COLD WELDING OF AEOLIAN MATERIALS IN THE VENUSIAN ENVIRONMENT: EXPERIMENTAL AND THEORETICAL CONSIDERATIONS;

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Previous investigations (1,2) with the Venus Simulator have shown that attrition debris worn from windblown particles is deposited as an accretionary layer on impacted rock surfaces at elevated temperatures representative of Venus; accretion could be a significant mechanical weathering process in areas where loose surface debris is entrained by the wind. The cause of accretion is probably cold welding (3), a physical process well-documented for metals in engineering applications. In the cold welding process, materials at a contact point are brought in sufficiently close proximity to permit interaction between surface energies of the two materials. When the contact is broken, the bonding induced at the interface proves to be greater than the local internal fracture strength of one of the materials and a small fragment is thus torn from one of the objects and remains adhering to the surface of the other. Cold welding (and the production of adhering debris) is enhanced by tangential stress at the contact and by elevated temperatures. Impacting particles in the Simulator are, of course, at elevated temperature, and they are usually rotating during flight such that impact stresses will contain a tangential element. For basalt, it has been found (4) that cold welding begins at a temperature of 505 K which is approximately 0.4 of the melting temperature of basalt. Similar onset temperature ratios are observed for metals (5). Atmospheric pressure was not found to influence the accretion process.

In theory, the amount of accretion (A) on a rock surface will be given by

$$A = f(S,Y,n), \tag{1}$$

where S is the adhesion potential (or "stickiness"), Y is the yield per impact (the amount of material broken from the impacting particle that is available for accretion), and n is the number of impacts. In order to investigate the role of S, the product $Y \cdot n$ was fixed in the experiments. Any variations in the observed amount of accretion (determined via scanning electron microscopy) on a target should then be a function of S only. This expectation can be justified on the basis of the general probabilistic model below.

A series of 13 different minerals was employed for impactors and, to set $Y \cdot n$ = constant, particles of each mineral were abraded in a pneumatic impelling device to determine their abrasion susceptibility (i.e., the yield). When one of the minerals was tested in the Simulator, the number of impacts was accordingly adjusted. Thus, "high-yield" minerals were designated relatively small impact counts. All Simulator tests were conducted at 47.5 bar/ 660 K (conditions at Maxwell Montes on Venus). The impacting minerals were tested against a variety of targets (from 8 minerals) in a series of permutations such that evaluation could be made of the role of target chemistry.

The amount of accretion on each target was determined by comparison of SEM photos with a calibrated reference chart of accretion grades. Figure 1 shows that the total measured accretion (as a percentage of the area of the target subject to impact) for all targets varied by only a factor of 3. There was no apparent grouping of data according to target chemistry. Figure 2 depicts the amount of accretion per impact, A/n, versus 1/n (which is proportional to yield). The straight-line relationship shows that the amount of accretion per impact is largely a function of the yield Y. Deviations from this line are a measure of experimental error, the stickiness S and, possibly, the effect of removal of accretion by subsequent impact events. Thus, the tests indicate that mineral chemistry is not important in determining accretion; the primary factor is yield which is a composite function of mineral hardness, brittleness, ductility, cleavage, etc.

In order to understand the interplay between accretion and removal of accretion by subsequent impacts, the development of an accretionary layer was modeled by statistical theory which predicts that the percentage of the area covered after n impacts, A(n), is:

$$A(n) = \frac{1 - (1 - (1 + z)\frac{x}{B})^n}{(1 + z)} \cdot 100, \tag{2}$$

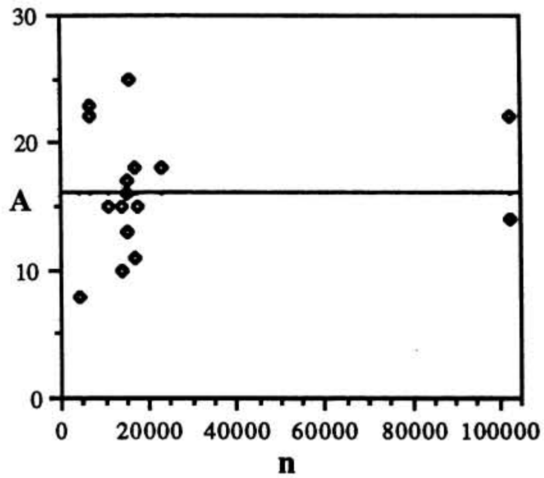

Fig. 1. Total measured accretion (in %), A, as a function of number of impacts, n.

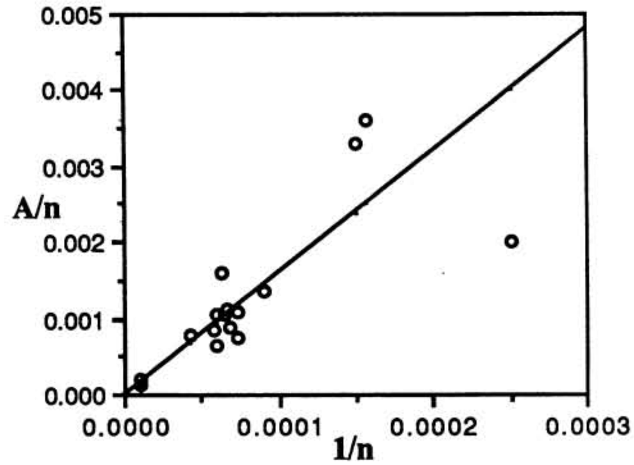

Fig. 2. Accretion per impact, A/n, as a function 1/n (which is proportional to yield).

where x is the average area added per impact when the particle impacts a clean target area, B is the area of the target subject to impact, and zx is the average area removed per impact when the particle impacts accretionary material. This model is based on the assumption that x and z are independent of the amount of material accreted on the target. The model makes no assumptions about the mechanism by which material is transferred from the particle to the target or by which material is removed from the target. Also, the result of eq. (2) does not depend on the specific form of the probability distributions for area added or area removed per impact. Eq. (2) predicts that as n gets large, the system approaches a state of dynamical equilibrium. In this state, $A = 100/(1+z)$.

In order to compare eqs. (1) and (2), it is necessary to relate the parameters S and Y in (1) to x and z in (2) and so the following physically-reasonable assumptions are made: (a) minerals with the same value of S have the same value of z and (b) for minerals with the same value of S, x is proportional to Y. It can then be shown that if n is chosen for each mineral so that $Y \cdot n$ = constant and *if it is assumed that S is the same for all minerals*, this equation gives a straight line through the origin for A/n versus 1/n. Note that a straight-line relationship is also predicted for the case of no interference (the effect of interference is only to reduce the slope of this line). Thus, the variation of points from the straight line shown in the figure, according to this model, is not due to interference between accretion and removal events, and must therefore be due to variations in "stickiness," alone (or to experimental error).

The Simulator data permits the following conclusions to be drawn for Venus. Firstly, cold welding appears to be a fairly universal process. With only one exception observed (calcite), all minerals yield material that will readily adhere to rock surfaces. Secondly, there is relatively little variation in the degree of inherent "stickiness" exhibited by a mineral -- the major control of the total amount of accretion to be expected on a rock surface (for n = constant) is the attrition susceptibility of the material. Thus, the bulk mechanical properties of materials (expressed as Y) are far more important than either the chemical or surface properties (expressed as S).

References: (1) Greeley, R. et al, 1987, *Nature 327*, 313-315, (2) Marshall, J.R. et al, 1988, *Icarus 74*, 495-515, (3) Marshall, J.R. and Greeley, R., 1988, *Trans. Am. Geophys. Union*, EOS, in press, (4) Marshall, J.R. et al, 1988, *Lunar Planet. Sci. Conf., XIX*, 726-727, (5) Weiss, P. (Ed.), 1962, *Adhesion and Cohesion*, Elsevier.