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Electric Arc and Electrochemical Surface Texturing Technologies

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ELECTRIC ARC AND ELECTROCHEMICAL SURFACE TEXTURING TECHNOLOGIES

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ABSTRACT

Surface texturing of conductive materials can readily be accomplished by means of a moving electric arc which produces a plasma from the environmental gases as well as from the vaporized substrate and arc electrode materials. As the arc is forced to move across the substrate surface, a condensate from the plasma redeposits an extremely rough surface which is intimately mixed and attached to the substrate material. The arc textured surfaces produce greatly enhanced thermal emittance and hold potential for use as high temperature radiator surfaces in space, as well as in systems which use radiative heat dissipation such as computer assisted tomography (CAT) scan systems. Electrochemical texturing of titanium alloys can be accomplished by using sodium chloride solutions along with ultrasonic agitation to produce a random distribution of craters on the surface. The crater size and density can be controlled to produce surface craters appropriately sized for direct bone in-growth of orthopaedic implants. Electric arc texturing and electrochemical texturing techniques, surface properties and potential applications will be presented.

1.0 INTRODUCTION

1.1 Electric Arc Texturing

Radiative cooling of smooth metal surfaces is minimally effective because such surfaces typically have an unacceptably low thermal emittance. The application of high-emittance metal-oxide coatings can significantly improve the thermal emittance. However, if the radiator is required to survive wide ranges in operating temperature, the differences in coefficient of thermal expansion can cause the coatings to spall. The formation of an electric arc between the metal surface and a conductive electrode can be used to develop an extremely rough surface in which a condensate of the vaporized substrate metal and the electrode material produces a high emittance surface which is integral with the substrate metal and thus unlikely to spall. This paper reports an investigation of carbon and silicon carbide arc texturing of various metals to improve their thermal emittance.

1.2 Electrochemical Surface Texturing

The long-term stability of an orthopaedic implant can be improved if the implant stem is mechanically attached to the bone by means of direct bone in-growth into pores in the surface as opposed to conventional polymethylmethacrylate bone cement. Electrochemical texturing of Ti-6% Al-4% V by means of sodium chloride baths with ultrasonic agitation holds promise to produce the desired geometry post structures on irregularly shaped surfaces at low cost. The electrochemical bath operating conditions which produce suitable surface textures is reported here.

2.0 APPARATUS AND PROCEDURE

2.1 Electric Arc Texturing

All metal samples were sanded with Number 600 3M Wetordry Tri-M-ite Paper prior to initial emittance measurement and before silicon carbide arc texturing for purposes of uniformity of the untreated surfaces. The carbon arc textured samples were not sanded prior to arc texturing. The apparatus used to arc texture metal surfaces is illustrated in figure 1 (refs. 1 and 2). As can be seen in figure 1, the arc texturing can be performed by the creation of either a sine wave or square wave electric arc between the metal surface and a conductive electrode of either carbon or silicon carbide. Initial tests comparing the performance of textured surfaces produced by both AC as well as DC arcs indicated that AC arcs produced higher emittances and therefore all texturing was performed using AC arc. The arc site is moved across the surface by simply manually moving the water-cooled electrically-insulated arc electrode across the surface. Arc texturing using carbon electrodes was performed at arc currents between 14 and 20 A using sine wave form arcs at frequencies between 100 and 1000 Hz. All silicon carbide arc texturing was performed at 15 A using 60 Hz sine wave arcs. The carbon arc texturing was performed in an inert argon atmosphere and the silicone carbide arc texturing was performed in an air environment.

Atomic oxygen was used on selected samples to remove carbon which is co-deposited with the substrate metals during carbon arc texturing by means of an RF plasma asher operated on air. Atomic oxygen exposure tests were performed to evaluate the thermal emittance which would occur after arc textured surfaces were operated at high temperatures on radiators exposed to atomic oxygen in low Earth orbit (refs. 1 and 3).

Thermal emittance characterization of arc textured surfaces was performed for room temperature emittance measurements using a Gier-Dunkle model DB-100 reflectometer which measures thermal emittance at 322 K. High temperature emittance measurements were calculated by integrating spectral emittance measurements with respect to the black body curve for the temperature of interest. Spectral emittance measurements were made using both a Perkin-Elmer Lambda-9 UV-VIS-NIR spectrophotometer for wavelengths ranging from 0.25 to 2.5 μm and a Hohlraum reflectometer for wavelengths from 1.5 to 15 μm (ref. 4).

2.2 Electrochemical Surface Texturing

Electrochemical texturing was performed by immersing cylindrical samples of Ti-6% Al-4% V, in a water solution which was saturated with sodium chloride. Sodium chloride was selected as the means to make the water sufficiently conductive to perform electrochemical texturing because of its biocompatibility. After electrochemical texturing for durations between 1 and 16 min, the samples were washed, dried and photographed by light microscopy. The samples ranged in size from 1 to 2 cm in diameter \times 1 to 3 cm long. Evaluation of the resulting surface texture was made on either an end face surface or the cylindrical side surface of the samples. The samples were immersed in an 800 ml saturated salt water solution in a stainless steel ultrasonic bath 15.2 cm wide by 30.5 cm long which also served as the negative electrode in the electrochemical cell. The titanium alloy to be textured was electrically connected to the positive output of a current controlled DC power supply. Currents ranging from 0.3 to 3.0 A were used with voltages ranging from 5 to 29 V. Ultrasonic agitation was conducted during the electrochemical texturing to assist in removal of oxides forming on the titanium surface.

3.0 RESULTS AND DISCUSSION

3.1 Electric Arc Texturing

A comparison of the total hemispherical emittance of untreated as-received W, 304 stainless steel, Ti 6% Al-4% V, Ti, Cu, and Nb-1% Zr with carbon arc textured samples of these same materials as a function of temperature is shown in figure 2. As can be seen, for every metal a significant thermal emittance increase is achieved through carbon arc texturing of the surfaces.

Table I shows the thermal emittance at 322 K of various metals sanded, prior to and after carbon arc texturing and silicon carbide arc texturing.

In addition, the thermal emittance of copper and Nb-1% Zr was measured after carbon arc texturing and subsequent exposure to atomic oxygen in an RF plasma asher to remove carbon from the surface of the sample. The removal of carbon through atomic oxygen oxidation of carbon arc textured Nb-1% Zr reduced the thermal emittance of the surface slightly. However, atomic oxygen exposure of carbon arc textured Cu increased the thermal emittance, even though the carbon had largely been removed from the surface. This is a consequence of the development of a substantial copper oxide on the surface because Cu does not form a protective oxide in an atomic oxygen environment as it does in atmospheric diatomic oxygen. Sliding the atomic oxygen treated copper sample on a sheet of paper resulted in a reddish brown streak because of a soft copper oxide.

As can be seen in table I, silicon carbide arc texturing was found to produce higher thermal emittances than the carbon arc textured surfaces. Another advantage of silicon carbide is that it appears to be unaffected by atomic oxygen, because a thin silicon dioxide film probably forms when it is exposed to atomic oxygen, which would result in a negligible change in thermal emittance.

3.2 Electrochemical Surface Texturing

Operation of the electrochemical texturing system with simultaneous ultrasonic agitation of the saturated sodium chloride solution bath was found to produce a highly pock-marked surface if the sample bias was as high as 24 V DC with respect to the stainless steel tank holding the bath and operated at a current of 3 A for a duration of 24 sec. The sample was a cylindrical rod of 9.52 mm diameter with only its end face exposed. Thus, the sample was exposed to a current density of 4.2 A/cm². As can be seen from figure 3 which shows optical photomicrographs of the electrochemically textured surfaces, the erosion appears as nearly hemispherical etched pockets of ~50 μm diameter randomly separated by unetched Ti-6% Al-4%V. The key advantage of this type of electrochemical etching is that the initial overall outside dimension of the metal is unaffected. Thus, if this technique is used for stems of orthopaedic prostheses for direct bone in-growth, the tools necessary to achieve a reliably tight fit for direct in-growth are simply the original size of the implant stem. This is quite independent of the pit texturing which is placed into the surface.

4.0 CONCLUSION

Electric arc texturing using silicon carbide electrodes can produce surfaces with higher thermal emittance than carbon arc texturing electrodes can produce. In addition, radiator surfaces made from silicon carbide arc texturing electrodes are less prone to emittance degradation from atomic oxygen exposure which may be critical for radiator surfaces operating in low Earth orbit. Terrestrial applications of arc textured surfaces include high temperature radiator surfaces which are under high mechanical stress such as rotating anodes for CAT scan systems.

Electrochemical texturing of Ti-6% Al-4% V can be achieved using several saturated sodium chloride water solution baths in conjunction with ultrasonic agitation to produce surfaces which have randomly distributed nearly hemispherical pits which are separated by regions completely unaffected by the etching. Such surfaces may be suitable for use on stems of orthopaedic implants for direct in-growth fixation.

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4. S. Rutledge, M. Forkapa and J. Cooper: 'Thermal Emittance Enhancement of Graphite-Copper Composites for High Temperature Space-based Radiators,' NASA TM-105178, AIAA Paper 91-3527, presented at the Conference on Advanced Space Exploration Initiative Technologies, Cleveland, Ohio, September 4-6, 1991.

TABLE I.—THERMAL EMITTANCE AT 322 K OF SANDED METALS PRIOR TO AND AFTER CARBON AND SILICON CARBIDE ARC TEXTURING

Metal	Sanded and untreated	Carbon arc textured	Carbon arc textured and exposed to atomic oxygen	Silicon carbide arc textured
6061-T6 Al	0.086	---	---	0.822
Cu	0.050	0.657	0.870	0.839
Ni	0.044	---	---	0.763
Nb-1% Zr	0.112	0.676	0.505	0.812
Type 304 stainless steel	0.146	0.511	---	0.600
Ti-6% Al-4% V	0.144	0.534	---	0.670
W	0.145	0.347	---	0.689

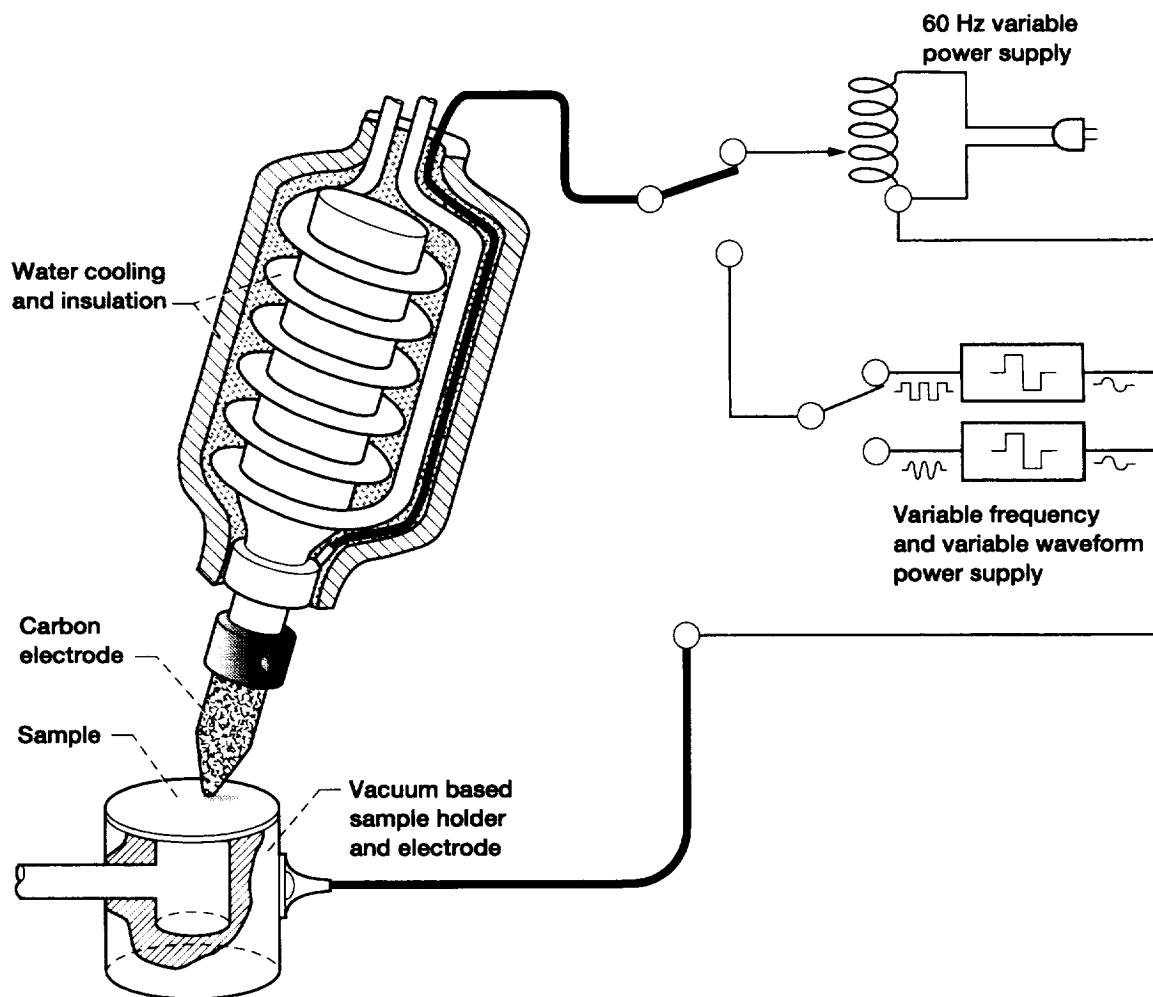


Figure 1.—Schematic diagram of a texturing apparatus.

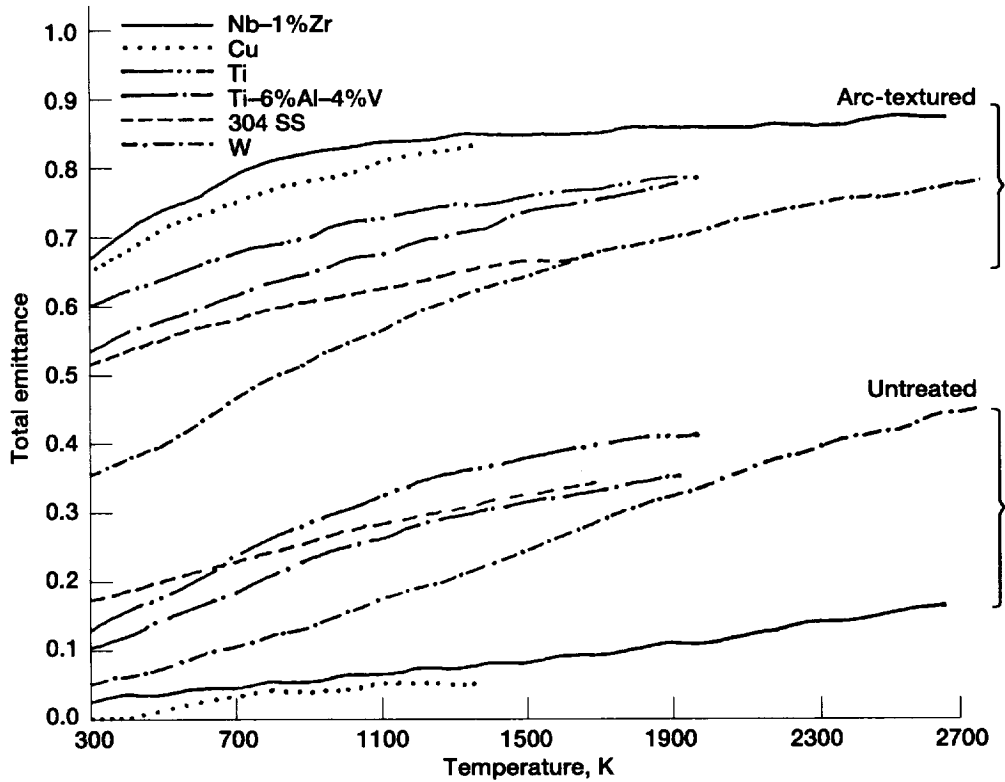


Figure 2.—Total hemispherical emittance vs. temperature for untreated and carbon arc textured surfaces.

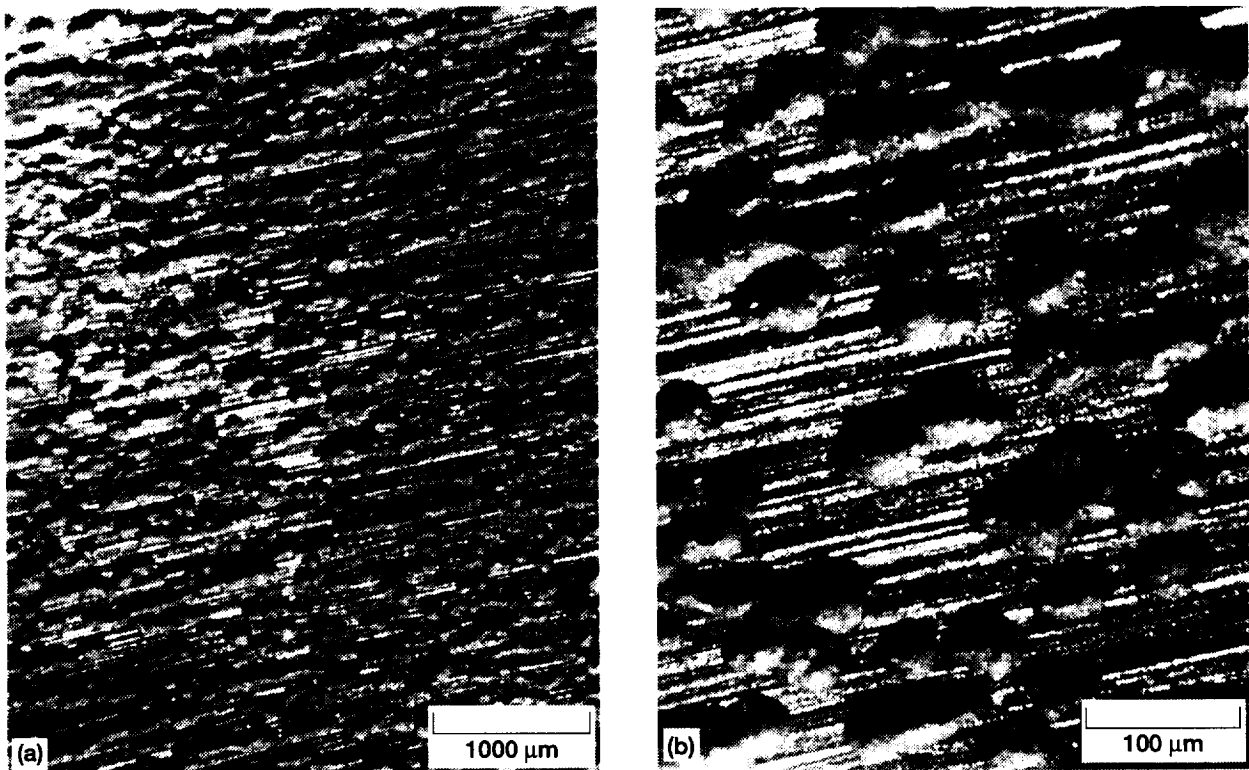


Figure 3.—Optical microscope photographs of electrochemical textured titanium-6% Al-4% V.

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