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DEGRADATION OF RADIATOR PERFORMANCE ON MARS DUE TO DUST

James R. Gaier, Marla E. Perez-Davis, Sharon K. Rutledge
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Mark Forkapa
Cleveland State University
Cleveland, Ohio 44115

ABSTRACT

An artificial mineral of the approximate elemental composition of Martian soil was manufactured, crushed, and sorted into four different size ranges. Dust particles from three of these size ranges were applied to arc-textured Nb-1%Zr and Cu radiator surfaces to assess their effect on radiator performance. Particles larger than 75 μm did not have sufficient adhesive forces to adhere to the samples at angles greater than about 27°. Pre-deposited dust layers were largely removed by clear wind velocities greater than 40 m/s, or by dust-laden wind velocities as low as 25 m/s. Smaller dust grains were more difficult to remove. Abrasion was found to be significant only in high velocity winds (89 m/s or greater). Dust-laden winds were found to be more abrasive than clear wind. Initially dusted samples abraded less than initially clear samples in dust laden wind. Smaller dust particles of the simulant proved to be more abrasive than large. This probably indicates that the larger particles were in fact agglomerates.

INTRODUCTION

NASA is doing the preliminary planning to send a manned expedition to Mars sometime in the early twenty-first century. One of the roles that the Lewis Research Center will play is that of designing the power system which will operate on the planet's surface. During these early planning phases it is critical to consider the Martian surface environment and how it might affect the power system.

There are several factors in the Martian environment which could put vulnerable power system components at risk. These include a carbon dioxide atmosphere which may react with surfaces that maintain high temperatures, such as radiators. The atmospheric pressure fluctuates from 700 to 1200 Pa, which is a region where the dielectric breakdown strength of the atmosphere will be low. Water and carbon dioxide ice may form, altering the surface characteristics. Mars lacks a substantial ionosphere, and that, coupled with the low atmospheric pressure means a significant number of energetic particles from the solar wind may impact the surface. The low pressure atmosphere will also enable high levels of ultraviolet light to penetrate to the surface. Results of the experiments aboard the Viking landers suggest that highly oxidizing species, such as peroxides or superoxides, may be present in the soil which could attack organic compounds (ref. 1).

The factor which has drawn the most concern, however, is that of Martian dust storms. Local dust storms arise in a wide variety of locations about the planet (ref. 2). Occasionally, about once per Martian year, these storms grow into large regional dust storms which cover large areas of the planet, sometimes engulfing the entire surface. During these storms the opacity of the atmosphere increases from about 0.5 to greater than 4 (ref. 3). Aeolian features seen in the Viking Lander photographs imply that the sand and dust velocities must occasionally rise to well over 45 m/s (100 miles/hour) (ref. 3). This could result in significant abrasion of spacecraft surfaces. In addition, after the storm, dust which has been suspended in the atmosphere will settle out, depositing a thin coating of dust on everything. This study was concerned with the effects of particle size of such dust on the degradation of high temperature radiator surfaces placed on the Martian surface.

METHODS AND MATERIALS

The technique of arc-texturing has shown promise as a way to make durable high-performance high temperature radiators (ref. 4). As a carbon arc is drawn across a metal surface the surface is microscopically roughened by a combination of melting, vaporization, and condensation of both the metal and carbon. The emittance of the roughened surface is enhanced by as much as a factor of 14. The radiator materials tested in this study were arc-textured niobium with one percent zirconium (Nb-1%Zr) and arc-textured copper (Cu).

Circular disks with a diameter of 2.4 cm and a thickness of 0.08 cm of both materials were fabricated and arc-textured. Their hemispherical reflectivity (ρ) was measured over the wavelengths of 0.4 to 2.5 μm using a Perkin-Elmer Lambda-9 spectrophotometer with an integrating sphere. A Perkin-Elmer Hohlraum reflectometer was used to measure the reflectivity over the wavelengths from 1.5 to 15 μm. The spectral emissivity ($\epsilon_{(\lambda)}$) was calculated from

$$\epsilon_{(\lambda)}=(1-\rho_{(\lambda)})$$

where λ is the wavelength. The spectral emissivity was then convoluted with the black body spectral emissive power ($\phi_{b(\lambda)}$) to approximate the total hemispherical emittance using (ref. 5):

$$\rho_{(\lambda)}=\frac{\int \rho_{(\lambda)}\Phi_{b(\lambda)}d\lambda}{\int \Phi_{b(\lambda)}d\lambda}.$$

This technique yields the emittance of the surface, but it is important to realize that this may not be the emittance of the radiator. If there is a layer of highly insulating dust on the surface (as is probably the case with Martian dust), the temperature of the bulk of the radiator may be higher than that of its surface, resulting in lower radiator efficiencies.

The dust used to coat the samples was a synthetic mineral manufactured by Ferro Corporation (Independence, OH) to have a chemical composition similar to Martian soil. It was not the purpose of these experiments to accurately simulate the Martian soil, but to generate several different dust samples with the same chemical composition, relevant to Martian dust, varying only in size. Table I compares the composition of this material to the soil composition found at the Viking Lander sites. The dust was dry sieved into four different ranges with nominal diameters of

10, 30, 60, and > 75 μm. There was not a sufficient amount of the 60 μm material to include it in our tests.

An initial layer of dust with a nominal diameter of 10 μm was deposited on half of the samples by placing them in a dusting chamber where the dust was elevated using dry air and allowed to settle out onto the samples. Details about the method of dusting are described elsewhere (ref. 6). The uniformity and extent of the dust deposition was monitored optically. The transmittance of cover-glasses placed next to the samples was used as a probe of the extent of the amount of dust deposited on the samples.

The winds on Mars were simulated using the Martian Surface Wind Tunnel (MARSWIT) at NASA Ames Research Center. The MARSWIT is a low pressure ($\approx 10^2$ Pa) wind tunnel 14 m in length with a 1 m by 1.1 m by 1.1 m test section located 5 m from the tunnel's entrance. This flow-through wind tunnel is located within a 4,000 m^3 vacuum chamber. The characteristics of the MARSWIT are described in detail elsewhere (ref. 7). The samples were placed in the MARSWIT at an attack angle 45° to the wind because this angle has been shown in previous tests to be the angle where dust was blown off of the samples most easily (ref. 8). The samples were tested under the conditions listed in table II.

The method used to simulate a Martian dust storm is illustrated in figure 1. The test dust was fed through a hopper into the top of the MARSWIT, near the entrance. First the wind was generated in the MARSWIT at a velocity below that which would clear dust off of the pre-dusted samples. Then the hopper feed was started, dropping the dust into the air stream. Immediately thereafter the wind velocity was increased to the test conditions. The time reported in table II is the time spent at the maximum speed. The finer particles were carried along the wind stream and struck the samples, much as would happen during a dust storm on Mars. The MARSWIT was shut down before the hopper was turned off, consequently there was no time when high velocity clear air hit the samples. Both initially clean and initially dusted samples were included in these tests.

The emittance of the samples was remeasured after the exposure tests and compared with the initial measurements. The transmittance of the accompanying cover-glasses was used as a probe of the extent of dust occlusion of the samples after the tests.

RESULTS AND DISCUSSION

LARGE PARTICLE SIZES

The largest particle sizes used in this study, being larger than 75 μm, might be better classified as sand. The smaller particles, having high adhesion to the sample plates, could be tipped to 90° or even inverted with no significant loss of particles. Particles larger than 75 μm however, would slide off of the plates when tipped to a high angle. Our measurements indicate that the angle of repose for these particles was about 27° (figure 2). However, these measurement were done in a gravity field of 1.0 g. On Mars, with a gravity of 0.377 g, a sliding force this strong could not be developed at any angle, so this material would be expected to behave like dust in the Martian environment. In fact, any particles with an angle of repose greater than about 22° would be expected to exhibit dust-like behavior. Therefore, particles larger than 75 μm were not used to dust sample plates, but were used in the wind stream to examine the effects of particle size on clearing, deposition, and abrasion.

INITIALLY DUSTED SAMPLES IN CLEAR WIND

Pre-dusted arc-textured samples were subjected to clear martian winds of 32 and 96 m/s. These velocities were chosen because previous studies indicated that these values would be below and above the threshold dust clearing velocities respectively at the 45° attack angle (ref. 9). Figure 3a shows that in the case of arc-textured Nb-1%Zr there are no significant changes in the total emittance of the surface over a 300 - 3000 K temperature range (the error of the instrument is estimated to be ± 5 percent. Figure 3b shows that in the case of arc-textured copper, the emittance of the sample subjected to low velocity winds shows no change, but that subjected to the high velocity wind decreased by 10 to 15 percent.

Visual inspection of these two samples subjected to the 32 m/s wind reveals a patchy pattern of dust clearing. There appeared to be miniature landslides of dust. In-situ inspection of the developing pattern revealed that the landslides did not occur during the wind test, but rather after the test when the chamber which contains the sample was being brought up to atmospheric pressure. The effect could not be reproduced by evacuating and then repressurizing samples in an 18 inch bell jar. Even attempts to create vibrations within the bell jar during repressurization did not reproduce the effect. The amount of material lost in this way from the Nb-1%Zr sample was small, but the patch cleared near the center of Cu disk is of significant size. The fact that the sample emittance is unchanged indicates that the emittance of the dust is similar to that of the sample.

Visual inspection of the samples subjected to the 96 m/s wind revealed that nearly all of the dust was removed. Regions developed where a significant amount of the arc texture was removed from the copper sample, but not from the Nb-1%Zr. This no doubt is the reason for the lower emittance of the copper sample. The comparison of the two materials thus reveals that the arc-textured Nb-1%Zr is more durable to abrasion. This may be due to the formation of a niobium carbide layer which enhances the bonding of the carbon to the metal. Copper does not form such a carbide layer.

INITIALLY CLEAR SAMPLES IN DUST-LADEN WIND

Small particles (30 μm) entrained in a low velocity (23 m/s) Martian wind tended to accumulate on surfaces. Figures 4a and 4b show that the low temperature emittance degrades slightly less for the arc-textured Nb-1%Zr sample than the Cu sample. Since the emittance is dominated by that of the dust, this may be an artifact of higher initial emittance of the Nb-1%Zr sample. The absolute final emittances for the two samples are nearly identical, which supports the notion that the emittance is dominated by the dust deposited on the samples.

When this same experiment is repeated but with large particles (75 μm), the results are quite different. Samples subjected to 24 and 40 m/s winds had very little dust remaining on their surfaces. Either the larger grains do not stick as well to the arc-textured surfaces or they slide off of the surface, which is inclined to an angle greater than the angle of repose. There is no significant change in the emittance of the Nb-1%Zr sample subjected to the 24 m/s wind-blown dust. There was a 5 - 15 percent drop in the emittance of the Nb-1%Zr sample subjected to the 40 m/s wind-blown dust, and perhaps a small drop in the Cu sample as well (fig. 4). From the color photographs a tinge of copper-color could be seen through the arc-textured layer which was not visible before the tests, so a slight amount of abrasion is suspected, at least in the case of the Cu sample.

These abrasion affects were clearly evident with both the smaller and larger wind-blown particles when the velocity was high (89 and 116 m/s respectively) (fig. 5) In the case of the arc-textured copper (89 m/s) it can be seen that nearly all of the carbon has been removed. The effects are also obvious from the change in the emittance (fig. 4) which dropped to below 40 percent of its original value in the low temperature region when the smaller particles were suspended, and below 60 percent with larger particles.

Both the photographs and the emittance measurements bear out that the smaller particles were somewhat more abrasive on the Nb-1%Zr samples (fig. 5). This can be most easily explained if the larger particles are in fact agglomerates of small particles. A larger particle at similar velocity will have greater kinetic energy than a smaller one. Thus, some of that energy must be dissipated by breaking the particle apart rather than by abrading the surface.

INITIALLY DUSTED SAMPLES IN DUST-LADEN WIND

When initially dusted samples were subjected to dust-laden wind, the result was always a net clearing of dust from the surface over the velocity range of 23 - 116 m/s. Thus, particles suspended in the wind substantially lowers the threshold velocity above which dust is removed from the surface (from 40 m/s to less than 23 m/s). At low velocity the smaller particles were not cleared from the surface as effectively as the larger, but at high velocity virtually all of the dust was cleared regardless of particle size.

The incomplete clearing of the small particles from the low velocity (23 m/s) wind resulted in an emitting surface which had a substantial fraction made up of the dust. The resulting emittance was only slightly lower than the pristine value for the Nb-1%Zr, but for the Cu samples the emittance dropped to about 80 percent of its pristine value (fig. 6). With larger particles (24 m/s) there was little dust on the sample and the emittance was essentially unchanged. At slightly higher velocities (40 m/s) and large particles there was no change in the Cu samples, but perhaps a slight degradation of the Nb-1%Zr. There was little evidence of abrasion of the samples.

Once again there was significant abrasion for both the small and large particle sizes at high velocity (fig. 5). Unlike the initially clear samples subjected to dust-laden wind, the large particles seemed to abrade the Nb-1%Zr slightly more than the small. This may be due to the fact that the velocity (and thus kinetic energy) was somewhat higher. It may also be that whether the particle is an agglomerate or not is not as important in the case where the particle hits a pre-dusted surfaces. In both cases the primary collisions are between dust particles. This is born out in that when the large particles impact the dust covered Nb-1%Zr, the emittance drop was about 10 percent less than when they impact an initially clear sample. The presence of dust on the radiator surfaces appears to retard the abrasion rate, probably by the dissipation of energy via the dust-dust collisions.

CONCLUSIONS

In order to determine the effects of Martian dust storms on arc-textured Nb-1%Zr and arc-textured Cu radiator surfaces, an artificial mineral of the approximate elemental composition of Martian soil was manufactured, crushed, and sorted into four different size ranges. Particles larger than 75 μm did not have sufficient adhesive forces to adhere to the samples when tilted to angles greater than about 27°. However, in the reduced gravity of the Martian surface, they would behave as dust, so the effects of blowing this size particle was studied. Pre-deposited dust layers (nominal 10 μm particle size) were largely removed by clear wind velocities greater than 40 m/s, or by dust-laden wind velocities as low as 25 m/s. Smaller dust grains were more difficult to remove. Abrasion of the arc-textured radiator surfaces was found to be significant only in high velocity winds (89 m/s or greater). Dust-laden winds were found to be more abrasive than clear wind. Initially dusted samples abraded less than initially clear samples in dust laden wind. Smaller dust particles proved to be more abrasive than large. This probably indicates that the larger particles in the artificial mineral were in fact agglomerates.

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Table I -- Composition of Dust Used in MARSWIT Test

Mineral	Viking Landser	Test Dust
SiO_2	44.7 %	53.5 %
Fe_2O_3	18.1	21.7
MgO	8.3	9.9
Al_2O_3	5.7	6.8
CaO	5.6	0.0
TiO_2	0.9	1.1
Na_2O	?	6.7
K_2O	0.0	0.3
CO_2	?	0.0
TOTAL	83.3 %	100.0 %

"?" indicate species not detectable by Viking Landers

Table II -- Test Conditions for MARSWIT Tests

Test	Initial Dust Size μm	Wind Dust Size μm	Velocity m/s
1	10	none	32
2	10	none	96
3	10	30	23
4	10	30	89
5	10	> 75	40
6	10	> 75	24
7	10	> 75	116

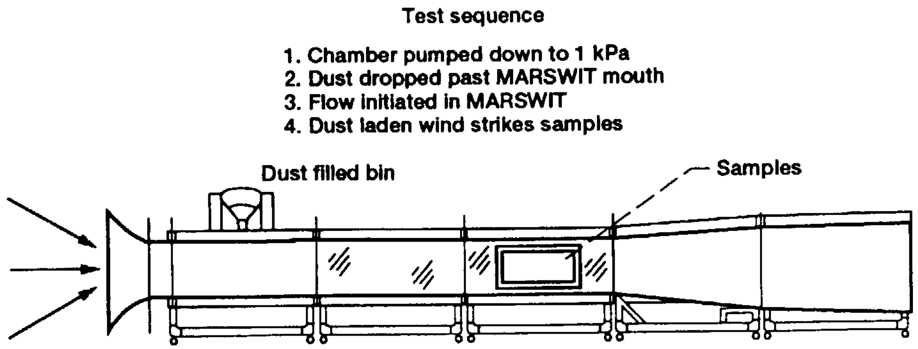
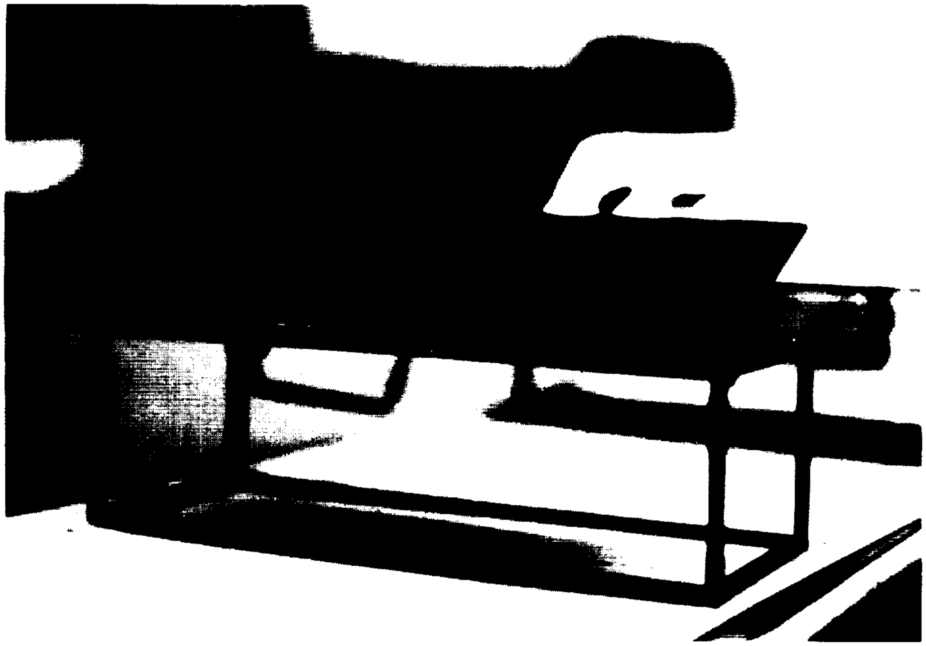
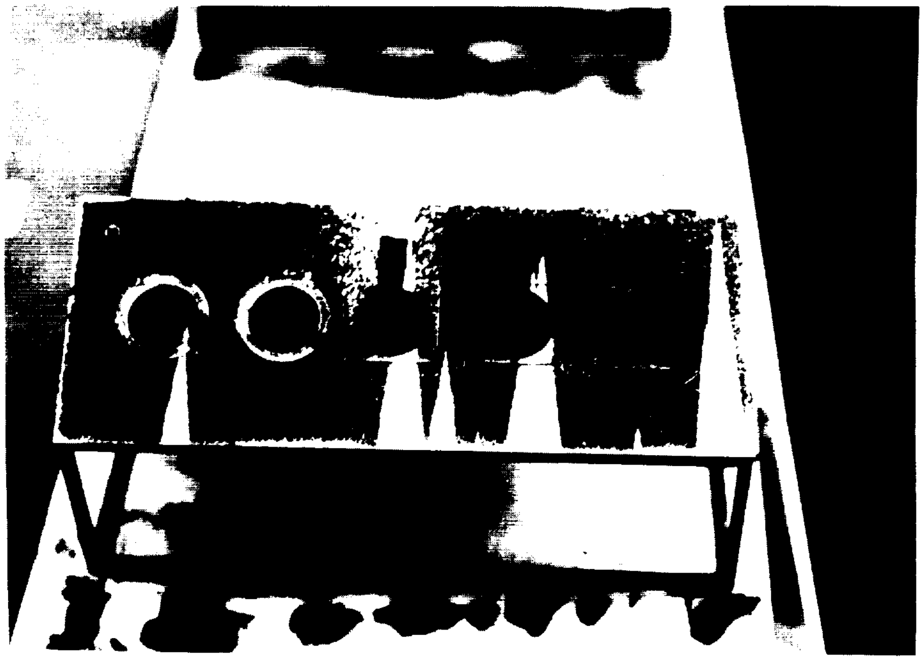


Figure 1.—Experimental set-up to simulate a Martian dust storm.

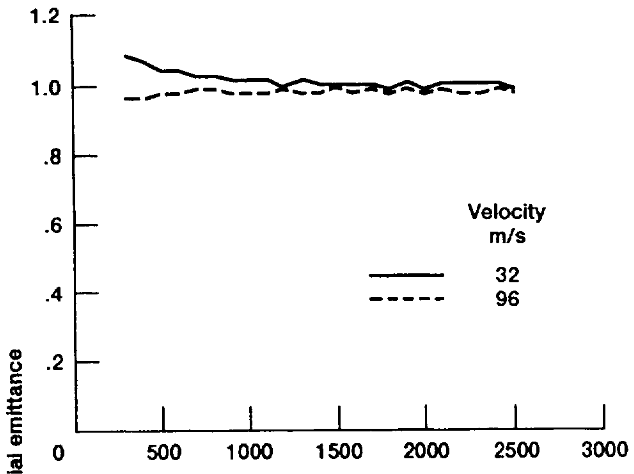


(a) 22.5°.

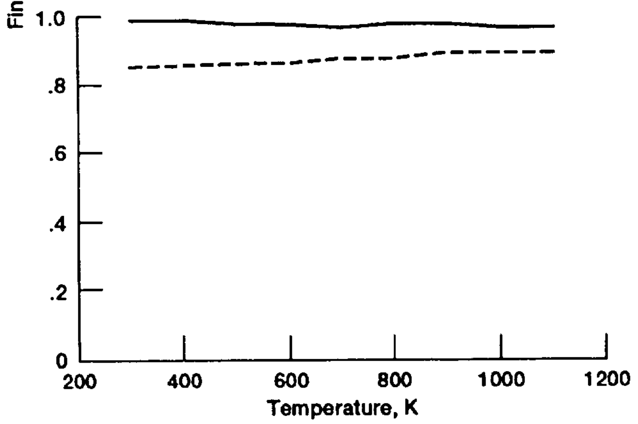


(b) 27°.

Figure 2.—Effect of tilting a plate covered with simulated Martian dust with nominal particle size greater than 75 μm.

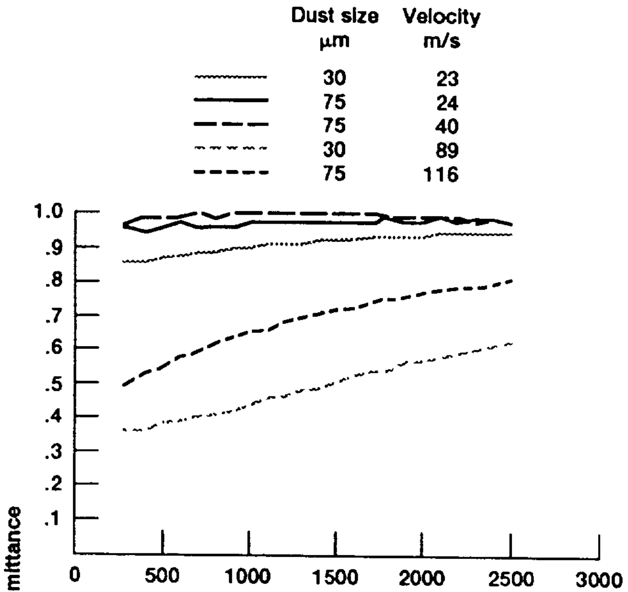


(a) Nb-1 % Zr.



(b) Cu.

Figure 3.—Emittance values for initially dusted arc-textured samples exposed to clear wind.



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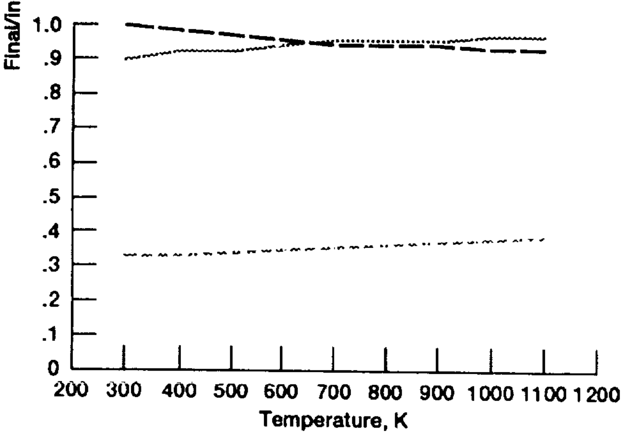
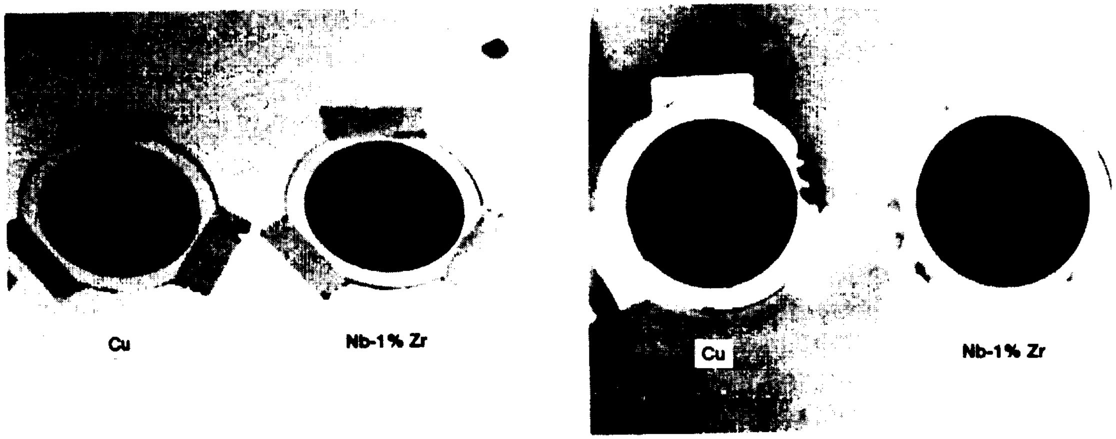


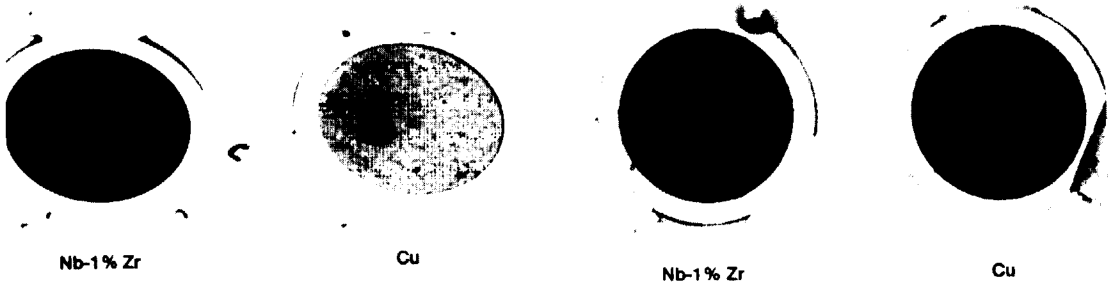
(b) Cu.

Figure 4.—Emittance values for arc-textured samples exposed to dust-laden wind.



(a) Initially clear-small particles-89 m/s.

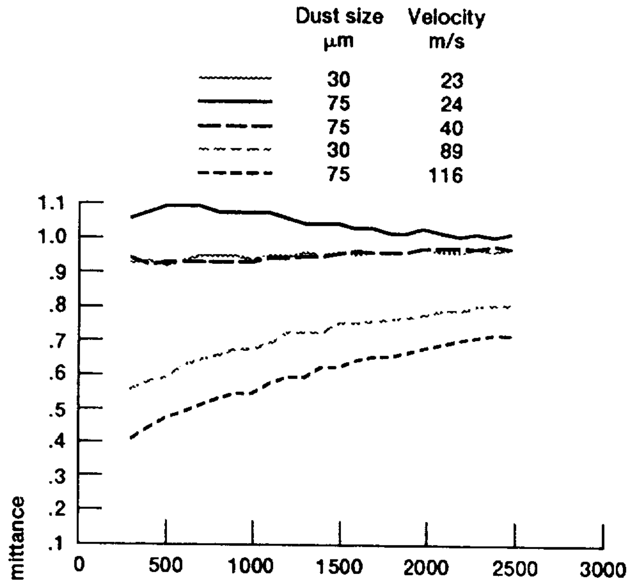
(b) Initially dusty-small particles-89 m/s.



(c) Initially clear-large particles-116 m/s.

(d) Initially dusty-large particles-116 m/s.

Figure 5.—Abrasion is apparent in these arc-textured metal samples subjected to high velocity winds.



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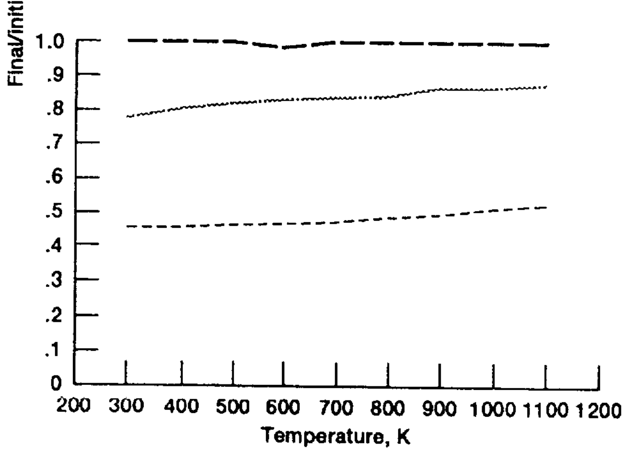

(b) Cu.

Figure 6.—Emittance values for initially dusted arc-textured samples exposed to dust-laden wind.