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SPECIFIC WEAR ENERGY IN HIGH STRESS ABRASION OF METALS

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ABSTRACT:

A certain amount of mechanical work is always needed for wear to occur in an operational system. The estimation of this work based on the measured electrical energy input is, however, usually quite difficult. The dual pivoted jaw crusher was designed to allow accurate wear and work measurements during the tests, enabling the division of consumed energy to specific wear and crushing energy portions. The major contributors to the specific wear energy are the frictional contacts during the sliding movement. In this work, high stress abrasion wear tests were conducted with several metals ranging from pure aluminum and copper to carbide-reinforced steels, and the specific wear energy was correlated to several material properties. The results show a linear correlation between some of the material properties and the specific wear energy, whereas a similar comparison of the material properties with the amount of wear or work done during the tests yields a non-linear correlation.

Keywords: Wear testing; work; high stress; abrasion; mining.

INTRODUCTION

By the most common definition, high stress abrasion refers to abrasion where the forces are high enough to cause fracturing of the abrasive particles [1]. In a jaw crusher, abrasion normally occurs when the particles of the feed material slide against one of the jaw plates while being pushed by the opposing jaw plate. Eventually the forces grow high enough to crush the particles between the jaws. Both of these events require work to move the jaw plates relative to each other. This work can be divided into events occurring before, during, and after fracturing of the feed particles. Closing of the jaws creates sliding and compressive movement of the particles against the jaw plates, consuming energy on friction and plastic deformation of the plate surfaces. Compression of unbreaking particles stores energy in the elastic deformation of the jaws and the particles, which is released at the point of fracturing or unloading of the unbroken particle. Previously, a method was suggested to separate the sliding and wear specific component of energy from the elastic and crushing specific component by changing only the lateral movement of the jaw plates between the tests [2]. This change led to a linear relationship between the wear of the jaw plates and the accumulated work in the test, as shown in Figure 1. Due to the brittle nature of rock fracturing, the specific crushing energy can be assumed to remain constant [2].

The separation of the specific wear energy from the specific crushing energy allows examining more accurately how the specific wear energy correlates with the mechanical properties of different metals. The Archard equation [3] is widely used also for abrasion, and by substituting the normal force and the unit sliding length with work, the equation can be rewritten as shown in Equation 1, where W_V is the volumetric wear, E_w the energy consumed by wear and sliding, K the wear coefficient, H_{def} the deformed hardness, and μ the friction coefficient. The linear relationship between wear and work in Figure 1 suggests that the right hand side of the equation remains constant with increasing movement [2].

$$Specific\ wear\ energy = \frac{E_w}{W_V} = \frac{\mu H_{def}}{K} \qquad (1)$$

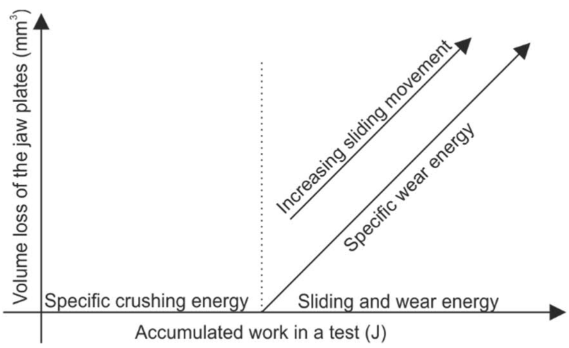

Figure 1. Schematic presentation of the relationship between specific crushing, sliding and wear energy, and the wear rate of the jaw plates.

MATERIALS AND METHODS

To examine the relationship between certain material properties and the measured specific wear energy E_w/W_V (J/mm²), tests were conducted with the Dual Pivoted Jaw Crusher (DPJC), a laboratory sized jaw crusher developed at Tampere University of Technology [2]. Unlike in the other jaw crusher designs, the movement of the approaching jaws in the DPJC is uniform, which allows the measurement of work directly from the measured contact forces and the displacement of the jaw plates. Each test crushed 4 kg of 10-12 mm Kuru granite from Finland. The crushing occurred between two rectangular sample jaw plates with dimensions of 75 x 25 x 10 mm. Both jaw plates were tilted 5° from the vertical, yielding a jaw opening of 10°. The closed side setting of the crusher was set to 3 mm, and the open side setting to 6 mm. Figure 2 shows the motion of the jaws lifting and crushing a rock particle with the DPJC. The approaching of the jaws follows a circular path with both horizontal and vertical movement, which causes particle compression between and sliding along the jaw plates.

The selected materials were Al1070 grade aluminum, high purity copper, S355 structural steel, and 400-500 HB wear resistant steels to cover a wider strength range of materials. Both sample plates in each test were manufactured of a similar material.

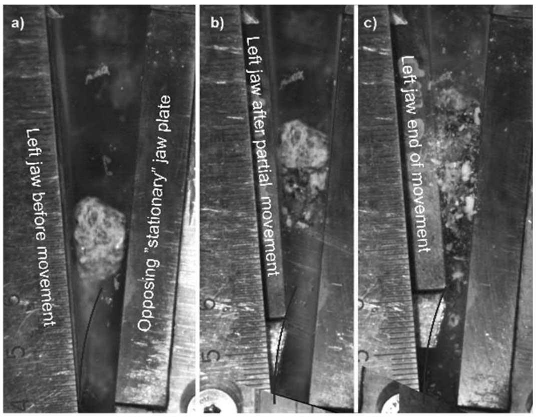

Figure 2. Jaw and particle movement during a DPJC crushing cycle: a) beginning, b) partially moved, c) end of movement.

RESULTS AND DISCUSSION

The softer materials with higher wear rates consume also much higher amounts of energy in the DPJC tests. For example, the wear rate of aluminum was around 1000 mm^3 per kilogram of crushed rock, whereas the corresponding number for the wear resistant steels was only around 16-20 mm^3/kg. Consequently, the measured specific wear energy for aluminum was 8000 J/kg, while for the wear resistant steels the energy consumption was only in the range of 1600-2000 J/kg. These values yield specific wear energies of 8 J/mm^3 for aluminum and 85-115 J/mm^3 for the wear resistant steels, describing how much sliding work is required for wear to occur in each case.

Figure 3 shows a schematic comparison of the mechanical properties of the materials and the measured specific wear energies obtained from the DPJC tests. As seen, the specific wear energy depends linearly on the tensile strength, while such a relationship was not found when either the wear rate or work done was compared to the material properties. Therefore, it can be concluded that the specific wear energy is a better indicator of the material's wear performance compared to the pure wear rates. It also allows a comparison to the specific cutting energy, which is reported to be in the range of 0.1 – 20 J/mm^3 depending on the working/testing method, material, and the material removal rate [4,5]. Compared to efficient cutters, the energy consumption in the material removal by crushing is on a reasonable level, being only by a factor of 10-20 higher than in cutting. In comparison, the energies required to remove material in dry ball-on-disc sliding wear tests have been reported to be around 10000 J/mm^3 for a steel with hardness of around 340 HV, which is significantly higher than the specific wear energy measured in the DPJC tests [6]. On the other hand, for the modified G65 abrasion tests with Cr_7C_3 overlays, the reported energy values have been in the range of 150-200 J/mm^3 [7], which are quite close to the values obtained from the DPJC tests.

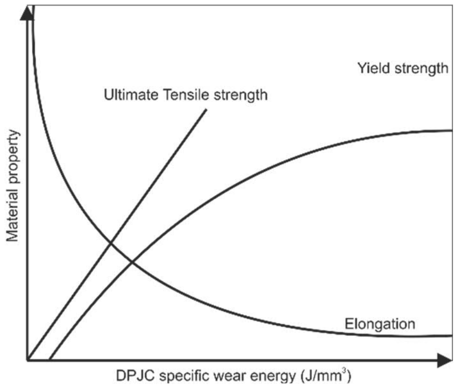

Figure 3. The relationship between material properties and the specific wear energy.

CONCLUSIONS

- In the Dual pivoted jaw crusher tests, the wear of the sample plates and the work done can be accurately measured, both correlating linearly with the increasing lateral movement of the jaws.
- The specific wear energy was found to correlate best with the ultimate tensile strength for all studied materials from soft aluminum to high strength steels.
- The measured specific wear energy values compare reasonably well with the energies measured for material removal by cutting and by sliding contacts.

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