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Critical review on different burnishing processes of Ti-6Al-4V Alloy

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ABSTRACT

Titanium and its alloys are the most commonly and most widely used due to its significant properties like good biocompatibility , good tensile strength , low density , and good creep property up to 300 degrees centigrade .It is used in the major engineering fields like civil engineering , nuclear engineering , aerospace engineering etc. Surface finish of the titanium material plays a prominent role in influencing its functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. In normal machining methods like turning, milling or even classical grinding can't meet the desired surface finish. To overcome this one of the method employed is burnishing, which is very simple and effective method for improvement in surface finish and can be carried out on lathe machine. The latest innovate technique used in the burnishing is the cryogenic burnishing in which the liquid nitrogen is supplied as the coolant. This work deals with study of different burnishing processes of titanium alloy Ti-6Al-4V.

Keywords : Titanium, Burnishing, Titanium Alloys , Cryogenic Burnishing

I. INTRODUCTION

To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with high dimensional and geometrical accuracy but also with high surface finish. The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. Unfortunately, normal machining methods like turning, milling or even classical grinding can't meet this stringent requirement. Surface modifications and surface treatments play vital roles for increased service life of several critical components and devices that are used for engineering and structural functions. Numerous surface engineering approaches such as thermal, chemical, mechanical treatments, hard and soft coatings as well as hybrid treatments are employed covering both commercial and experimental treatments. One of the most competent surface engineering methods i.e. mechanical treatment, is the burnishing process. The finishing processes, namely grinding, lapping, polishing and honing, etc. are generally used to improve the surface finish. Unlike the above mentioned established methods, which normally depend upon chip removal, the burnishing process is a cold-working clipless process, which effortlessly produces an even and work-hardened surface by plastic deformation of surface irregularities. Burnishing improves the surface characteristics by plastically deforming the surface layers. Moreover, the conventional methods induce tensile residual stresses at the surface, whereas the burnishing process induces residual compressive stresses. Table 1.1 illustrates gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing.

Table 1: Illustrates gradual improvement of surface roughness produced by various processes

Process	Part Geometry	Surface roughness (R_a) in μm
Grinding	Flat, External cylinder	0.406 – 1.6 0.203 – 0.406
Honing	Round hole	0.102 – 0.813
Lapping	Flat or slightly spherical	0.0254 – 0.406
Super finishing	Flat, External cylinder	0.0127 – 0.203
Polishing	Different shapes.	0.0254 – 0.813
buffing	Different shapes.	0.0127 – 0.406

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the workpiece and imparting a feed motion to the same. During burnishing considerable residual compressive stress is induced in the surface of the workpiece and thereby fatigue strength and wear resistance of the surface layer increase. This process will smooth and harden the surface, creating a finish which will last longer than one that hasn't been burnished. It is characterized by a distinctive combination of elements, namely induction of profound and balanced compressive residual stress, work hardening, decreasing surface roughness as well as micro notches. Further, burnishing process is also a cost-effective, requires less skill and can be performed in conventional machine shop environments. The burnishing process decreases the surface defects and modifies the microstructure of traditional and non-traditional machined surfaces. Burnishing is a finishing process, accomplished by applying a highly polished hard ball to roll against the metallic surface under pressure, which results in smoothing of the surface, increase in hardness and corrosion resistance. Moreover, the tensile residual stresses in the surface zone are transformed into compressive stresses after burnishing, thus increasing the fatigue life of the components. Burnishing leads to an enhancement in the fatigue behaviour of work pieces under dynamic load and accomplishes higher wear resistance. Some of the applications of burnishing process are on automotive crankshafts, inner and outer bearing races, bogies axles, etc. Many research studies have been conducted to investigate the effects of burnishing feed, speed and force on surface roughness and hardness, during burnishing process.

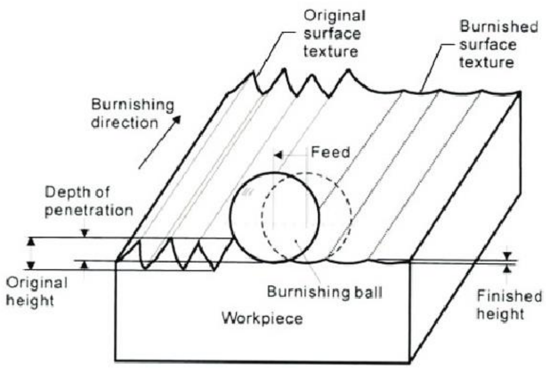

Figure 1. Schematic representation of burnishing operation

II. CLASSIFICATION OF BURNISHING PROCESSES

Burnishing process can be typically classified into two categories as:

1. Based on deformation element
    - a. Ball burnishing
        - i. Flexible
        - ii. Rigid
    - b. Roller burnishing
2. Based on the motion of the tool, on the surface
    - a. Normal or ordinary
    - b. Impact
    - c. Vibratory

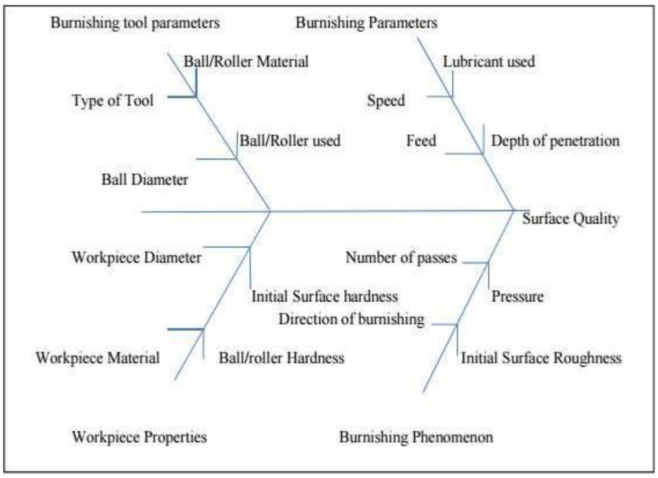

Figure 2. Fishbone Diagram for Burnishing Process

Many researchers and doctors around the globe reported that release of metal ions from the metal implant adversely effects the healing of bone and the surrounding tissues. In addition to this corrosion of the implant itself is bound to affect the essential properties of the implant such as fatigue life and tensile strength leading to the poor mechanical compatibility and eventually may result in failure of the implants. Titanium based materials are regarded as highly corrosion resistant mainly due to the strong passive oxide film formation at room temperature on their surface. This film which largely consists of TiO_2, protects material and provides chemical inertness in different media. However the titanium's passive state is not entirely stable and under certain conditions, the localized breakdown on a highly microscopic scale has been found to occur. Consequently, a strong destructive attack may occur on the surface of material due to its reaction with hostile environment. Any deficiency in the performance of the titanium's surface film is severely harmful to the corrosion behavior as well as on other required characteristics. Therefore, surface modification is often performed in order to enhance its mechanical, biological and chemical properties.

The importance of the surface modification is increasing the research interest and huge unexplored area is the driving force behind this work. The present study has been done with a view to provide the alternative method for surface modification methods and techniques for improving corrosion behavior of Ti alloys in human body fluid.

III. LITERATURE REVIEW

The effectiveness of cryogenic cooling in machining titanium alloy was pointed out in [1], where it was recommended the simultaneous cooling of the workpiece and the tool in order to enhance their chemical stability and hardened.

In [2] the effects of the cutting conditions on the surface integrity in machining wrought Ti6Al4V were evaluated, showing that the cryogenic cooling led to a reduction in grain size due to the suppression of grain growth after dynamic recrystallization,which was the result of severe plastic deformation.

Sun et al. [3] applied cryogenic cooling when machining Ti6Al7Nb and found an improvement in the surface and sub-surface hardness due to the mitigation of thermal softening effect and, as a consequence, less transformation from α to β phase.

Tang et al. [4] applied cryogenic burnishing to Ti6Al4V and they found an improvement in corrosion resistance due to the formation of a nanocrystalline layer together with a less defective passive film on the surface.

In [5], the cryogenic cooling was proved to give surface characteristics capable to increase theTi6Al4V tribological response.

Revankar [6] employed Taguchi technique for optimization of burnishing parameters to improve surface roughness and hardness of titanium alloy. It was found that surface roughness improves with an increase in burnishing force and number of passes and same is the case for hardness but with an increase in speed, hardness decreases.

Grzesik [7] presents the effect of ball burnishing on surface integrity of hardened 41Cr4 steel parts. It was investigated that ball burnishing not only improves surface roughness but also increases service properties of the component.

Tadic et al. [8] used high stiffness ball burnishing tool for increasing geometrical and accuracies of openings. Cylindricity and roundness errors were reduced as the depth of penetration increases. FEM analysis was done for stress field distribution in the workpiece.

Grochala et al. [9] investigated the effect of burnishing after milling and stresses at the surface. FEM model of the milled and burnished surface was developed. It was observed that after burnishing surface roughness was reduced and stresses were developed on the surface.

Zhang and Liu [10] studied the effect of sequential turning and burnishing on the surface integrity of Cr-Ni based stainless steel. It was concluded that surface roughness, topography, residual stresses and microhardness of the material get improved due to plastic deformation of the material. Burnishing parameters were optimized based on required surface integrity.

Gharib et al.[11] investigated improvement in ductility of 1050A rolled sheets of aluminum due to newly developed ball burnishing tool. A quadratic mathematical model was developed considering speed, feed, and force as burnishing parameters to predict surface roughness. It was observed that burnishing improves the ductility of material but hardness remains same.

Rodriguez et al. [12] used deep ball burnishing to improve the surface quality of material. Finite element model of ball burnishing was used to predict residual compressive stresses produced on the surface of the material. It was found that pressure plays a vital role in improving surface quality.

Grzesik and Zak [13] presented novel sequential process of turning with and without cryogenic cooling of the component and ball burnishing operation. From results, it was observed that burnishing can be controlled additionally by cryogenic pre-cooling of the component.

Tao Zhang et al. [14] formulated a second-order empirical model to predict surface roughness and compressive stresses considering burnishing parameters namely pressure, speed, and feed for 17-4 PH stainless steel, an aerospace alloy.

Jawalkar and Walia [15] used Taguchi method for optimization of roller burnishing process parameters to improve surface finish and surface hardness of the En-8 material. It was observed that burnishing speed, feed, and a number of passes contributes maximum in improving surface finish.

Yang et al. [27] experimented on six plasma sprayed HA on Ti– 6Al–4V substrates by varying the cooling conditions and the substrate temperatures [31]. The residual stresses and bonding strengths were measured by XRD “sin2 φ” technique and a standard adhesion test (ASTMC-633).Results of the bonding strength evaluation shows that the HA coating with the lowest residual stress exhibited a higher bonding strength(9.187 0.72MPa).

Mavis et al. [29] had developed several compositions of the liquid coating medium for the dip coating of HA on Ti–6Al–4V substrates , using chemically precipitated hydroxyapatite precursor powders. To evaluate the adhesion strength, two steel cylinders 5 mm in diameter were attached to both sides(coated and uncoated after the coating layer was ground off) of the dipped strips by a thin layer of glue. The adhesive strengths were determined by measuring the tensile stress needed to separate the cylinders from the strips . It is reported that, the HA coatings obtained were highly porous, with bonding strengths of more than30MPa.

Koch et al. [30] investigated pulsed laser deposition of hydro-xyapatite on Ti–6Al–4V for medical and dental applications. A pull-off testing method was used to determine the coating-to- substrate adhesion strength. Garcia-Sanzetal had also examined hydroxyapatite films prepared using pulsed laser deposition using a pull-off test based up on a modified ASTMC-633procedure. The measured tensile strength of hydroxyapatite grown at480 1C was 58 MPa and failure was observed at the coating–substrate interface.

Man et al. [31] reported the influence of pre-treatments on the adhesion of the HA coating to the substrate. Five types of pre- treatments, shown in Fig. 5 were:(i)mirror finished specimen,(ii) 60 grit grinded SiC paper (specimen2),(iii)320 gritgrindedSiC paper (specimen3), (iv)mirror finish with1-μm diamond paste (specimen 1),and(v)10setching with Knollsolution after polishing (specimen4).The surface roughness of the specimens were determined using a profile meter (Taylor Hobson Surfronic 25) and the adhesion strengths between HA coatings and the substrates were evaluated in accordance to ASTMC-63. The maximum adhesion strength obtained was 16MPa for specimen 5 (nitride etching).

Few of the disadvantages which might be holding back the adoption of the industry:

- Lack of machine – tool interface designed for cryogenic machining.
- Lack of knowledge of tool manufacturers and end-users
- In some cases, it is necessary to pre-cool the workpiece in order to prevent thermal shocks
- High initial cost
- High complication level of optimizing the flow and pressure
- Relatively high price of LN2 and CO2
- Cutting fluid is not reusable as it is in some case of conventional machining
- The machine tools builders are too conservative
- Lack of tools specially designed for cryogenic cooling, in terms of geometry, substrate and coating

IV. PROPERTIES OF TITANIUM ALLOY

Titanium is so highly valued due to its interesting properties. The key properties of titanium are:

Strength-Titanium possesses high strength when alloyed with additional metals and elements. This can produce the desired level of strength or ductility. Titanium is just as strong as steel.

Lightweight - Titanium is also lighter than steel whilst having a similar strength. This quality is very desirable for medical and construction applications. Titanium's high strength-to-weight ratio is very appealing to builders as they continually look to produce buildings that are high in strength using lighter materials.

Corrosion-resistant - titanium is highly resistant to most types of corrosion. Most metals will corrode in the presence of salt water, acids, and other chemical solutions, however Titanium shows surprising resilience to these. Titanium is also very resistant to stress corrosion cracking unlike steel.

Biological Compatibility - Titanium can be used within the human body due to its bio-inert qualities. This means that titanium is not toxic to the human body and will not be rejected as easily when used in processes such as Osseo integration; when a foreign object is fused to human bone in order to provide structural support for prosthetics or implants.

V. APPLICATIONS OF TITANIUM ALLOY

Because of the hugely diverse set of properties titanium possesses, it is an incredible metal to work with. Titanium is suitable for a range of applications including the following:

Medical - In the medical field, titanium has become one of the most widely used metals. It is bio-inert, it does not react with anything inside the body, making it the prime candidate for use in procedures such as dental implants, orthopaedic rods, bone plates, and other prosthetics. It can also be used to produce a range of medical instruments such as scalpels and drills.

Aircraft - The most common use for titanium is in aircraft construction. Titanium is the leading metal used in the construction of jet engines and airframes. Its lightweight characteristics make it especially important for use in increasing jet efficiency.

Automotive - Titanium is staple for the car and motorcycle industry. Since these machines have several moving parts, the need for durable material is very high. Titanium alloys offer the ideal solution for car and motorcycle parts such as rods, valves and camshafts. Titanium parts such as these are crucial to the racing industry.

Industrial - There are also different industrial applications for titanium. Constantly new uses for titanium in construction are being discovered. It makes an excellent building material for outdoor applications since it is lightweight and resistant to corrosion.

Chemical Processing - Titanium is useful in the chemical and pharmaceutical world, where equipment is often in constant contact with hazardous and corrosive materials.

VI.CONCLUSION

The overall studies and previous works have concluded the following:

1. Improvement in surface roughness and wear resistance is seen in cryogenic burnishing when compared with other processes.
2. Ball burnishing is mostly preferred than the roller burnishing in many research works
3. Taguchi optimization for burnishing of titanium alloy (Ti–6Al–4V) to minimize the surface roughness and maximize the hardness using ball-burnishing tool has shown good improvement.
4. The overall study revealed that the cryogenic processing has emerged as novel sustainable processes, offering new opportunities for producing functionally superior products.

VII. REFERENCES

[1]. D.O. Sullivan, M. Cotterell, Temperature measurement in single point turning, J.Mater. Process. Technol. 118 (2001) 301–308.

[2]. G. Rotella, O.W. Dillon, D. Umbrello, L. Settineri, I.S. Jawahir, The effects of cooling conditions on surface integrity in machining of Ti6Al4V alloy, Int. J. Adv. Manuf.Technol. 71 (2013) 47–55,http://dx.doi.org/10.1007/s00170-013-5477-9.

[3]. Samatham Madhukar, Dasari Jagath Prakash, Birudala Raga Harshith Reddy, Dr.V.V.Satyanarayana , An Experimental Investigation on Machinability of Titanium (Grade -2) using Cryogenic Machining , International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE) Vol 2, Issue 4, April 2017,pp.647-653. ISSN (Online) 2456-1290

[4]. Y. Sun, B. Huang, D.A. Puleo, J. Schoop, I.S. Jawahir, Improved surface integrity from cryogenic machining of Ti-6Al-7Nb alloy for biomedical applications, Procedia CIRP 45 (2016) 63–66, http://dx.doi.org/10.1016/j.procir.2016.02.362.

[5]. J. Tang, H.Y. Luo, Y.B. Zhang, Enhancing the surface integrity and corrosion resistance of Ti-6Al-4V titanium alloy through cryogenic burnishing, Int. J. Adv.Manuf. Technol. (2017) 2785–2793, http://dx.doi.org/10.1007/s00170-016- 9000-y.

[6]. S. Madhukar, A. Shravan, P. Vidyanand Sai and Dr. V.V. Satyanarayana, A Critical Review on Cryogenic Machining of Titanium Alloy (Ti-6Al-4V). International Journal of Mechanical Engineering and Technology, 7(5), 2016, pp. 38–45. http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=7&IType=5

[7]. S. Bruschi, R. Bertolini, A. Bordin, F. Medea, A. Ghiotti, Influence of the machining parameters and cooling strategies on the wear behavior of wrought and additive manufactured Ti6Al4V for biomedical applications, Tribol. Int. 102 (2016) 133–142,http://dx.doi.org/10.1016/j.triboint.2016.05.036.

[8]. N.H. Loh, S.C. Tam, A study of the effects of ball burnishing parameters on surface roughness using factorial design, Prec. Eng. 18 (1989) 53–61.

[9]. Samatham Madhukar, Aitha Shravan ,Katarapu Ram Kumar and J. Jagadesh Kumar , An Experimental Investigation on Machinability of Titanium and Steels using Cryogenic Machining , International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE) Vol 2, Issue 5, May 2017, pp.830-837. ISSN (Online) 2456-1290

[10]. W. Grzesik, ―Functional Properties of Hardened Steel Parts Genereted By Turning and Ball Burnishing Operations,‖ Adv. Manuf. Sci. Technol., vol. 36, no. 4, pp. 5–17, 2012.4

[11]. B. Tadic, S. Randjelovic, P. Todorovic, J. Zivkovic, V. Kocovic, I. Budak, and D. Vukelic, ―Using a high-stiffness burnishing tool for increased dimensional and geometrical accuracies of openings,‖ Precis. Eng., vol. 43, pp. 335– 344, 2016.

[12]. Paaka Vidyanand Sai, Samatham Madhukar, Malis Krishna Prasad Reddy, N V S Ramachandra Rao, " A Review on Machinability Aspects of Titanium Grade-2", International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 3 Issue 2, pp.270-275, March-April 2017. URL : http://ijsrset.com/IJSRSET173287.php

[13]. D. Grochała, S. Berczyński, and Z. Grządziel, ―Stress in the surface layer of objects burnished after milling,‖ Int. J. Adv. Manuf. Technol., vol. 72, no. 9–12, pp. 1655–1663, 2014.

[14]. P. Zhang and Z. Liu, ―Effect of sequential turning and burnishing on the surface integrity of Cr-Ni-based stainless steel formed by laser cladding process,‖ Surf. Coatings Technol., vol. 276, pp. 327–335, 2015.

[15]. F. Gharbi, S. Sghaier, H. Hamdi, and T. Benameur, ―Ductility improvement of aluminum 1050A rolled sheet by a newly designed ball burnishing tool device,‖ Int. J. Adv. Manuf. Technol., vol. 60, no. 1–4, pp. 87–99, 2012.

[16]. a. Rodríguez, L. N. López de Lacalle, a. Celaya, a. Lamikiz, and J. Albizuri, ―Surface improvement of shafts by the deep ball-burnishing technique,‖ Surf. Coatings Technol., vol. 206, no. 11–12, pp. 2817–2824, 2012.

[17]. Aitha Shravan, Samatham Madhukar, Bootla Akhil, Dr. A. A. Sri Rama Krishna , " Experimental and Numerical Analysis of Metal Removal Rate and Surface Finish on Al-Ti Alloy", International Journal of Scientific Research in Science, Engineering andTechnology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 3 Issue 1, pp.407-411, January-February 2017. URL : http://ijsrset.com/IJSRSET1731104.php

[18]. W. Grzesik and K. Zak, ―Modification of surface finish produced by hard turning using super finishing and burnishing operations,‖ J. Mater. Process. Technol., vol. 212, no. 1, pp. 315–322, 2012.

[19]. T. Zhang, N. Bugtai, and I. D. Marinescu, ―Burnishing of aerospace alloy: A theoretical-experimental approach,‖J. Manuf. Syst., pp. 2–8, 2014.

[20]. C. S. Jawalkar and R. S. Walia ―Study Of Roller Burnishing Process On En-8 Specimens Using Design of Experiments‖, Journal of Mechanical

Engineering Research Vol.1(1) PP-038-045, Nov. 2009

[21]. Miyamoto H, Harada K, Mimaki T, Vinogradov A, Hashimoto (2008) Corrosion of ultra-fine grained copper fabricated by equalchannelangular pressing. Corros Sci 50(5):1215–1220. doi:10.1016/j.corsci.2008.01.024

[22]. Jiang Z, Dai X, Middleton H (2011) Investigation on passivity oftitanium under steady-state conditions in acidic solutions. MaterChem Phys 126(3):859–865. doi:10.1016/j.matchemphys.2010.12.028

[23]. Pacha-Olivenza MA, Gallardo-Moreno AM, Vadillo-Rodríguez V,González-Martín ML, Pérez-Giraldo C, Galván JC (2013)Electrochemical analysis of the UV treated bactericidal Ti6Al4Vsurfaces. Mater Sci Eng C 33(3):1789–1794. doi:10.1016/j.msec.2012.12.079

[24]. Guo HX, Lu BT, Luo JL (2006) Study on passivation and erosionenhancedcorrosion resistance by Mott-Schottky analysis. Electrochim Acta 52(3):1108–1116. doi:10.1016/j.electacta.2006.07.026

[25]. Cheng YFLJL (1999) Electronic structure and pitting susceptibilityof passive film on carbon \ steel. Electrochim Acta 44(17):2947–2957

[26]. Zheng ZJ, Gao Y, Gui Y, Zhu M (2012) Corrosion behaviour ofnanocrystalline 304 stainless steel prepared by equal channel angularpressing. Corros Sci 54:60–67. doi:10.1016/j.corsci.2011.08.049

[27]. Ralston KD, Birbilis N, Davies CHJ (2010) Revealing the relationshipbetween grain size and corrosion rate of metals. Scr Mater63(12):1201–1204. doi:10.1016/j.scriptamat.2010.08.035

[28]. Lu H, Li Y, Wang F (2006) Enhancement of the electrochemicalbehavior for Cu–70Zr alloy by grain refinement. Surf Coat Technol201(6):3393–3398. doi:10.1016/j.surfcoat.2006.07.208

[29]. Youssef KMS, Koch CC, Fedkiw PS (2004) Improved corrosionbehavior of nanocrystalline zinc produced by pulse-current electrodeposition.Corros Sci 46(1):51–64. doi:10.1016/S0010-938X(03)00142-2

[30]. Balyanov A (2004) Corrosion resistance of ultra fine-grained Ti.Scr Mater 51(3):225–229. doi:10.1016/j.scriptamat.2004.04.011

[31]. Li J, Li SJ, Hao YL, Yang R (2014) Electrochemical characterizationof nanostructured Ti–24Nb–4Zr–8Sn alloy in 3.5% NaCl solution.Int J Hydrog Energ 39(30):17452–17459. doi:10.1016/j.ijhydene.2014.01.144

[32]. Kim HS, BushMB (1999) The effects of grain size and porosity onthe elastic modulus of nanocrystalline materials. Nanostruct Mater11(3):361–367. doi:10.1016/S0965-9773(99)00052-5

[33]. YangY-C,ChangE.Influence of residual stress on bonding strength and fracture of plasma-sprayed hydroxyapatite coatings on Ti–6Al–4V substrate. Biomaterials 2001;22:1827–36.

[34]. MavisB,Taş AC. Dip coating of calcium hydroxyapatite on Ti–6Al–4V substrates. JournaloftheAmericanCeramicSociety2000;83:989–91.

[35]. KochC,Johnson S,KumarD ,JelinekM, ChriseyD ,DoraiswamyA ,et al. Pulsed laser deposition of hydroxyapatite thin films. Materials Science and Engineering: C2007;27:484–94.

[36]. Man H,ChiuK ,ChengF ,WongK .Adhesion study of pulsed laser deposited hydroxyapatite coating on laser surface nitride titanium.Thin Solid Films 2009;517:5496–501.

[37]. Shu Yanga,, Domenico Umbrellob, Oscar W. Dillon Jr. a, David A. Puleoc, I.S. Jawahira , Cryogenic cooling effect on surface and subsurface microstructural modifications in burnishing of Co–Cr–Mo biomaterial, Journal of Materials Processing Technology 217 (2015) 211–221

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