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ARC-TEXTURED METAL SURFACES FOR HIGH THERMAL EMITTANCE SPACE RADIATORS

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SUMMARY

Carbon arc electrical discharges struck across the surfaces of metals such as Nb-1% Zr, alter the morphology to produce a high thermal emittance surface. Metal from the surface and carbon from the arc electrode vaporize during arcing, and then condense on the metal surface to produce a microscopically rough surface having a high thermal emittance.

Quantitative spectral reflectance measurements from 0.33 to 15 μm were made on metal surfaces which were carbon arc treated in an inert gas environment. The resulting spectral reflectance data were then used to calculate thermal emittance as a function of temperature for various methods of arc treatment.

The results of arc treatment on various metals are presented for both ac and dc arcs. Surface characterization data, including thermal emittance as a function of temperature, scanning electron microscopy, and atomic oxygen durability, are also presented. Ac arc texturing was found to increase the thermal emittance at 800 K from 0.05 to 0.70.

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INTRODUCTION

Advanced space power systems will require high thermal emittance radiators which operate at high temperatures to efficiently reject waste heat with a minimum radiator area and mass. Space nuclear and solar dynamic power systems may require such high temperature radiators for overall system efficiency and mass minimization. Although the radiator operating temperatures, configurations, orbital environment, and lifetime will depend upon the type of power

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system and the specific mission, there are two radiator characteristics which need to be addressed for most low earth orbital (LEO) missions. These are high thermal emittance and environmental durability.

Atomic oxygen in the LEO environment appears to be the durability issue of greatest concern. However, thermal cycling, UV radiation, micrometeroid/debris, and space system effluents may be significant contributors to degradation depending upon the radiator surface material used to obtain high thermal emittance.

The SP-100 space nuclear power system shown in figure 1 may be required to operate at temperatures as low as 500 K and as high as 950 K, depending upon the specific mission. Techniques previously used to produce high thermal emittance surfaces for lower temperature radiators include the use of anodized aluminum, low solar absorptance and high thermal emittance paints, and metallized second surface polymer films. Such surfaces may not have the high temperature, thermal cycling, and atomic oxygen durability required for space nuclear applications. The emittance properties are dominated by surface chemistry as opposed to surface morphology properties. For reasons of reliability and durability, it would be desirable to obtain high thermal emittance by surface alteration of the radiator bulk material rather than the application of paints or coatings that may spall or otherwise degrade in thermal emittance (ref. 1). This paper discusses a technique which alters the surface morphology of potential radiator materials to develop high thermal emittance.

APPARATUS AND PROCEDURE

Candidate high temperature radiator materials whose surfaces were altered by means of arc texturing include, [niobium with 1 percent ziconium (Nb-1% Zr), titanium with 6 percent aluminum and 4 percent vanadium (Ti-6% Al-4% V)], titanium, copper, and type 304 stainless steel. Arc-texturing was performed by manually moving the site of the discharge over the entire surface of the test coupon. A carbon arc discharge was obtained between a 6.35 mm diameter water-cooled, spectroscopic grade carbon rod and a test coupon of sample radiator material. The electric arc was operated in a nitrogen or argon environment. The dc or ac arc current was varied between 11 and 16 A. By manually moving the carbon arc electrode wand, as illustrated in figure 2, the entire surface of the test radiator sample could be covered with arc sites. Because of significant visual darkening of the arc-treated areas, it was easy during sample preparation to discern which areas had been adequately arc-textured, and which areas needed to be treated further.

The thermal emittance of the arc-textured surfaces was evaluated by means of a Perkin-Elmer λ - 9 spectrophotometer and a Hohllraum reflectometer. The Perkin-Elmer spectrophotometer was used to obtain spectral emittance data over wavelengths ranging from 0.4 to 2.5 μm. The Hohlraum reflectometer was used to obtain spectral emittance data over wavelengths from 1.5 to 15 μm. The data from both instruments was combined to make a smooth transition from UV through the IR to allow calculation of the integrated thermal emittance from room temperature up to 3000 K by integration over the black body spectra for each radiator temperature.

Some radiator materials, such as Nb-1% Zr, readily oxidize at high temperatures in an oxygen environment. Concepts to inhibit oxidation of this material by atomic oxygen through the application of sputter-deposited coatings of MgF_2 were evaluated. These thin film coatings were applied by ion beam sputter deposition from targets composed of these materials. Techniques used for ion beam sputter deposition are described in references 2 to 4.

Simulation of the LEO atomic oxygen environment was provided by radio frequency (13.56 MHz) plasma ashers operated on air plasma at pressures of 30 to 100 μm. Because the radiators will be operating at high temperatures, it is necessary to simulate this, as well as atomic oxygen, in order to fully assess LEO durability. A plasma asher was modified to contain both a room temperature and heated substrate sample holder, as illustrated in figure 3, so that both sample holders would be exposed to identical fluences.

RESULTS AND DISCUSSION

Total reflectance data from the Perkin-Elmer λ - 9 spectrophotometer and the Hohlraum reflectometer for Nb-1% Zr are shown in figure 4. The data reveal a significant reduction in both visible and IR reflectance of the arc-textured surface, which has a very dark or black-appearing surface. The cause of the reduced reflectance (and therefore, increased thermal emittance) of the surfaces is the rough morphology produced on a microscopic level, as illustrated in the scanning electron microscope photograph in figure 5. It is believed that the electric arc causes melting and vaporization of the radiator surface, as well as vaporization of the carbon arc electrode. Movement of the site of the arc allows condensation of these materials over the sites of microscopic arc craters. The net effect produces a highly irregular absorbing surface predominantly composed of bulk radiator material with a portion of the condensed electrode carbon intermixed.

The thermal emittances as a function of radiator temperature for Nb-1% Zr, Cu, Ti, Ti-6% Al-4% V, and type 304 S.S. are shown in figure 6 for untreated and arc-textured surfaces. The untreated surfaces in this figure are the original surface finishes from commercial sheet metal suppliers. An ac arc with a current of 14 to 15 A was used to arc-texture the various materials. Figure 6 illustrates results for temperatures up to either the melting points of the various materials or 3000 K.

Obviously, the amperage of the arc plays a significant role in the degree of alteration of the surface morphology of the radiator materials tested. Figure 7 shows the dependence of the thermal emittance of radiator materials at 800 K on ac arc current, based on data obtained from ac arcs of 11 to 16 A. A comparision of thermal emittance dependence on ac, dc, and polarity variables is shown in figure 8 for Nb-1% Zr radiator materials at 800 K. As can be seen, ac arc-texturing produces the highest thermal emittance. Sixty cycle arc texturing may not represent the optical frequency. Efforts are underway to investigate frequency optimization for thermal emittance of ac arc-textured surfaces.

The results of atomic oxygen durability evaluation of arc-textured Nb-1% Zr radiator surfaces is shown in figure 9. The arc-textured Nb-1% Zr surface was ion beam sputter deposited with 950 Å of MgF_2 in an attempt to provide a barrier to oxidation by atomic oxygen in the asher environment. As can be seen, the MgF_2 thin film coating caused very little change in thermal emittance. However, there was a large accompanying reduction in emittance when the sample was heated to 900 K during exposure to atomic oxygen. A slight reduction in thermal emittance upon atomic oxygen exposure also occurs when the radiator samples are oxidized in the plasma asher at room temperature. This may be due in part to oxidation of the carbon that resulted from the condensation of the radiator surface metal vapor and the carbon vapor from the electrode during arc-texturing. The sample was exposed to the RF plasma asher environment for 24 hours. This represents an equivalent atomic oxygen damage fluence (as measured by Kapton® polyimide oxidation) of 6×10^{20} atoms/cm^2. MgF_2 is known to be atomic oxygen durable. However, at 900 K, it is not clear whether or not there may be pathways through defects in the coating to allow oxidation of the underlying Nb-1% Zr. In addition, Nb-1% Zr is a well-known bulk absorber of a wide range of sizes of atomic species. Thus, the integrity of the MgF_2 thin film might be in doubt at these temperatures. If no oxygen barrier coating is used in a LEO environment, Nb-1% Zr may readily transport atomic oxygen directly into the liquid metal heat pipe working fluid and cause it to be oxidized. The Nb-1% Zr may also become embrittled by atomic oxygen attack.

Although arc-texturing has been shown to produce high thermal emittance surfaces by manually manipulating the arc site across ample radiator material, the technique has potential for being performed automatically. The electric arc can be rastered across the surface of flat sheets, tubes or tubes with fins by means of an electrically driven arc wand manipulator and a moving bed to support a radiator tub or fin.

CONCLUSIONS

Arc-texturing has been shown to increase the thermal emittance of Nb-1% Zr, Cu, Ti, Ti-6% Al-4% V, and type 304 S.S. radiator surfaces as measured by the reflectance properties of these surfaces and subsequent integration over the black body spectra to calculate thermal emittances at radiator temperatures from room temperature to either 3000 K or the melting point of each material. The highest thermal emittances for NB-1% Zr and Cu radiator surfaces were obtained with ac arcs of 14 to 16 A. However, the optimum arc current and arc frequency have not yet been established. The arc-texturing surface modification technique has potential for being applied automatically to large area radiator surfaces. The application of 950 Å of MgF_2 to arc-textured Nb-1% Zr causes a slight reduction in thermal emittance. However, it does not fully provide a barrier for thermal emittance durability in a high temperature (900 K) atomic oxygen environment. Arc-texturing appears to be a viable technique to produce high thermal emittance radiator surfaces with properties dominated by surface microscopic morphology as opposed to chemically controlled optical properties.

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4. B.A. Banks, M.J. Mirtich, S.K. Rutledge, and D.M. Swec, "Sputtered Coatings for Protection of Spacecraft Polymers," NASA TM-83706, 1983.

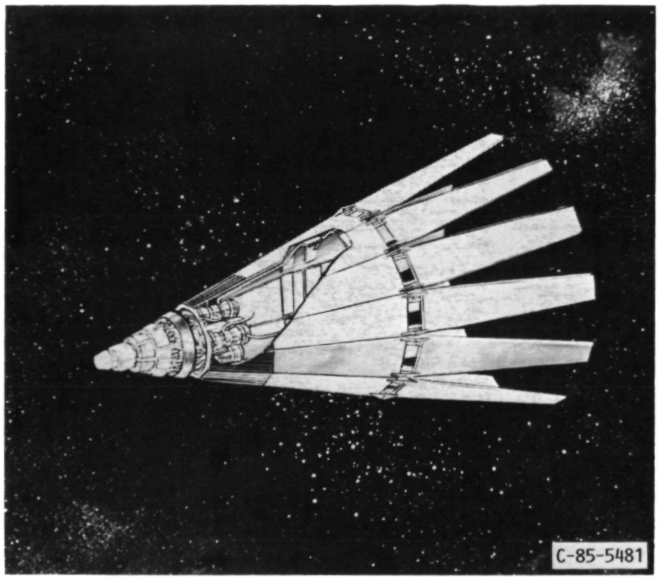


FIGURE 1. - SP-100 SPACE NUCLEAR POWER SYSTEM.

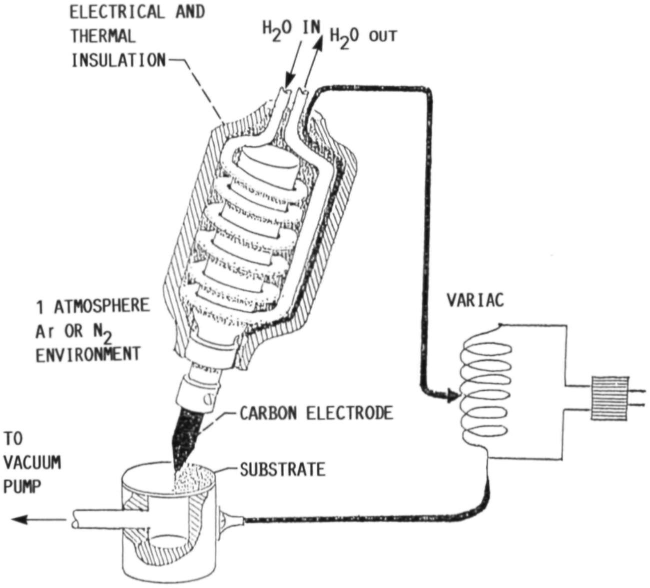


FIGURE 2. - TECHNIQUE FOR ARC-TEXTURING SURFACES.

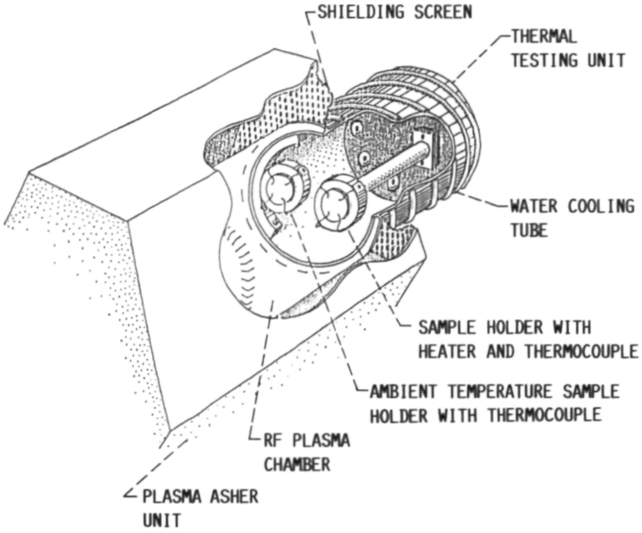


FIGURE 3. - HIGH TEMPERATURE RF PLASMA ASHER.

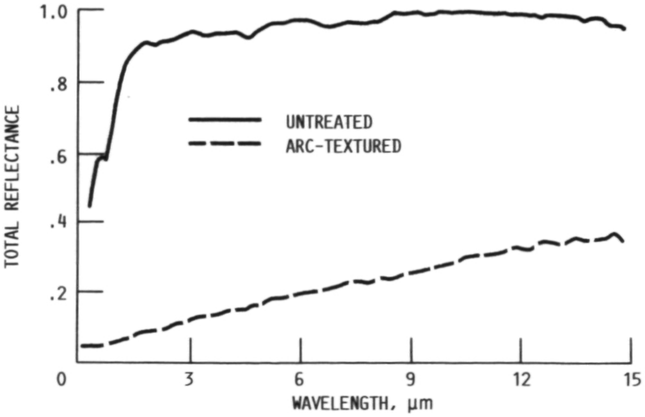
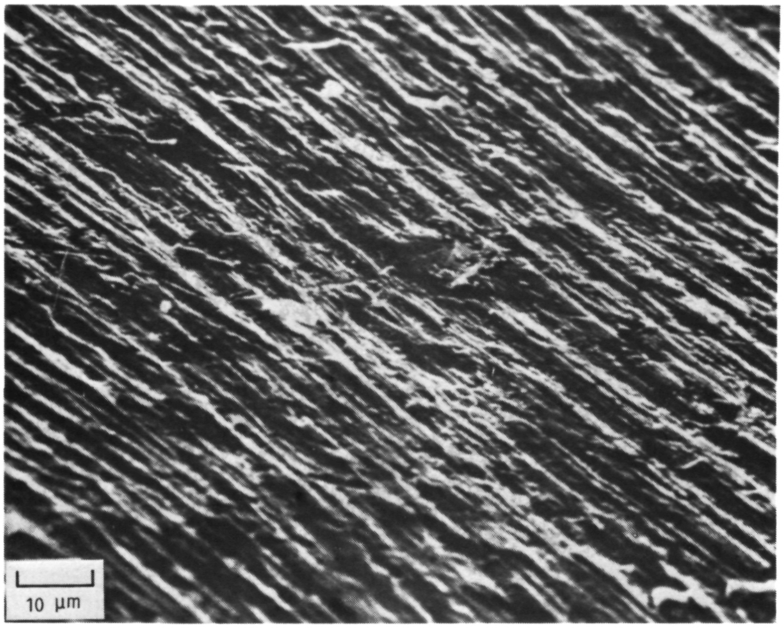
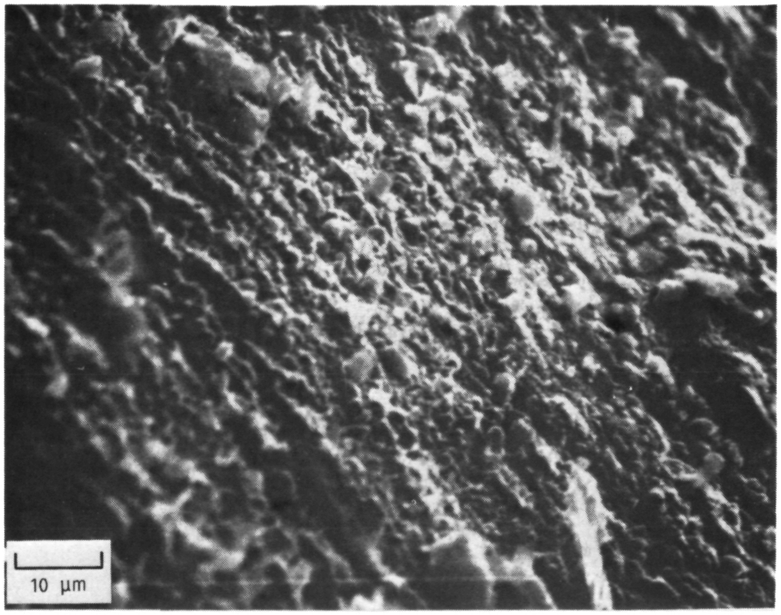


FIGURE 4. - TOTAL REFLECTANCE VERSUS WAVELENGTH FOR UNTREATED AND ARC-TEXTURED Nb-1Zr.

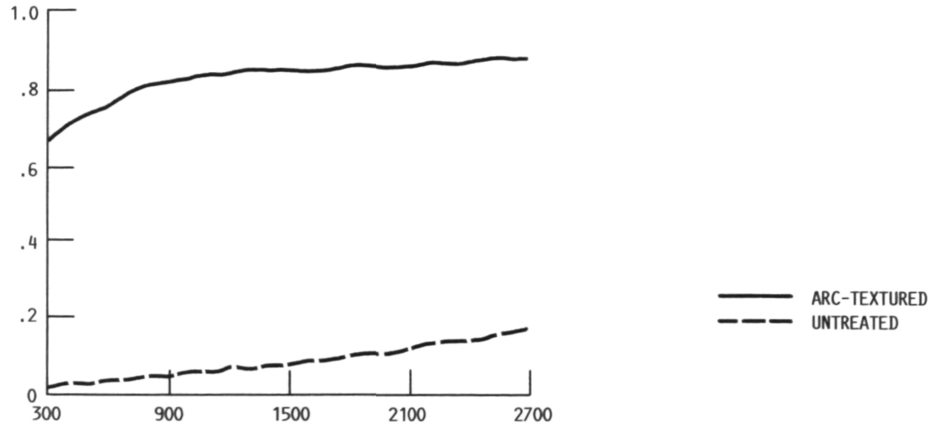


(A) UNTREATED.

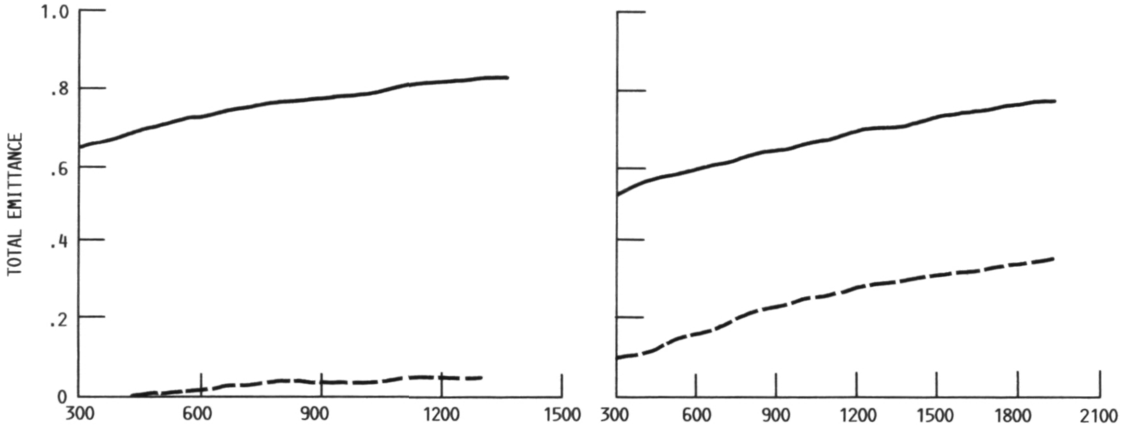


(B) ARC-TEXTURED.

FIGURE 5. - SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS OF UNTREATED AND ARC-TEXTURED Nb-1Zr.

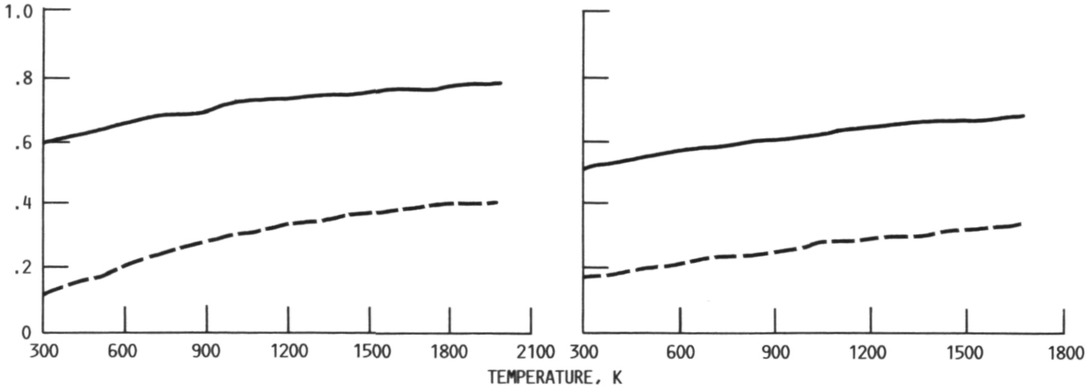


(A) Nb-1Zr.



(B) Cu.

(D) Ti-6Al-4V.



(C) Ti.

(E) TYPE 304 STAINLESS STEEL.

FIGURE 6. - THERMAL EMITTANCE VERSUS RADIATOR TEMPERATURE FOR VARIOUS UNTREATED AND ARC-TEXTURED SURFACES.

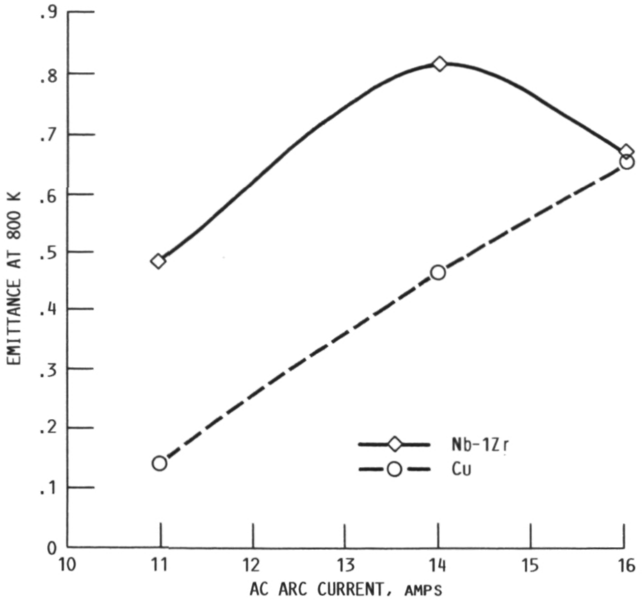


FIGURE 7. - DEPENDENCE OF THERMAL EMITTANCE AT 800 K ON AC ARC-TEXTURING CURRENT.

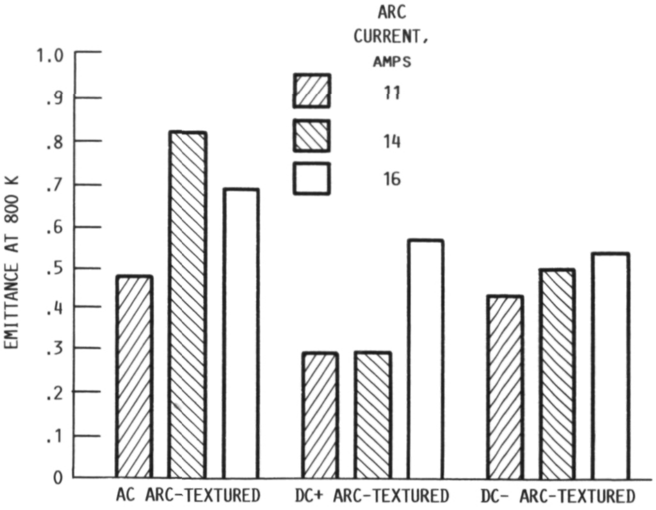


FIGURE 8. - AC, DC, AND POLARITY DEPENDENCE OF THERMAL EMITTANCE OF Nb-1Zr AT 800 K.

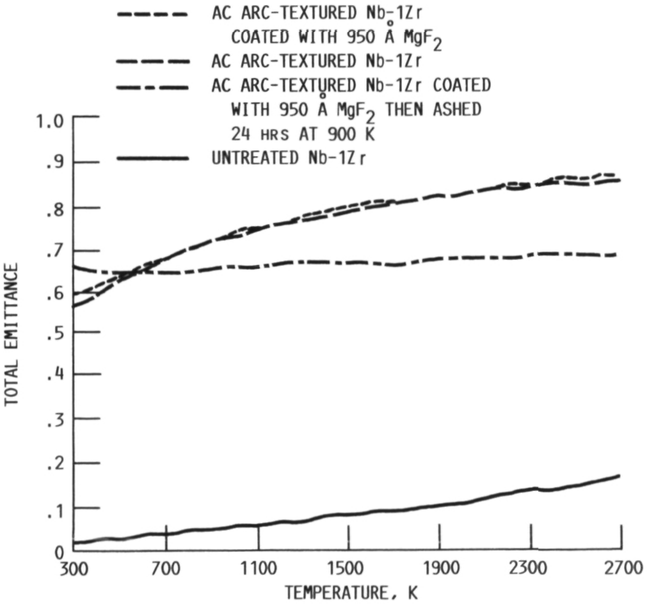


FIGURE 9. - Nb-1Zr THERMAL EMITTANCE VERSUS RADIATOR TEMPERATURE FOR UNTREATED, ARC-TEXTURED AND 950 Å MgF_2 COATED, AND ARC-TEXTURED THEN MgF_2 COATED, THEN 900 K RF PLASMA ASHER TREATED SURFACES.

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16. Abstract

Carbon arc electrical discharges struck across the surfaces of metals such as Nb-1%, alter the morphology to produce a high thermal emittance surface. Metal from the surface and carbon from the arc electrode vaporize during arcing, and then condense on the metal surface to produce a microscopically rough surface having a high thermal emittance. Quantitative spectral reflectance measurements from 0.33 to 15 μm were made on metal surfaces which were carbon arc treated in an inert gas environment. The resulting spectral reflectance data were then used to calculate thermal emittance as a function of temperature for various methods of arc treatment. The results of arc treatment on various metals are presented for both ac and dc arcs. Surface characterization data, including thermal emittance as a function of temperature, scanning electron microscopy, and atomic oxygen durability, are also presented. Ac arc texturing was found to increase the thermal emittance at 800 K from 0.05 to 0.70.

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