Abrasion

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Abrasion (or abrasive wear) is probably the most easily recognized form of wear. It is self-evident, for example, that hard particles will scratch softer surfaces, when they are forced against, and moved relative to, those surfaces. Not to be confused with solid particle erosion, which involves the striking of surfaces by gas-borne particles, abrasion is normally associated either with surfaces involved with the movement of packed particles (soil, sand, rocks, etc.), or hard particles trapped between machine surfaces. The former case is generally known as two-body abrasion or low stress abrasion; the latter is known as three-body abrasion or high stress abrasion. High stress abrasion is generally regarded as the more severe, because it can induce fracture of the abrasive particles, thereby ensuring the presence of sharp edges for the cutting action.

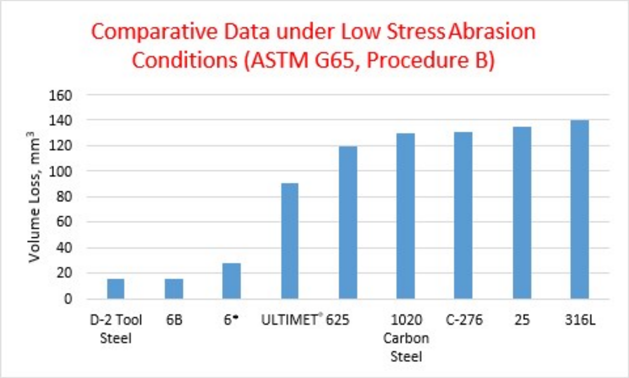
In the field of metallic materials, it has been found that alloys whose microstructures contain large volume fractions of hard precipitates (carbides, for example) provide the highest resistance to two-body (low stress) abrasion. Thus, the high-chromium irons, which contain large precipitates of chromium carbide, are favored for many earthmoving applications. For even higher resistance to low stress abrasion, mixtures of steel and carbide particles are available for co-deposition by welding. In this case, the steel melts in the welding arc, but the carbide particles are transferred intact from the welding consumable to the weld pool, where they become locked in place by the re-solidifying steel. These so- called composite materials normally contain tungsten carbide.

While a high volume fraction of carbides or intermetallics may be beneficial to low stress abrasion resistance, it is very detrimental to ductility. Consequently, it is common for weld overlays of the high chromium irons and tungsten carbide composites to crack during cooling, or upon impact in service. To cope with conditions requiring a modicum of ductility, therefore, alloys with moderate precipitate contents are available.

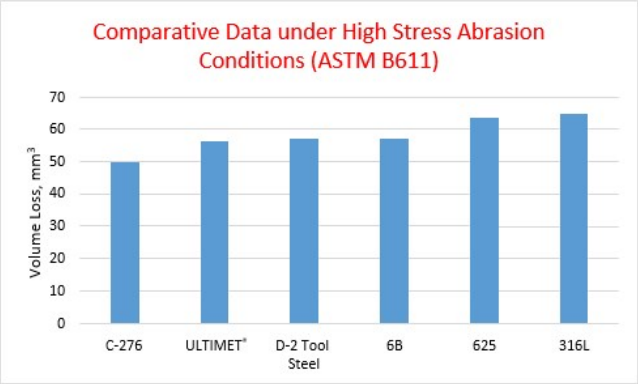
Cast cobalt alloys with different levels of low stress abrasion resistance are available, and, as with the high chromium irons, the higher the carbon content, the higher in general is the resistance to this form of wear (in the case of castings and weld overlays). In choosing cobalt alloys, however, the need for low stress abrasion resistance is often tempered by accompanying needs for corrosion resistance and crack-free overlays, both of which require the carbon content to be minimized.

To assess the low stress abrasion resistance of materials in the laboratory, the dry sand / rubber wheel test described in ASTM Standard G 65 is normally employed. The test procedure involves forcing a sample against a rotating, chlorobutyl rubber wheel (of diameter 229 mm), while feeding sand of a well-defined size and shape (rounded quartz grain sand, 212 to 300 μm diameter) to the wheel / sample interface at a specified rate. Data (relating to 2000 revolutions of the rubber wheel) for several wrought alloys are presented in the following chart, along with the corresponding value for STELLITE® 6 weld metal. These include 6B, which is compositionally similar to STELLITE® 6 alloy, but which exhibits much higher resistance to low stress abrasion by virtue of a more beneficial carbide structure. Other alloys include a tool steel (D-2), a carbon steel (1020), an austenitic stainless steel (316L), two low-carbon, cobalt-based materials (HAYNES® 25 and ULTIMET® alloys), and two nickel-based materials (625 and C-276 alloys). The difference in performance between Alloys 6 and 6B indicates the advantages of considering alternate product forms, in attempting to solve wear problems.

Low Stress Abrasion Data



*All weld metal, applied by the TIG (GTA) welding process 2000 revolutions at 200 revolutions per minute
Load: 13.6 kg
Feed Rate: 390 g/min
Three-body (high stress) abrasion is not only a much more severe form of wear than two-body abrasion, but also it appears equally damaging to soft and hard metallic materials, as illustrated in the following chart. These data were generated using the ASTM B 611 test procedures, which involve forcing a sample against a rotating, high strength steel wheel (of diameter 165 mm), while stirring a sand/water slurry (1500 g of the 212 to 300 µm rounded quartz grain sand to 940 g of water) by means of paddles on both sides of the steel wheel, in an enclosed chamber. Test parameters include a load of 22.7 kg and a rotational speed of 245 revolutions per minute. The test results relate to just 250 revolutions of the steel wheel.

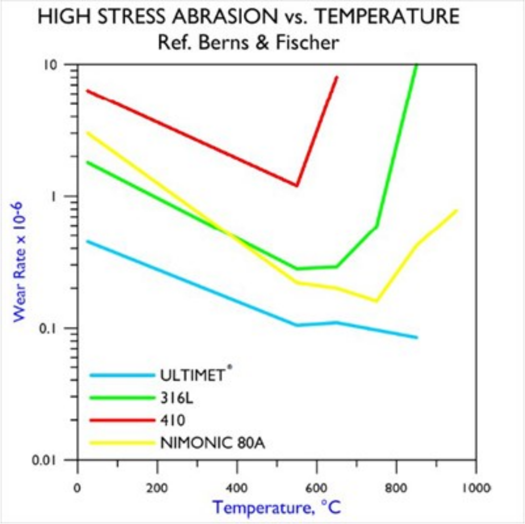


It is evident that the material ranking is quite different for low- and high-stress abrasion. For example, the two materials which perform extremely well under low stress abrasion conditions (hardened D-2 tool steel and Alloy 6B) are mediocre under high stress conditions. Evidently, performance in three-body abrasion is not related to material hardness, nor the presence of hard precipitates within the microstructures of metallic materials.

As to the effects of temperature upon abrasive wear resistance, data generated under three-body conditions are provided in *Berns and Fischer, 1993*, whose work involved abrasive particles of flint, ranging in size from 63 to 100 µm, with a mean value of 80 µm. The apparatus used by these workers had a ring-on-disc configuration, with outer and inner ring diameters of 24.9 mm and 18 mm, respectively. The disc (of diameter 30 mm, with a 5 mm diameter hole in the center) was rotated at 28 mm/s. The test load was limited to 0.82 MPa, so that the abrasive particles could be fed into, and flow within, the interface. Both the ring and disc were made from the test alloy, and weight losses of both used to determine a dimensionless wear rate, by considering the surface areas, densities, and wear path lengths. Tests were performed by these workers, under argon, at temperatures between 550°C and 1050°C, and at room temperature.

Two types of metallic material were tested by these workers, specifically materials with and without large (5 to 15 µm) particles within their microstructures. Some of the results related to the second group (no precipitates or precipitates less than 1 µm in size) are plotted in the figure below. Considering first the room temperature results for these selected (wrought) materials, namely ULTIMET® alloy (low carbon Co-Cr-Mo), NIMONIC® 80A (Ni-Cr), 316L (austenitic stainless steel), and 410 (martensitic stainless steel), these indicate that significant differences do exist between alloys, under three-body abrasion conditions. This is in contrast to the high stress abrasion results shown above, which infer that many metallic materials fall within a narrow performance band, under such conditions.

The Effect of Temperature upon High Stress Abrasion



A possible explanation of the room temperature wear rate differences is that the test load is insufficient to cause massive fracture of the flint particles, thus placing the wear process in a pseudo-low stress abrasion category, rather than the high stress category normally associated with three-body abrasion. Among the other materials tested were hardened D-2 tool steel and Alloy 6 (in cast form). At room temperature, the wear rates for these materials were approximately 0.2 and 0.3, as compared with 0.45 for ULTIMET® alloy. At least in terms of ranking, these values correlate well with the low stress abrasion numbers generated using the dry sand/rubber wheel test, which, ironically, is a three-body system used to simulate two-body conditions.

Surprisingly, the wear rates of all the test materials from *Berns and Fischer, 1993* were significantly lower at 550°C than at room temperature. Also, it appears that there is a critical temperature, beyond which high rates of degradation are encountered. It was concluded by these workers that the wear rate up to the critical temperature is largely controlled by the solid solution strength and work hardening rate. The critical temperature is believed to be the temperature (augmented by frictional heating) at which dynamic recrystallization of the surface supplants work hardening. Notably, the cobalt alloys exhibited relatively low wear rates, which is commensurate with their high strengths and work hardening rates at elevated temperatures, and exhibited relatively high critical temperatures.

In summary, two types of abrasion have been identified, although the lines of demarcation between them are somewhat blurred, and probably dependent upon the precise nature of the abrading species and the forces involved. Under so-called two-body or low stress conditions, at temperatures close to ambient, the abrading particles remain largely intact and can ride on hard microstructural outcrops (such as carbides), if these exist. Consequently, materials containing large quantities of hard microstructural precipitates are resistant to such conditions. Surfaces moving through packed abrasives (as commonly encountered in the mining and construction industries) give rise to this form of degradation. At high temperatures, it appears that the strength and work hardening characteristics of the solid solution (matrix) are critical to the abrasion resistance of metallic materials.

Three-body or high stress abrasion relates to abrasive particles trapped between surfaces in relative motion. At temperatures close to ambient, metallic materials appear to fall within a narrow band of performance, irrespective of their microstructure or hardness.