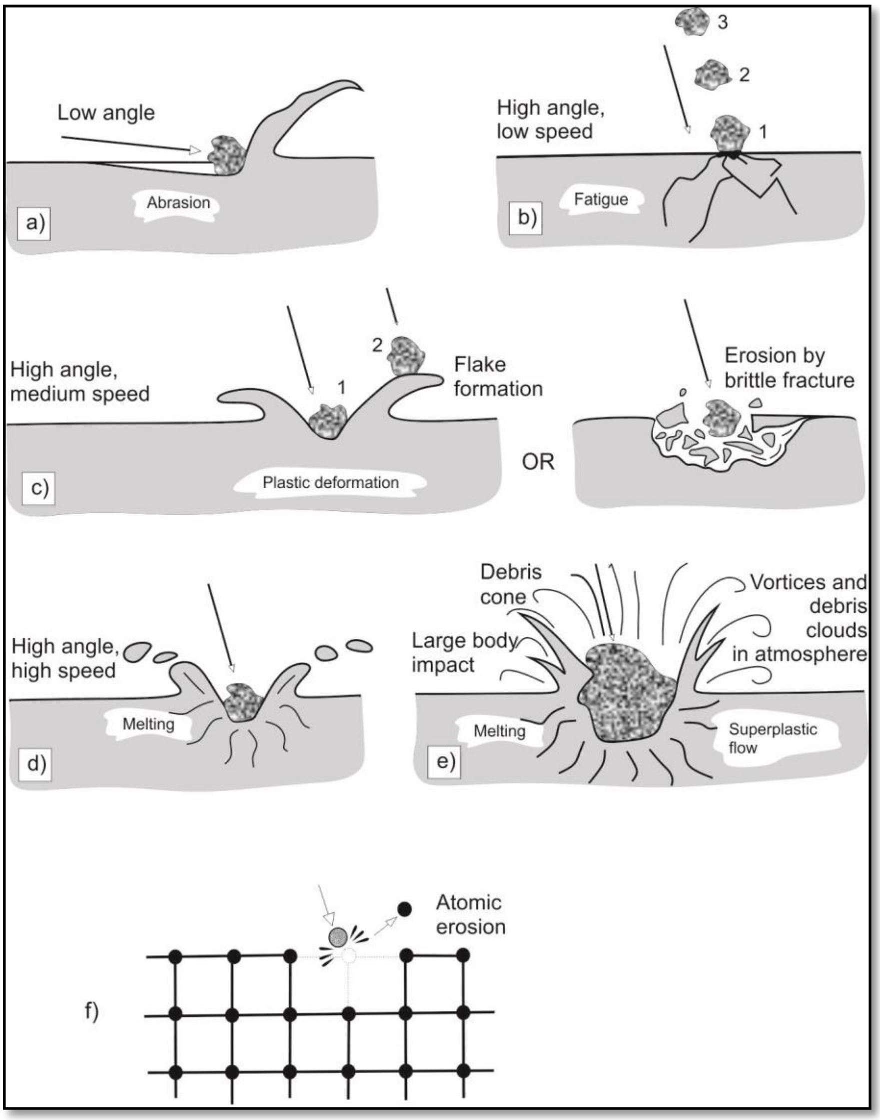

a) abrasion at low impact angles

b) surface fatigue during low speed, high impingement angle impact

c) brittle fracture or multiple deformation during medium speed, large impingement angle impact

d) surface melting at high impact speeds

e) macroscopic erosion with secondary effects

f) crystal lattice degradation from impact by atoms

Figure 5: Schematic illustration of the different types of erosive wear.

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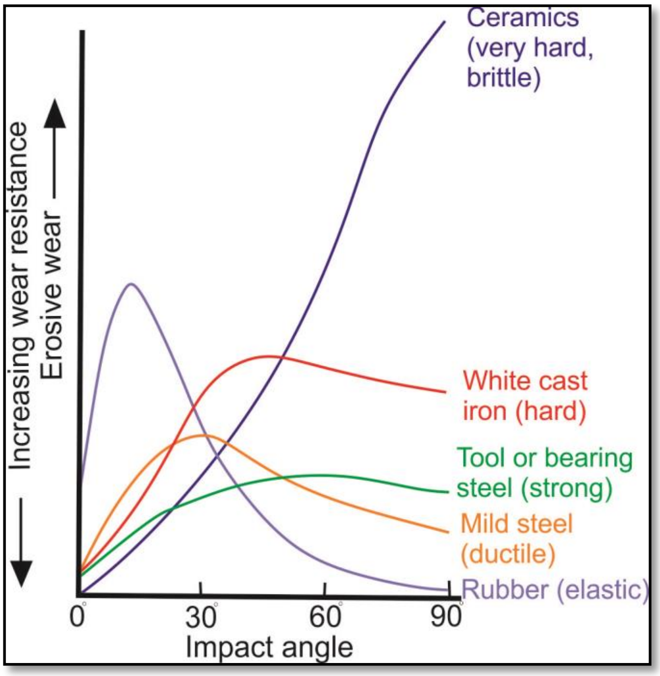

Figure 6: Effect of impact angle on the wear resistance and erosive wear of different types of materials.

Figure 6 shows the effect of impact angle on the wear-resistance and erosive wear characteristics of different types of materials. With increasing impact angle, the wear-resistance of the harder, more brittle ceramics decreases and erosive wear increases. At higher impacting angles, the wear-resistance of the softer, more ductile mild steels increases and erosive wear decreases. The requirement of harder surfaces for low impact angle applications and softer, more ductile surfaces for high impact angles is confirmed by the data shown in Figure 6.

Coating selection criteria for erosion-resistant coatings include:

- For an angle of impingement < 45°: coatings selected should be harder and more abrasion-resistant, typically such as HVOF tungsten carbide coatings.
- For an angle of impingement > 45°: coatings selected should be softer and more ductile / tougher, such as HVOF chrome carbide coatings.
- When a corrosive medium is present, the corrosion resistance of the coatings should also be taken into consideration.

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- At high service temperatures (temperatures ranging from 540°C to 815°C): coatings should have high hot hardness and oxidation-resistance. Typical coatings can include the HVOF chrome carbide coatings, as well as the plasma transfer arc welded Stellite 6 coatings.

Conclusions:

It is clear that the cause and effect of wear is complex. A harder surface does not necessarily mean a higher wear-resistant surface, especially when erosion at high impact angles is the prevalent wear mechanism in a system. The prevalent wear mechanism(s) needs to be carefully identified when identifying a suitable and effective solution. One should keep in mind that there is not always a single wear mechanism acting on a surface, but more usually a multitude of wear mechanisms.

Through the careful **selection** (knowledge of the wear mechanism in order to identify the best thermal spray coating) and **application** (careful process control and quality) of a suitably selected thermal spray coating, the wear-resistance of base materials can be extended to provide a composite material that will have the required mechanical properties in the base material without sacrificing wear-resistance on the surface.

Thermaspray has the expertise to advise you on the best wear-resistant coatings to protect your equipment. Please contact us to discuss your requirements.

References:

- South African Institute of Tribology – Materials and Wear – Principles of Wear and Selection of Wear Resistant Materials
- Engineering Coatings – Design and application – Stain Grainger and Jane Blunt – Second Edition
- ASM Handbook of Thermal Spray Technology

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