

Additively Manufactured Tantalum Parts for Orthopedic Applications

This paper provides a brief summary of findings in the scientific and medical literature regarding the benefits of using tantalum materials in orthopedic applications including use of additive manufacturing processes. Samples of some of these references are provided below for the reader.

Tantalum has been in use in certain medical applications since the 1940's and increased in recorded use through the latter half of the 20 century to the present. For example, numerous articles have been published that reviewed the use of tantalum in staplesⁱ for ligation; wire for Stentsⁱⁱ; coatings for medical devicesⁱⁱⁱ and for orthopedic applications.^{iv} These articles also review the reported attributes in these applications such as Tantalum's inert bioactivity;^v antithrombotic property; enhancement of macrophage response;^{vi} bactericidal properties.^{vii}

Over the last 25 years, in orthopedic implants, various Stainless steels, Titanium and CoCrMo alloys have been diffusion bonded or simply sintered into near net shape or thermally sprayed onto mass-produced forms, in order to improve fixation of an orthopedic implant.^{viii} These articles also review the attributes of these materials and techniques in these applications.^{ix}

By comparison, the literature referenced below has discussed inert *in vivo* and *in vitro* properties of porous Tantalum and address osseointegration as compared to certain other metals and alloys, and address the elastic modulus being similar to subchondral and trabecular bone, and attributes related to stress shielding,^x as well as possessing a high coefficient of friction for biomaterials which can result in initial stabilization of an implant immediately after surgery.^{xi} Specific studies have noted the porous Tantalum morphology as a framework for bone growth and osteoblast interaction.^{xii} Additional evidence have indicated that human osteoblasts (cell line hFOB) exhibit potentially six time higher living cell density on Tantalum as compared to Titanium.^{xiii} Researchers have also discovered that the elastic modulus of porous Tantalum can be modified over an order of magnitude by changing the porosity between 27 and 55%.^{xiii} Indeed, as further noted in these articles, some commercial applications have been developed with porous tantalum implants that indicate, both *in vitro* and *in vivo*, osseointegration, secure mechanical attachment, biocompatibility, and minimal metal wear, yet providing friction.^{xiv}

Recently there have been reports of using Additive Manufacturing techniques to produce fully dense open-celled structures for load bearing implants.^{xv} Selective Laser Melting (SLM) specifically has been shown capable of making structures with high range interconnected porosity. SLM produced tantalum porous-structure also demonstrated mechanical properties relatively similar to human bone and osseointegration as compared to similar porous Ti-6Al-4V structures. One conclusion reached from this work was that "laser-melted tantalum shows excellent osteoconductive properties, has higher normalized fatigue strength and allows for more plastic deformation due to its high ductility."^{xvi}

ⁱ Kylberg F. The use of tantalum clips in general surgery. Acta Chir Scand. 1975; 141(3): 242-4.

Chandler, Harry, (ed). 1998. Metallurgy for the Non-Metallurgist, First Edition, p. 65. ASM International.

Davis, Joseph R. (ed). 1997. ASM Specialty Handbook: Heat-Resistant Materials. ASM International.

Bronzino, Joseph D.; Peterson, Donald R. 2006. Biomedical Engineering Fundamentals. CRC Press.

ⁱⁱ Glocker, David. Tantalum-coated Stents. Advanced Materials and Processes 166(4):58-59. April 2008.

- Cheng, Y; Ci, W.; Li, H. T. and Zheng, Y. F. Surface modification of NiTi alloy with tantalum to improve its biocompatibility and radiopacity. *J Mater Sci* (2006) 41: 4961.
- Neal A.ScottMD, PhD, et.al. Comparison of the thrombogenicity of stainless steel and tantalum coronary stents. *American Heart Journal*. Volume 129, Issue 5, May 1995, Pages 866-872.
- van der Giessen, W. J., et.al. Coronary stenting with a new, radiopaque, balloon-expandable endoprosthesis in pigs. 1991;83:1788-1798. *Circulation*. American Heart Association.
- ⁱⁱⁱ Materials and Coatings for Medical Devices: Cardiovascular. ASM Materials for Medical Devices Database Committee, p. 124 – 129. 2009. ASM International.
- Shrivastava, hrivastava (ed). *Medical Device Materials V: Proceedings from the 2009 Materials & Processes for Medical Devices Conference*. 2009. ASM International.
- ^{iv} Balla, Vamsi Krishna; Bodhak, Subhadip; Bose, Susmita and Bandyopadhyay, Amit. Porous Tantalum Structures for Bone Implants: Fabrication, Mechanical and In vitro Biological Properties. *Acta Biomater*. 2010 Aug; 6(8): 3349–3359.
- Paganias, Christos G.; Tsakotos, George A.; Koutsostathis, Stephanos D. and Macheras, George A. Osseous integration in porous tantalum implants. *Indian J Orthop*. 2012 Sep-Oct; 46(5): 505–513.
- ^v Barbinta AC, Chelariu R, Crimu CI, Istrate B, Nazarie S, Earar K, Munteanu C. Metallographic characterization of a new biomedical titanium-based alloy for orthopedic applications. *Bulletin of the Transilvania University of Brasov. Series I: Engineering and Science*. 2013; 6(55):83-8.
- ^{vi} C. B. Johansson, H. A. Hansson, and T. Albrektsson, “Qualitative interfacial study between bone and tantalum, niobium or commercially pure titanium,” *Biomaterials*, vol. 11, no. 4, pp. 277–280, 1990.
- ^{vii} Schildhauer T.A., Peter E, Muhr G, Köller M. Activation of human leukocytes on tantalum trabecular metal in comparison to commonly used orthopedic metal implant materials. *J Biomed Mater Res A*. 2009 Feb;88(2):332-41.
- ^{viii} Galante J, Rostoker W, Lueck R, Ray RD. Sintered fiber metal composites as a basis for attachment of implants to bone. *J Bone Joint Surg [Am]* 1971;53-A:101–114.
- Pilliar RM, Cameron HU, Macnab I. Porous surface layered prosthetic devices. *J Biomed Eng*. 1975; 10:126–131.
- Spector M. Bone ingrowth into porous metals. In: Williams DF, editor. *Biocompatibility of orthopaedic implants*. Florida: CRC Press; 1982. pp. 89–128.
- Stein T, Armand C, Bobynd JD, Krygier JJ, Miller J, Brooks CE. Quantitative histological comparison of bone growth into titanium and cobalt-chromium porous coated canine implants. *Orthop Trans*. 1991;15:178.
- ^{ix} Antunes RA, Oliveira MC. Corrosion fatigue of biomedical metallic alloys: Mechanisms and mitigation. *Acta Biomaterialia*. 2012; 8:937–962.
- Perl DP, Brody AR. Alzheimer’s disease: X-ray spectrometer evidence of aluminum accumulation in neurofibrillary tangle-bearing neurons. *Science*. 1980;208:297–299.
- Anwar HA, Hart AJ, Visuvanathan S, Aldam CH. The effects of the heavy metals from total hip replacement wear debris on bacterial growth. *J Bone Joint Surg Br*. 2009; 91:300.
- Keegan GM, Leatmonth ID, Case CP. A systemic comparison of the actual potential and theoretical health effects of cobalt and chromium exposures from industry and surgical implants. *Crit Rev Toxicol*. 2008;38:645–674.
- Hosman AH, Mei HC, Bulstra SK, Kuijjer R, Busscher HJ, Neut D. Influence of Co-Cr particles and Co-Cr ions on the growth of staphylococcal biofilms. *Int J Artif Organs*. 2011; 34:759–765.
- Lhotka C, Szekes T, Stefan I. Four years study of cobalt and chromium blood levels in patients managed with two different metal-on-metal total hip replacement. *J of Orthopedic Res*. 2003; 21:189–195.
- Lin DJ, Chuang CC, Lin JHC, Lee JW, Ju CP, Yin HS. Bone formation at the surface of low modulus Ti–7 5Mo implants in rabbit femur. *Biomaterials*. 2007; 28:2582–2589.
- Amel-Farзад H, Peivandi MT, Yusof-Sani SMR. In-body corrosion fatigue failure of a stainless steel orthopaedic implant with a rare collection of different damage mechanisms. *Eng Fail Anal*. 2007; 14:1205–1217.
- Manivasagam G, Dhinasekaran D, Rajamanickam A. biomedical implants: corrosion and its prevention – A review. *Rec Pat Corros Sci*. 2010;2:40–54.
- Finì M, Aldini NN, Torricelli P, Giavaresi G, Borsari V, Lenger H. A new austenitic stainless steel with negligible nickel content: An in vitro and in vivo comparative investigation. *Biomaterials*. 2003;24:4929–4939.
- Müller R, Abke J, Schnell E, Macionczyk F, Gbureck U, Mehrl R. Surface engineering of stainless steel materials by covalent collagen immobilization to improve implant biocompatibility. *Biomaterials*. 2005; 26:6962–6972.
- Takemoto S, Hattori M, Yoshinari M, Kawada E, Oda Y. Corrosion behavior and surface characterization of titanium in solution containing fluoride and albumin. *Biomaterials*. 2005; 26:829–837.
- Okazaki Y, Gotoh E. Comparison of metal release from various metallic biomaterials in vitro. *Biomaterials*. 2005; 26:11–21.

- ^x Levine BR, Sporer S, Poggie RA, Valle CJD, Jacobs JJ. Experimental and clinical performance of porous tantalum in orthopedic surgery. *Biomaterials*. 2006; 27:4671–4681.
- Levine B, Della Valle CJ, Jacobs JJ. Applications of porous tantalum in total hip arthroplasty. *J Am Acad Orthop Surg*. 2006;14:646–655.
- Rubitschek E, Niendorf T, Karaman I, Maier HJ. Corrosion fatigue behavior of a biocompatible ultrafine-grained niobium alloy in simulated body fluid. *J Mech Behav Biomed Mater*. 2012; 5:181–192.
- Sevilla P, Aparicio C, Planell JA, Gil FJ. Comparison of the mechanical properties between tantalum and nickel–titanium foams implant materials for bone ingrowth applications. *J Alloys Compd*. 2007; 439:67–73.
- ^{xi} Shimko DA, Shimko VF, Sander EA, Dickson KF, Nauman EA. Effect of porosity on the fluid flow characteristics and mechanical properties of tantalum scaffolds. *J Biomed Mater Res B Appl Biomater*. 2005;73:315–24.
- Zhang Y, Ahn PB, Fitzpatrick DC, Heiner AD, Poggie RA, Brown TD. Interfacial frictional behavior: Cancellous bone, cortical bone, and a novel porous tantalum biomaterial. *J Musculoskeletal Res*. 1999;3:245–51.
- Miyazaki T, Kim HM, Kokubo T, Ohtsuki C, Kato H, Nakamura T. Mechanism of bonelike apatite formation on bioactive tantalum metal in a simulated body fluid. *Biomaterials*. 2002;23:827–32.
- Kokubo T, Kim HM, Kawashita M. Novel bioactive materials with different mechanical properties. *Biomaterials*. 2003;24:2161–75.
- Levine BR, Sporer S, Poggie RA, Della Valle CJ, Jacobs JJ. Experimental and clinical performance of porous tantalum in orthopedic surgery. *Biomaterials*. 2006;27:4671–81.
- ^{xii} D. M. Findlay, K. Welldon, G. J. Atkins, D.W.Howie, A. C.W. Zannettino, and D. Bobyn, “The proliferation and phenotypic expression of human osteoblasts on tantalum metal,” *Biomaterials*, vol. 25, no. 12, pp. 2215–2227, 2004.
- Paganias, Christos G.; Tsakotos, George A.; Koutsostathis, Stephanos D. and Macheras, George A. Osseous integration in porous tantalum implants. *Indian J Orthop*. 2012 Sep-Oct; 46(5): 505–513.
- ^{xiii} Balla VK, Banerjee S, Bose S, Bandyopadhyay A. Direct Laser Processing of Tantalum Coating on Titanium for Bone Replacement Structures. *Acta Biomater*. 2009 doi:10.1016/j.actbio.2009.11.021.
- ^{xiv} Hacking SA, Bobyn JD, Toh K, Tanzer M, Krygier JJ. Fibrous tissue ingrowth and attachment to porous tantalum. *J Biomed Mater Res*. 2000; 52:631–638.
- Miyazaki T, Kim HM, Kokubo T, Ohtsuki C, Kato H, Nakamura T. Mechanism of bonelike apatite formation on bioactive tantalum metal in a simulated body fluid. *Biomaterials*. 2002; 23:827–832.
- Kokubo T, Kim HM, Kawashita M. Novel bioactive materials with different mechanical properties. *Biomaterials*. 2003;24:2161–2175.
- Bobyn JD, Toh KK, Hacking SA, Tanzer M, Krygier JJ. Tissue response to porous tantalum acetabular cups: a canine model. *J Arthroplasty*. 1999;14:347–354
- Matsuno H, Yokoyama A, Watari F, Motohiro U, Kawasaki T. Biocompatibility and osteogenesis of refractory metal implants, titanium, hafnium, niobium, tantalum and rhenium. *Biomaterials*. 2001 ;22:1253–1262.
- Levine BR, Sporer S, Poggie RA, Della Valle CJ, Jacobs JJ. Experimental and clinical performance of porous tantalum in orthopedic surgery. *Biomaterials*. 2006; 27:4671–4681.
- ^{xv} Krishna BVamsi, Bose Susmita, Bandyopadhyay Amit. Low Stiffness Porous Ti Structures for Load Bearing Implants. *Acta Biomater*. 2007; 3:997–1006.
- Krishna BVamsi, Xue Weichang, Bose Susmita, Bandyopadhyay Amit. Engineered Porous Metals for Implants. *JOM*. 2008;60(5):45–48
- Bandyopadhyay Amit, Krishna BVamsi, Xue Weichang, Bose Susmita. Application of Laser Engineered Net Shaping (LENS) to Manufacture Porous and Functionally Graded Structures for Load Bearing Implants. *J Mater Sci - Mater Med*. 2009; 20:S29–S34.
- ^{xvi} Wauthle, Ruben; Van der Stok, Johan; Yavari, Saber Amin and Schrooten, Jan. Additively manufactured porous tantalum implants. *Acta Biomaterialia*. March 2015



For more information contact:

Craig Sungail
Vice President R&D
e: CSungail@globaladvancedmetals.com
1223 County Line Road, Boyertown, PA, 19512, US

Ryan Clement
Vice President of Sales and Marketing
e: rclement@globaladvancedmetals.com
100 Worcester Street, Suite 200, Wellesley, MA, 02481, US

DISCLAIMER: The information contained in this document was obtained from third party sources. GAM has not independently tested or confirmed the accuracy or conclusions of these sources and GAM is not responsible for any errors or omissions, or for the results obtained from the use of the information provided in this article and the articles cited below. All information in this article is provided “as is”, with no guarantee of completeness or accuracy of the results obtained from the use of the information in this article and the articles cited below, and without any kind of warranty, express or implied.

25 January 2019