The Machinability of Cast Ti-Sn Alloys for Dental Applications

黃忠榮、何文福

E-mail: 387133@mail.dyu.edu.tw

ABSTRACT

This study is one of the Bio-Medical Material laboratory research series on Titanium alloy that has superior mechanical and mechinability properties. Microstrucutre, mechanical properties, machinability are observed on a series of Titanium (Ti) – Tin (Sn) alloy test samples produced by a dental cast machine and compared with commercially pure (grade II) Titanium (cp Ti) samples used as control. Sn content of as-cast Ti-Sn samples varied between 1 to 30 wt% (Ti-xSn, x = 1, 5, 10, 20, and 30). Microstructure XRD analysis concludes diffraction peaks of all the Ti-xSn alloy samples matched those for α Ti, and no β or other intermediate phase.Hardness of Ti-xSn alloy increases when Sn content increases. Started from the 246HV observed on Ti – 1Sn, hardness value raised to the highest 357HV observed on Ti – 30Sn. After Sn content exceeds 20 wt%, the mechanical property transformed from ductile to brittle. Machinability is evaluated the aveage cutting force and the smooth of the cutting surface. Test samples are machined with Computer Numeric Control (CNC) doctor bed. Under the same tool setting, the cutting force observed increases significantly on the Ti – xSn samples have higher Sn content. The cutting force of alloy under the 110 m/min cutting speed and 30 mm/min feed rate is 8.33N. The cutting surface coarse level of Ti – 20Sn is 0.57 nm, the lowest among all samples. From the observed test results of this study, Ti – xSn alloy possess impressive mechanical and machinablility properties. It is reasonable to believe that Ti – xSn alloy could be better choices for dental casting and many other Computer Aided Design /Manufacturing (CAD/M) machining applications. High potential shall be expected.

Keywords : dental alloy、Ti-Sn alloy、mechanical、microstructure、machinability

Table of Contents

REFERENCES

[1]Helmus MN, Tweden K, Materials selection. Encyclopedic Handbook of Biomaterials and Bioengineering. Materials A 1(1):27-59, 1995.
[2]林峰輝、白育綸，生物醫用材料，新文京，1998。
[3]陳劉旺，生醫材料，化工，38，2，P51，1991。
[4]Narushima T, Titanium and its alloys as biomaterials The Japan Institute of Metals 55(11):561-565, 2005.
[5]Ratner BD, Biomaterials science: an introduction to materials in medicine. Academic Press, San Diego, 1996.
[6]Park JB, Lakes RS, Biomaterials: an introduction. Plenum Press, 2nd ed., New York, 1922.
[7]Hulbert SF, Bokros JC, Hench LL, Wilson J, Heimke G, Ceramics in clinical applications-past, present and future, in Ceramics, in Clinical Applications, edited by Vincenzini P, Elsevier. Amsterdam, Netherlands pp. 3-27, 1987.
[8]Silver FH, Biomaterials, medical devices, and tissue engineering: an integrated approach. Chapman & Hall, 1st ed., New York, 1994.
[9]劉秀琴，醫療器材產業之孕育-人工骨的誕生，材料與社會，78期，82年6月，pp. 47-50。
[10]筏義人，生体材料學，產業圖書株式會社，東京，日本，1994。
[11]Inglis AE, Advances in implant arthroplasty in the upper extremity, circa 1988. Clinical & Experimental Rheumatology 7(3):141-144, 1989.
[12]Williams D F, Blood Compatibility. CRC press, 1987.
[13]Lelah D, Cooper SL, Polyurethane in medicine, CRC Press 1986.
[14]黃世偉，高分子材料與醫療器材，科學發長，455期，2010年11月，pp.14-19。
[15]Block MS, Kent JN, Guerra LS, Implants in dentistry. Philadelphia: Saunders pp. 45-62, 1997.
[16]Rateitschak KH, Wolf HF, Color atlas dental medicine. Thieme Medical Publishers pp. 11-24, 1995.
[17]Park JB, Lakes RS, Biomaterials: an introduction. Plenum Press, 2nd ed., New York, 1992.
[18]Paul R, Alkaline aqueous electrolyte cell for biomedical application. Journal of The Electrochemical Society 127(8) pp.1667-1678, 1980.
[19]Okazaki Y, Rao S, Ito Y, Tateishi T, Corrosion resistance, mechanical properties, corrosion fatique strength and cytocompatibility of new Ti alloys without Al and V. Biomaterials 19:1197-1215, 1998.
[20]Okazaki Y, Ito Y, Kyo K, andtateishi T, Corrosion resistance and corrosion fatigue strength of new titanium alloys for medical implants without V and Al. Materials Science and Engineering v213 pp. 138-147, 1996.
[21]Hench LL, Ethridge EC, Biomaterials - an Interfacial approach. Acdamic Press, New York, pp. 18-21, 1982.
[22]Browning E, Toxicity of Industrial Metals. 2nd ed. Butterworths. Lodon, 1969.
[23]Doremus RH, Review bioceramics. Journal of Materials Science 27(3):287-297, 1992.
[24]Hench LL, Bioceramics: from concept to clinic. Journal of the American Ceramic Society 74(17):1487-1510, 1991.
[25]Wroblewski BM, 15-21 year results of the charnley low friction arthroplasty, Clinical Orthopaedics 211:30-35, 1986.
[26]Steflik DE, McKinney RV, Sisk AL, Koth DL, Singh BB, Parr GR, Ultrastructural investigations of the bone and fibrous connective tissue interface with endosteal dental implants. Scanning Microscopy 4(4):1039-1047, 1990.
[27]Lautenschlager EP, Monaghan P, Titanium and titanium alloys as dental materials. International Dental Journal 1993;245-531.
[28]Kobayashi E, Matsumoto S, Doi H, Yoneyama T and Hamanaka H,“Mechanical properties of the binary titanium-zirconium alloys and their potential for biomedical materials,”Journal of Biomedical Materials Research, 29:943-950, 1995.
[29]Robare EW, Bugle CM, Davidson JA, Daigle KP. Development of processing methods for Ti-13Nb-13Zr. In: Weiss I, Srinivasan R, Bania PJ, Eylon D, Semiatin SL, editors. Advances in the Technology of Titanium Alloy Processing. The Minerals. Metals and Materials Society, 1997. p.283-291.
[30]Nouri A, Chen X, Li Y, Yamada Y, Hodgson PD, Wen C, Synthesis of Ti-Sn-Nb alloy by powder metallurgy. Materials Science and

Engineering A 485:562-570, 2008.
[31]Wang BL, Zheng YF, Zhao LC, Effects of Sn content on the microstructure, phase constitution and shape memory effect of Ti-Nb-Sn alloys. Materials Science and Engineering A 486:146-151, 2008.
[32]Kokubo T, Nakamura T, Miyaji F, Bioceramics 9: Proceedings of the 9th International Symposium on Ceramics in Medicine. Otsu Japart p.11, 1996.
[33]島村 昭治，未來?拓?先端材料，工業調查?，1989; pp. 186-190。
[34]Williams DF, Biocomatibility of Clinical implant materials. v2, CRC press, Inc. Boca Raton, Florida, pp. 112, 1981.
[35]Mckellop HA, Rostlund TV, The wear behavior of ion-implanted Ti-6Al-4V against UHMW polyethylene. Journal of Biomedical Materials Research 24:1413-1425, 1990.
[36]Richard V.N,“Introduction to dental materials”, Publisher: Mosby, 2nd ed., 2002.
[37]Combe EC, Trevor Burke FJ, Douglas WH, Dental biomaterials. Boston: Kluwer Academic Publishers pp. 476, 1999.
[38]Williams DF, Biocomatibility of Clinical implant materials. v2, CRC press, Inc. Boca Raton, Florida pp. 112, 1981.
[39]草道英武，金????????用，日刊工業新聞社，東京，日本，1983。
[40]Moffat DL, Larbalestier DC, The competition between Martensite and Omega in Quenched Ti-Nb Alloys. Metall Trans, A19 (7):1677-1686, 1988.
[41]Covington LC, Corrosion resistance of titanium. Met. Handb., 9th, ASM publications, Ohio, 3:413-415, 1979.
[42]郁仁貽，冶金學概論(下冊)，徐氏基金會出版，1988。
[43]黃瓊嫻，骨內錨定，科學發展，2005；394。
[44]賴耿陽，金屬鈦，復漢出版社，1990，pp. 1-60。
[45]楊榮顯，工程材料學，全華科技圖書股份有限公司，2005。
[46]Nishiyama Z, Transformation, Academic Press. New Tork, 1978.
[47]Murray JL, Phase diagrams of binary titanium alloys. ASM Metal Park ohio pp. 197-211. 1987.
[48]楊哲青，生醫用鈦合金之滑動磨潤性質研究，國立成功大學材料科學與工程學系碩士論文，2003。
[49]Collings EW, The physical metallurgy of titanium alloys. Met. Park OH: American Society of Metals pp. 3-5, 1984.
[50]Williams DF, Biocompatiblity of clinical implant materials. ed. CRC Press, 1981.
[51]Molchanova, EK, Phase Diagrams of Titanium. Isr. Pro. Sci. Trans., Jerusalem, 1965.
[52]Machado AR, Wallbank J, Machining of titanium and its alloys - a review. Proc. Institution of Mechanical Engineers B 204(1):53-60, 1990.
[53]Blenkinsop PA, High temperature titanium alloys. IMI Titanium Limited, Birmingham, England pp. 189-198, 1986.
[54]Kahles JF, Field M, Eylon D, Froes FH, Machining of titanium alloys. J. Met. 37(4):27-35, 1985.
[55]Borradaile JB, Jeal RH, Mechanical properties of titanium alloys. Warrendale Metallurgical society of AIME, vols. 1-3, 1980.
[56]郁仁貽，“冶金學概論(上冊)，徐氏基金會出版，1988。
[57]吳啟岳，金屬材料，三民書局印行，1976。
[58]Niinomi M, Recent research and development in titanium alloys for biomedical applications and healthcare goods. Science and Technology of Advanced Materials 4:445-454, 2003.
[59]Bania PJ, Hall JA, Titanium Science and Technology. Deutsche Gesellschaft fur Metallkunde. Oberursel. Germany, 1985.
[60]Ogata T, Tanaka Y, Miura E, Takuma Y, Shiraishi T, Hisatsune K, Castability and Mechanical Properties of Experimental Ti-Zr-Sn Alloys for Dental Application. Journal of the Japanese Society for Dental Materials 240-246, 2005.
[61]Das J, Ettingshausen F, Theissmann R, Loser W, Eckert J, Microstructure and mechanical properties of Ti-Fe-(Sn) ultrafine eutectic alloys. Transactions of the Indian Institute of Metals 60(2-3):229-233, 2007.
[62]Murray JL, Phase diagrams of binary titanium alloys. v15, ASM International, Met. Park, Ohio, 1987.
[63]Kawhara K. Cytotoxicity of implantable metals and alloys. Bull Jpn Inst Met 1992;31:1033-1039.
[64]鄭文偉，“添加合金元素對鈦或鈦合金鑄造性及性質研究”，成功大學，2002。
[65]Okazaki Y, Kyo K, Ito Y, Tateishi T, Corrosion resistance and mechanical properties of new titanium alloys for centrifugally cast dental. Materials Transactions, 38:163-170, 1997.
[66]Okazaki Y, Rao S, Ito Y, Tateishi T, Corrosion resistance, mechanical properties, corrosion fatigue strength and cytocompatibility of new Ti alloys without Al and V. Biomaterials 19(13):1197-1215, 1998.
[67]Maeshima T, Ushimaru S, Yamauchi K, Nishida M, Effect of heat treatment on shape memory effect and superelasticity in Ti-Mo-Sn alloys. Materials Science and Engineering A 438-440:844-847, 2006.
[68]Hao YL, Li SJ, Sun SY, Yang R, Effect of Zr and Sn on Young’s modulus and superelasticity of Ti-Nb-based alloys. Materials Science and Engineering A 441:112-118, 2006.
[69]Sutou Y, Yamauchi K, Takagi T, Maeshima T, Nishida M, Mechanical properties of Ti-6at.%Mo-4at.%Sn alloy wires and their application to medical guidewire. Materials Science and Engineering A 438-440 pp. 1097-1100, 2006.
[70]Matsumoto H, Watanabe S, Hanada S, Microstructures and mechanical properties of metastable β TiNbSn alloys cold rolled and heat

treated. Journal of Alloys and Compounds 439:146-155, 2007.
[71]Hao YL, Li SJ, Sun SY, Zheng CY, Yang R, Elastic deformation behaviour of Ti-24Nb-4Zr-7.9Sn for biomedical applications. Acta Biomater 3:277-286, 2007.
[72]王濤，戴品強，謝宇玲，項忠楠，生物醫用Ti-16Nb-4Sn合金的超彈性和形狀記憶效應，熱加工工藝，37(2):9-12, 2008。
[73]Han JH, Park DH, Bang CW, Yi S, Lee WH, Kim KB, Sn effect on microstructure and mechanical properties of ultrafine eutectic Ti-Fe-Sn alloys. Journal of Alloys and Compounds, 2008.
[74]Long M, Rack HJ. Titanium alloys in total joint replacement-a materials science perspective. Biomaterials 1998;19:1621-1639.
[75]Steinemann SG. Surgical implant and alloy for use in making an implant. US Patent No. 4040129. 1977.
[76]岡崎義光，生体材料???????合金開?，輕金屬， 1999;49(12):613-620。
[77]桜井 弘， 金屬?人体???必要?，講談社?一????，1996。
[78]寺岡久之，森井??，小林 純， ?養?食糧， 34:221，1981。
[79]Silver FH. Biomaterials, Medical Devices and Tissue Engineering: An Integrated Approach. Boston: Chapman & Hall Press:London, 1994. p.15.
[80]Molchanova EK. Phase Diagrams of Titanium Alloys. Israel Program for Scientific Translations. Jerusalem, 1965. p.154.
[81]Leyens C, Peters M. Titanium and Titanium Alloys: Fundamentals and Applications. John Wiley & Son Inc, 2003.
[82]Cabrini RL, Olmedo D, Guglielmotti MB. A quantitative method to evaluate corrosion products in tissues. Acta Odontol Latinoamer 2003;16:27-33.
[83]Stojilovic N, Bender ET, Ramsier RD (2005) Surface chemistry of zirconium. Prog Surf Sci 78:101-184.
[84]Saldana L, Mendez-Vilas A, Jiang L, Multigner M, Gonzalez-Carrasco J. L, Perez-Prado M.T, et al. Biomaterials 28 4343,2007.
[85]Tewari, N., P. Vasudevan, and B.K. Guha. 2005. “ Study on Biosorption of Cr (Vl) by Mucar hiemalis ” . Biochemical Engineering Journal. 23:185-492.
[86]Nomura N, Tanaka Y, Suyalatu, Kondo R, Doi H, Tsutsumi Y, Hanawa T, Effects of phase constitution of Zr-Nb alloys on their magnetic susceptibilities. Mater Trans. 50:2466-2472, 2009.
[87]Mackenzie JK, Bowles JS. The crystallography of martensite transformations. Acta Metall 1954;2:138.
[88]Ankem S, Seagle SR. Heat treatment of Metastable Beta Titanium Alloys. Beta Titanium Alloys in the 1980 ’ s. in: Boyer RR, Rosenberg HW, editors. The Metallurgical society of AIME. 1984.
[89]Bowen AW. Omega Phase Formation in Metastable Beta-Titanium Alloys. Beta Titanium Alloys in the 1980's 1983;2:85-103.
[90]Yamada K, Ogawa A, Ouchi C, Eylon D. Effect of Al on omega phase transformation behavior in Ti-8 V-5 Fe-(1-3) Al alloy. Mater Trans 1996;37(4):855-859.
[91]Kobayashi S, Nakai K, Ohmori Y. Analysis of phase transformation in a Ti-10 mass% Zr alloy by hot stage optical microscopy. Mater Trans 2001;42(11):2398-2405.
[92]Ohmori Y, Ogo T, Nakai K, Kobayashi S. Effects of ω-phase on β to α, α〞 transformations in a metastable β titanium alloy. Mater Sci Eng A 2001;312:182-188.
[93]Beneteaua A, Weisbeckera P, Geandierb G, Aeby-Gautiera E, Appolairea B. Austenitization and precipitate dissolution in high nitrogen steels: an in situ high temperature X-ray synchrotron diffraction analysis using the Rietveld method. Mater Sci Eng A 2005;393(1-2):63-70.
[94]Sikka SK, Vohra YK, Chidambaram R. Omega phase in materials. Prog Mater Sci 1982;27:245-310.
[95]金聖泰， 小田豐， 住井俊夫，齒科???鑄造?????評價?關??研究，齒科學報，1994;94:845-857。
[96]Zinelis S. Effect of pressure of helium, argon, krypton, and xenon on the porosity, microstructure, and mechanical properties of commercially pure titanium castings. J Prosthet Dent 2000;84(5):575-582.
[97]Sunnerkrantz PA, Syverud M, Hero H. Effect of casting atmosphere on the quality of Ti-crowns. Scand J Dent Res 1990;98:268-272.
[98]Miyakawa O, Watanabe K, Okawa S, Nakano S, Kobayashi M, Shiokawa N. Layered structure of cast titanium surface. Dent Mater J 1989;8(2):175-185.
[99]Takahashi J, Kimura H, Lautenschlager EP, Chern Lin JH, Moser JB, Greener EH. Casting pure titanium into commercial phosphate-bonded SiO2 investment molds. J Dent Res 1990;69:1800-1805.
[100]Oda Y, Kudoh Y, Kawada E, Yoshinari M, Hasegawa K. Surface reaction between titanium castings and investments. Bull Tokyo Dent Coll 1996;37(3):129-136.
[101]Wang RR, Welsch GE, Castro-Cedeno M. Interfacial reactions of cast titanium with mold materials. Int J Prosthodont 1998;11(1):33-43.
[102]Kuroda D, Niinomi M, Morinaga M, Kato Y, Yashiro T. Design and mechanical properties of new β type titanium alloys for implant materials. Mat Sci Eng A 1998;243:244-249.
[103]佟天夫， 熔模鑄造工藝， 機械工業出版社， 1991， p. 335-42。
[104]Sjogren G, Andersson M, Bergman M. Laser welding of titanium in dentistry. Acta Odontol Scand 1988;46:247-253.
[105]Berg E, Davik G, Hegdahl T, Gjerdet NR. Hardness, strength, and ductility of prefabricated titanium rods used in the manufacture of spark erosion crowns. J Prosthet Dent 1996;75:419-425.

[106]王千億，王俊傑,機械製造I，全華科技圖書股份有限公司，台北，pp. 226-248，1996。
[107]簡文通，機械製造，全華科技圖書股份有限公司，台北，6-1至6-40，1997。
[108]Sun J, Guo YB, A comprehensive experimental study on surface integrity by end milling Ti – 6Al – 4V, Journal of Materials Processing Technology 209 : 4036 – 4042, 2009.
[109]Canteroa JL, Tardiob MM, Cantelia JA, Marcosc M, Migueleza MH, Dry drilling of alloy Ti-6Al-4V, International Journal of Machine Tools & Manufacture 45:1246 – 1255, 2005.
[110]Ohkubo C, Hosoi T, Ford JP, Watanabe I, Effect of surface reaction layer on grindability of cast titanium alloys. Dental Material, 22(3): pp. 268-274, 2006.
[111]Kikuchi M, Takahashi M, Sato H, Okuno O, Nunn ME, Okabe T, Grindability of cast Ti-Hf alloys. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 77(1): pp. 34-38, 2006.
[112]Takeyama H, Yoshikawa T, Takada T, Jpn J, Japan Society of Precision Engineering, 41 pp. 392-394 1975.
[113]Takeyama H, Murata R, Study on machinability of pure titanium. Japan Society of Precision Engineering, 28(6): pp. 331-337, 1962.
[114]Miyakawa O, Reactivity of titanium with abrasive materials and its polishing. Journal of the Japan, Prosthodontic Society, 42(4): pp. 540-546, 1998.
[115]Takeyama H, Murata R, Temperature dependence of tool wear. Japan Society of Precision Engineering, 27(1): pp. 33-38, 1961.
[116]洪良德，切削刀具學，全華科技圖書，台北，台灣，pp. 60-63，1992。
[117]徐明堅，最新切削加工技術，復漢出版社，台南，台灣， pp. 179-182，1992。
[118]姜宗佑，生醫用鈦-鉻二元合金之結構及性質探討，大葉大學，2007。
[119]Koike M., ltoh M., Okuno O., Kimura K., Takeda O., Okabe T.H. and Okabe T.，“ Evaluation of Ti-Cr-Cu alloys for dental applications ”, J. Mater. Eng. Perform., 14(6):778-783, 2005.
[120]Takahashi M, Kikuchi M and Takada Y，“ Grindability and microstructures of experimental Ti-Zr alloys, ”齒科材料器械，25(5):327，2006。
[121]Blackman R.B.，“ Evaluation of the dimensional changes and surface roughness of gold crowns cast with rapidly prepared phosphate-bonded investment: a pilot study ”, J. Prosth. Dent., 82(2):187-193, 2000.
[122]Kikuchi M, Takahashi M, Okuno O, Machinability of Experimental Ti-Ag Alloys. Dent. Mater. J 27(2):210-220, 2008.
[123]Goeuriot D, Dubois JC, Merle D, Thevenot F, Exbrayat P, Enstatite Based Ceramics for Machinable Prosthesis Applications. Journal of the European Ceramic Society 18(14):2045-2056, 1998.
[124]Ezugwu EO, Wang ZM, Titanium alloys and their machinability-a review. Journal of Materials Processing Technology 68(3): 262-274, 1997.
[125]Murray JL, Alloy Phase Diagrams. ASM International, Mater. Park, Ohio, pp. 294, 1987.
[126]Bagariaskii IA, Nosova GI, Tagunova TV, Factors in the formation of metastable phase in titanium-base alloys. Soviet Physics - Doklady, 30:1014-1018, 1959.
[127]Combe EC, Notes on dental materials. Churchill Livingstone, New York, pp. 64, 1977.
[128]Ammen CW, The Metalcaster ’ s Bible. McGraw Hill, PA, U.S.A., 1980.
[129]William DC, Materials science and engineering: an introduction. John Wiley & Sons, New York, 2003.