Hydroxyapatite Waterjet Treatment of Implants

by A.E. Alade, W. Weber, B. Sadasivam, D. Arola (Department of Mechanical Engineering University of Maryland Baltimore County), P. Milidantri (Everest Metals)

Dr. Dwayne Arola, an Associate Professor in the Department of Mechanical Engineering at the University of Maryland Baltimore County, oversees the University's Advanced Manufacturing Lab.

"We are pleased to share this research with the readers of **The Shot Peener**. This project is one component of our research program that focuses on problems at the intersection of solid mechanics, materials and manufacturing. We address the effects from manufacturing processes on the mechanical properties and structural integrity of conventional, advanced engineering and biological materials. Part of the research activities within the Laboratory for Advanced Manufacturing Processes (LAMP) are focused on surface treatments, and their contribution to short- and long-term component performance, health, and safety issues. The Hydroxyapatite Waterjet Treatment of Implants study is part of our most recent efforts in the fields of orthopedics and restorative dentistry that have focused on the influence of existing treatment modalities on the mechanical behavior of implantable materials and their ability to promote life-long health. The laboratory is well equipped to investigate fundamental issues related to machining and material removal, and to solve research and development problems of industrial relevance. I welcome any comments or questions from the readers of your magazine."

—Dr. Dwayne Arola
darola@umbc.edu

Dr. Arola's Active Research:

- The Role of Fatigue Crack Growth in Dentin on Dental Restoration Failures, sponsored by the Whitaker Foundation
- Development of Apatite Jet Treatments for Human Enamel: A New Tool for General Dentistry, sponsored by the Technology Development Corporation (TEDCO) of Maryland
- CAREER: Aging, Tooth Fracture and the Success of Restorative Dentistry, sponsored by the National Science Foundation
- Research Experiences for Undergraduates (REU) Supplement, sponsored by National Science Foundation
- Refinement and Standardization of Test Methods for Characterization of Ceramics, sponsored by the National Institute of Standards and Technology

INTRODUCTION

Hydroxyapatite (HA) coatings are applied to the surface of dental and orthopaedic implants to enhance the development of a surface topography and surface chemistry that supports early osseointegration and mechanical interlock. Deposition of HA coatings is most often achieved via thermal plasma spray, which results in a porous coating of embedded HA particles. While porous coatings are considered essential for stable primary fixation, the fatigue strength of these coated devices is often less than that of the metal in wrought form [1]. Additional complications arise due to delamination and fracture of the coating from the substrate. The reduction in fatigue strength is attributed to stress concentrations posed by the porous surface topography and through microstructural changes that result from the deposition process. Abrasive Waterjet Peening (AWJ) is a newly developed method of surface treatment that has been proposed for orthopedic applications [2]. Studies on AWJ peening of metals have shown that the process is capable of introducing a surface texture that supports mechanical interlock, results in compressive residual stress and that particles can be impregnated within a substrate to provide the desired surface chemistry [3-5]. While promising, treatments had not been performed using HA particles. Based on the difference in hardness of HA with respect to other more common mineral and ceramic abrasives, the ability to impart residual stresses and surface characteristics favorable to orthopedic applications has remained unknown. Thus a small exploratory study was performed to confirm that the waterjet treatment with HA particles is feasible. The primary objectives of the investigation were to confirm that HA particles can be introduced within the treated surfaces and that an increase in fatigue strength can be achieved.

MATERIALS AND METHODS

Commercially pure Titanium (cpTi) and a Titanium alloy (Ti6Al4V) were selected for the study based on their use in dental and orthopedic implants. The cpTi has a yield and ultimate tensile strength of 590 MPa and 660 MPa, respectively, while the Ti6Al4V has a yield and ultimate tensile strength of 1114 MPa and 1220 MPa, respectively. Each of the metals was obtained in wrought form as sheet (1.52 mm thickness) and circular rod (12.7 mm diameter). Rectangular specimens were sectioned from the sheet of both materials with dimensions of 18 mm x 127 mm. Fatigue specimens were prepared from the round stock of Ti6Al4V according to the standard RR Moore configuration with a 12.7 mm grip section and 6.35 mm gage section.

The surface treatments of all specimens were conducted using an OMAX Model 2652 abrasive waterjet. The machine is capable of discharging a mixture of water and abrasives at pressures within the range of 150-300 MPa. The nozzle assembly consisted of a 0.36 mm diameter sapphire orifice and a tungsten carbide mixing tube of 0.9 mm internal diameter and 89 mm length. A schematic of the peening process is shown in Figure 1 on page 8.

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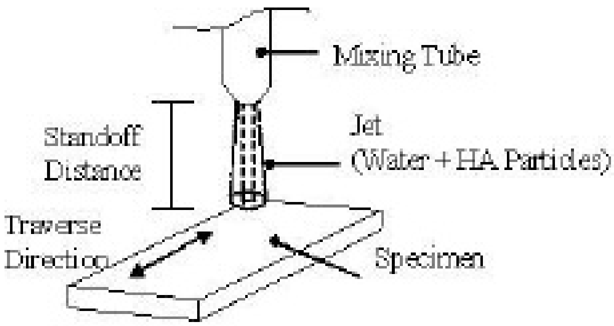

Figure 1 Process parameters for treatment

Surface treatments in the present study were conducted according to results of previous investigations on the treatment of Ti6Al4V and AISI 304 with either garnet or aluminum oxide particles [2, 4-6]. To maximize the HA concentration and magnitude of compressive residual stress the treatment pressure, standoff distance, particle flow rate and angle of incidence were held constant at 280 MPa, 220 mm, 0.3 kg/min and 90°, respectively. All treatments in the present study were performed using MCD apatitic abrasive particles (produced by "himed" of Old Bethpage, NY). The traverse speed was selected to achieve treatment intensities ranging from 0.01 to 0.05 sec/mm^2, which corresponds to surface traverse speeds of 0.5 m/min to 2.54 m/min; intensities of 0.01, 0.015, 0.02, 0.025, 0.03 and 0.05 sec/mm^2 were used.

Particles embedded within the treated surfaces were identified using a JEOL JSM-5600 scanning electron microscope (SEM). An accelerating voltage of 20 kV and working distance of 20 mm were used for all measurements. The particles were identified according to the surface chemistry, by the presence of calcium (Ca) and phosphorus (P) and the concentration of particles was determined according to a map of the chemistry over the surface area examined, which was achieved using Energy Dispersive X-Ray Analysis (EDXA). For each specimen the concentration of HA particles were quantified at two locations using a magnification of 200X.

The residual stress resulting from AWJ peening was estimated from the curvature imparted to the rectangular specimens, using a simple mechanics of materials approach. Details of the methods of evaluation are described in Reference [2]. The aforementioned approach provides a first-order estimate of the surface residual stress and a useful means for comparing residual stress over the range of treatment parameters. The subsurface residual stress distribution can be determined using the layer removal method [7] and is reserved for future study.

In addition to characterizing properties of the treated surfaces, the influence of HA treatments on the fatigue strength of Ti6Al4V was also studied. The R.R Moore fatigue specimens were treated using conditions that resulted in the maximum compressive residual stress in the rectangular specimens and consisted of a pressure, standoff distance, particle size range and treatment intensity of 280 MPa, 220mm, #40-#60 and 0.03 sec/mm^2 respectively.

Fatigue testing was conducted at room temperature under fully reversed fatigue (R = -1) using a standard R.R. Moore rotating bending machine [8]. The fatigue life distribution of the specimens was modeled according to the methodology followed in Reference [2]. Results of the model were used in estimating the apparent endurance strength of the metals (at 1E07 cycles) and the contribution of HA treatment to the fatigue strength. Fracture surfaces of the specimens were examined using a Nikon SMZ 800 stereomicroscope and the SEM to identify additional features characterizing the source of failure.

RESULTS AND DISCUSSION

Surface treatment of the cpTi and Ti6Al4V specimens was conducted using identical conditions. In an evaluation of the treated surfaces with the SEM, hydroxyapatite particles were clearly evident. An example of particles in the surface of a specimen is shown in Figure 2(a). The concentration of Calcium and Phosphorus on the surface of the treated specimens was quantified using EDXA. An example grayscale map of the surface chemistry distribution on the surface of a treated specimen is shown in Figure 2(b). The surface area comprised of either Calcium (Ca) or Phosphorus (P) is highlighted in white, whereas the surface area corresponding to either Ti, Al or V are shown in black.

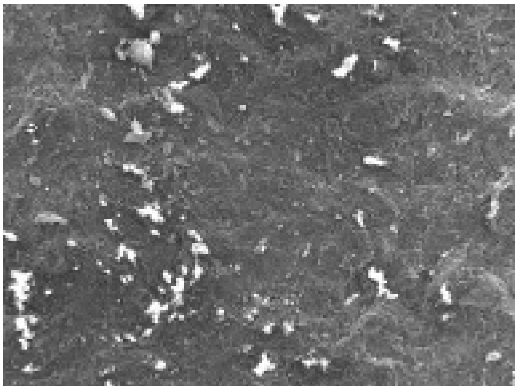

Figure 2a Embedded HA particles on the surface of a treated sample

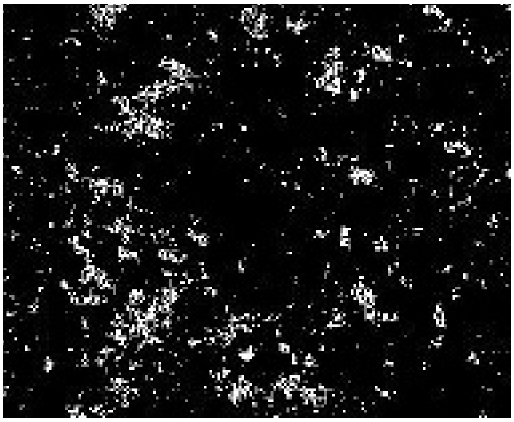

Figure 2b Grayscale map of the surface chemistry distribution (white = HA)

Residual stresses in the specimen were evaluated as a function of the percentage of embedded particles resulting from AWJ peening of Ti6Al4V and CP titanium and shown in Figure 3 on page 10. Despite an increase in average surface roughness (from 1 to nearly 6 μm), there was a marked increase in the fatigue life of Ti6Al4V when treated with HA. On a logarithmic scale, there was a 50 MPa increase in the stress amplitude required for failure in HA treated Ti6Al4V specimens. This fatigue life increase can be seen in Figure 4 (page 10).

CONCLUSIONS

A waterjet laden with hydroxyapatite (HA) particles was utilized in conducting surface treatments of commercially pure

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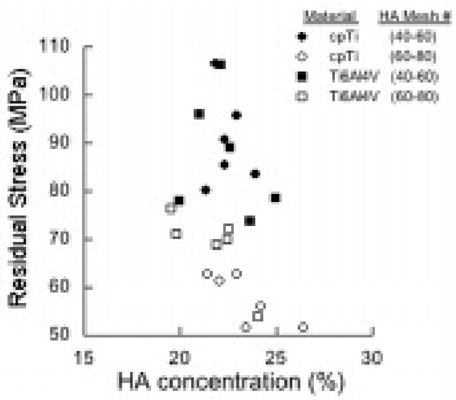

Figure 3 Relationship between the percentage of embedded particles and residual stress resulting from AWJ peening of Ti6Al4V and CP titanium

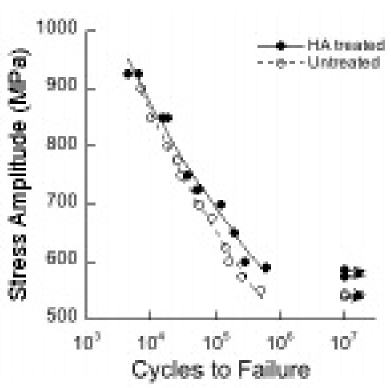

Figure 4 Stress life diagram for treated and untreated Ti6Al4V

titanium (cpTi) and a titanium alloy (Ti6Al4V). The concentration of HA and residual stress resulting from treatment of each metal were evaluated and the increase in fatigue strength of Ti6Al4V specimens subjected to the waterjet treatments was determined. Based on results of the investigation the following conclusions were drawn:

a) HA particles were impregnated within the surface of the cpTi and Ti6Al4V targets and the surface concentration of HA ranged from 19 to 25% coverage. There was no apparent influence of the treatment intensity or particle size on the concentration of impregnated HA particles.
b) Regardless of the process conditions, the surface treatment resulted in compressive residual stresses. In both the cpTi and Ti6Al4V the stress ranged from 50 to 110 MPa. Treatments conducted with the larger HA particles and treatment intensity resulted in the largest residual stress.
c) Surface treatment of the Ti6Al4V with an intensity of 3 s/cm^2 resulted in a 10% increase in the fatigue strength with respect to the untreated metal. Results of the experimental evaluation suggest that further increase in fatigue strength can be achieved through an increase in the treatment intensity beyond that used in the present study.

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Shockform Inc. signs exclusive agreement with Sonats S.A. to market Stressonic® Peening Technology in North America

Montreal, QC. ShockForm Inc. has signed an exclusive agreement with France`s Sonats S.A. to do the marketing and sales of their Ultrasonic Peening Technology in North America.

Shockform Inc. will provide North American companies in the Aerospace, Energy, and Transportation sectors with technical and financial data to help them take advantage of the many benefits offered by the Stressonic® peening technology. Shockform Inc.`s president, Sylvain Forgues, stated "We are very pleased to have signed an agreement with Sonats S.A. We feel strongly that the lower peening costs and shorter cycle times offered by the Stressonic® technology will be very attractive to our customers. Our team of highly qualified specialists will work with clients to help them understand the technology and find the applications that will give them a competitive advantage."

Shockform Inc. provides sales and marketing services to small and medium companies with new and innovative technologies in the important field of structural fatigue life management. For further information, contact Sylvain Forgues at (514) 813-2533.

The Shot Peener Exhibits at SME's Manufacturing for Performance Conference

Mishawaka, Indiana. The Shot Peener magazine hosted a booth at the Society of Manufacturing Engineers' (SME) Manufacturing for Performance Conference and Exhibits. The event took place in January, 2006 in Indianapolis, Indiana, the U.S.'s hub for racing activity.

The Shot Peener staff worked as advocates of the shot peening process at the event by promoting shot peening as a way to improve vehicle performance, speed and safety to the designers and builders of motor sports vehicles and components.

Jack Champaigne (left), Editor of The Shot Peener, explains the benefits of the shot peening process to Benny Parsons (right), International Motor Sports Hall of Famer and former NASCAR champion. Jim Lorizz, Senior Tehcnical Editor for SME, is in the middle. Mr. Parson delivered the keynote address at the Manufacturing for Performance Conference.