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3D Printing and Titanium Alloys: A Paper Review

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Abstract:

3D printing is becoming an important and potential sector in the manufacturing industry. In additive manufacturing industry now believed that, in near future they will produce all kind of product includes food, cloths, machines, and medicines even human body parts. Richard van Noort (2012) provides an overview of how 3d printing becoming a crucial part in dental laboratories. On the other hand, titanium is a metallic material that has good biocompatibility and corrosion resistance. That's why titanium is becoming popular in 3D printing. Yaoyang Xiong et al. (2012) evaluated the feasibility of using 3DP to fabricate porous titanium implants. The purpose of this paper is to analyses those papers whose main focused on 3d printing and titanium alloys. A classification is made based on the following set of criteria: literature review, analysis method, limitation and finally conclusion with some future scope.

Key words: 3D printing, titanium alloy, dental device, additive manufacturing

1. INTRODUCTION

3D printing is a methodology using three-dimensional CAD data sets for producing the 3D haptic physical model. It is also referred to as rapid prototyping, solid free form, computer automated or layered manufacturing depending on the kind of production method used. In the medical industry, its applications are increasing day by day. From Richard van Noort (2012), Florencia Edith Wiria et al (2010) we can understand who it really influences the medical industry. Titanium (Ti) is used in a myriad of medical prosthetic devices, running the gamut from artificial joints and dental implants to heart valves and fixture screws Yaoyang Xiong et al. (2012). The bone tissue could grow inside the porous Ti structure and maintain a long and stable connection between the implant and the human bone. Therefore, porous Ti seemed to be a viable candidate for use in dental and biomedical applications. So using titanium alloy to produce human organ or body part with 3D printer is not a dream at all. Using some trigger word like "3D printing", "3D printing and titanium alloys", "3D printing of Titanium alloys" I searched on Google, Google scholar, Mary and John Gray library for some well-cited papers. Among those, I choose 10 papers. People who are interested in more titanium alloys and 3D printing I would suggest going through Jana Markhoff et al.(2015) Florencia Edith Wiria et al(2010) papers for more details. A classification is made based on the following set of criteria: literature review, analysis method, limitation and finally conclusion with some future scope.

2. LITERATURE REVIEW

Several 3D printing related papers have been published during the past two decades. There are very few papers on 3D printing of titanium alloys. Most of the papers just concern about 3D printing and its application. On the other hand, some papers concern about titanium alloys property and characteristics or the Influence of different 3d porous Titanium Scaffold Designs on Human osteoblasts Behavior in dynamic static and dynamic cell investigation Jana Markhoff et al. (2015). Paper Florencia Edith Wiria et al (2010) and Garrett E. Ryan (2008) focused on fabrication of titanium alloys. So with good citrated more papers on "3D printing of Titanium alloys" are rare. In the paper, Ali Reza Asa et al (2013) focused on FDM method and the 3D printer. M. Katou et al. (2007) and M. Terakubo et al. (2005) worked on three-dimensional micro welding. On the other hand Michele Lanzetta et al. (2003) studied on an improved surface finish in 3d printing using bimodal powder distribution. “The future of dental device” by Richard Van Noort (2012) is one of the most interesting papers where the reader could be familiarized with a different range of layer fabrication. “Progress toward an integration of process-structure property-performance models for 3D printing of titanium alloys” by P.C. Collins et al. (2014) are one of the updated paper which describes the development of a process model and a novel approach to extract a constitutive equation to predict tensile properties in Ti-6A1-4V (Ti-64).

2.1. 3D printing technology

3D printing also known as additive manufacturing used to create three dimensional object. 3D printing is created with computer aided design. The process could be divided into 3 category.

2.1.1. Modeling

Using computer aided design it’s possible to create 3D model. On the other hand photogrammetry, 3d scanner may be used to create the model.

2.1.2. Printing

The created model is checked if there is any error exist or not. Then the STL file in processed by a software called ‘slicer’ which convert the model into a series of thin layers and produce G-code. Then the G-code file is printed with 3D printing client software. Depending upon the model it may take hours to several days to produce the object.

2.1.2. Finishing

Although the printer produced resolution is sufficient for many applications for greater precision some printable polymers allow the surface finish to be smoothed and improved using chemical vapor process.

2.2. 3D printing materials

Many materials can be used for 3d printing like PLA, Polyamide (nylon) Silver, Steel, Glass filed polyamide, ABS plastic, Stereo lithography material (epoxy resins), Titanium etc.

2.3. Titanium alloys

Titanium alloys are classified in four categories: 1.Alpha alloys, example: Ti-5AL-2SN-ELI, Ti-8AL-1MO-1V. 2. Near-alpha alloys, examples: Ti-5Al-5Sn-2Zr-2Mo, IMI 685, and Ti 1100 3.Alpha and beta, example: Ti-6Al-4V, Ti-6Al-4V-ELI, and Ti-6Al-6V-2Sn 4. Beta and near beta alloys, example: Ti-13V-11Cr-3Al, Ti-8Mo-8V-2Fe-3Al, Beta C, and Ti-15-3. Among those Ti-6A1-4V alpha beta alloy is more popular in 3D printing. P.C. Collins et al. (2014) focused on alpha beta alloys.

3. ANALYSIS METHOD

To analyze those 10 papers I have divided the papers into 4 categories like primary concern, methods, results, and advantages. Finally future scope and a brief conclusion in made.

Paper	Major concern	Methods	Results	Advantages
1.Michele Lanzetta et al(2003)	Improved surface finish in 3d printing using bimodal powder distribution.	1. HP DoD inkjet cartridge was used for this work. 2. The main powders tested include single alumina made by plasma spherodization 3. Printhead speed,	1.line formulation 2. The improved surface finish is due to a smoothing effect where the small additive powder fills the gaps between the large main powders.	The use of bio modal powders in 3d printing improved surface finished.

		drop frequency, droplet spacing are used as process parameters.		
2.M. Terakubo et al. (2005)	Freeform fabrication of titanium metal by 3d micro welding	1. A tungsten rod was used as arc electrode. 2. The microstructures of the titanium beads formed were observed by using 3D-SEM.	Titanium beads formed under two different shielding gas flows. 2. An arch-shaped object was formed by bridging two titanium pins of 30 layers.	Simple 3D titanium objects were formed by continuous stacking and welding of titanium beads under computer control.
3.M. Katou et al. (2007)	Freeform fabrication of titanium metal and intermetallic alloys by three-dimensional micro welding.	1. (Ti, Ni) metal is placed under a tungsten electrode for arc discharge. 2. The microstructure and chemical composition of objects were analyzed by using 3D-SEM and EDX. 3. The hardness at the cross-section of a pin object was also measured.	1. The arc peak current increased, the temperature of arc increased resulting in increase of the melting of titanium wire and substrate.	3DMW has been developed which combines the (TIG) welding ,(RP) and (SHS)
4.Garrett E. Ryan (2008)	Porous titanium scaffolds fabricated using a rapid prototyping and powder metallurgy technique.	1. A porous wax model was fabricated using a thermojet 3D printer. 2. CAD software is used to create 3 different wax template.	A porous titanium scaffold with controlled porous structure and high strength has been created using a combination of RP and PM techniques.	The results of this study demonstrate the potential of such scaffolds for use in orthopaedic tissue engineering applications.
5.Florencia Edith Wiria et al. (2010)	Fabrication of porous titanium implant prototype using 3D printing	1. CAD is used to designed titanium implant. 2. Design is transferred into a STL file extention.3. The implant prototype is then transferred to a 3DP for fabrication.	The titanium implant prototype is fabricated.	1. As a bone-engineering material, the titanium implant prototypes present good mechanical properties and biocompatibility.
6.F.Rengier et al. (2010)	1. 3D printing based on imaging data.	Generation of 3d object with 3 steps includes image acquisition, image post-processing, and 3D printing.	3D object is created	1.Surgical planning 2.Implant and tissue designing 3.Medical research etc.
7.Richard van Noort (2012)	Provide an overview of major changes in dental laboratories.	Give us an overview of five additive manufacturing technologies.	Importance of additive manufacturing/3D printing in dental device can easily imagined.	Digital technology makes previous manual tasks easier, faster and cheaper.
8.Yaoyang Xiong et al. (2012)	Evaluated the feasibility of using 3DP to fabricate porous titanium	1. Production of green porous Ti implants. 2. Sintering of green	1. A total of 16 porous Ti implant prototypes were produced by 3DP.	The Ti implant fabricated by 3DP reduced the elastic modulus of pure bulk

	implants.	porous Ti Implants. 3. SEM and EDM analysis.	2. Porosity of sintered Ti implants decreased and surface hardness increased.	Ti to closely match that of natural bone.
9.Ali Reza Asa et al. (2013)	To measure the effects of the build direction on the mechanical properties of materials and components made of FDM and 3D printer.	1. To test the effect of pressure on the strength layering piece the only parameter is examined.2. For a 3d printer a piece for layering in the azial, transverse, and diagonal is made.	1. Compressive strength of FDM axial build direction is equal 42.37Mpa. 12.4% greater than the strength of the FDM for the transverse building direction.	Helps to understand the mechanical properties of materials made of FDM and 3D printer.
10.Jana Markhoff et al.(2015)	Influence of different 3d porous Titanium Scaffold Designs on Human osteoblasts Behavior in dynamic static and dynamic cell investigation	1. Generation and fabrication of microstructure Titanium scaffolds. 2.Isolation and cultivation of Human osteoblasts 3. Cell biological test.	1. Cubic structure-influence of the manufacturing method 2.Fabrication via selective laser melting	1. Titanium is an adequate material to bridge large bone defects.

Table: simple analysis of 3D printing and titanium alloy papers

3.1. Major concern

Michele Lanzetta et al. (2003) mainly focused on individual lines, the primitive building block of 3D printed parts. M. Terakubo et al. (2005) major concern was the fabrication of porous titanium where α-phase titanium were developed during bead formation due to the rapid cooling of the melt. On the other hand, M.Katou (2007) focused on free-form fabrication method which combines TIG, RP and SHS. Jana Markhoff et al. (2015) and Garrett E. Ryan (2008) also focused on 3dimensional object related to titanium alloys. Apart from this Ali Reza Asa et al (2013) focused on one 3D printing method FDM and its mechanical properties.

3.2. Methods

In Richard van Noort (2012) author described five major additive manufacturing or 3d printing method. This five method includes stereo lithography (SLA), Fused deposition modeling (FDM), Selective electron beam melting (SEBM), Laser powder forming and inkjet printing. This paper did not specify any specific benefit of titanium alloys. Florencia Edith

Wiria et al. (2010) paper General CAD is used to designed titanium implant. Then the design is transferred into an STL file extension. The implant prototype is then transferred to a 3DP for fabrication. An in-vitro cell culture study is carried out by seeding cells on to the porous titanium structure. On the other hand Garrett E. Ryan (2008) material and methods include several steps. First steps are scaffold fabrication which include porous wax model was fabrication using a thermojet 3D printer. This author also prefers CAD software to create different wax template. Other two steps includes the process optimization and in vitro experiments. In vitro experiments, the cell colonization of the scaffold was analyzed by scanning electron microscopy. Jana Markhoff et al. (2015) also used the similar method to generate and fabricate Micro-structured Titanium scaffolds. The scaffolds were fabricated of titanium powder (Ti-64) using two different (AM) and (SLM solutions Gmbh, Germany) methods. Michele Lanzetta et al. (2003) used HP DoD inkjet cartridge for the experiment. The main powders tested include single alumina made by plasma spherodization. Printhead speed, drop frequency, droplet spacing are used as process parameters. The parameters are related as follows:

Printhead speed = Drop spacing×drop frequency. On the other hand in M. Terakubo et al. (2005) paper a tungsten rod was used as arc electrode. When pulsed micro-arcs have emitted the tip of a thin metal wire with a diameter of .1-.3mm is fused and a micro metal bead is formed instantaneously. The microstructures of the titanium beads formed were observed by using 3D-SEM. Yaoyang Xiong et al. (2012) methods include Production of green porous Ti implants, Sintering of green porous Ti Implants and SEM and EDM analysis. Another example of SEM analysis is found in M. Katou et al. (2007). In this paper (Ti, Ni) metal is placed under a tungsten electrode for arc discharge. The microstructure and chemical composition of objects were analyzed by using 3D-SEM and EDX. The hardness at the cross-section of a pin object was also measured. Yaoyang Xiong et al. (2012) method includes Production of green porous Ti implants, sintering of green porous Ti Implants and SEM and EDM analysis. So we can easily summarize that most of the author generally focused on SEM and EDM analysis when considering Ti implants.

3.3. Results

In Michele Lanzetta et al. (2003), we find that the improved surface finish is due to a smoothing effect where the small additive powder fills the gaps between the large main powders. In M. Terakubo et al. (2005) titanium beads formed under two different shielding gas flows. An arch-shaped object was formed by bridging two titanium pins of 30 layers. M. Katou et al. (2007) results show that the arc peak current increased, the temperature of arc increased resulting in an increase of the melting of titanium wire and substrate. On the other hand in Garrett E. Ryan (2008), a porous titanium scaffold with controlled porous structure and high strength has been created using a combination of RP and PM techniques. The successful titanium implant is also seen in Florencia Edith Wiria et al. (2010). In F. Rengier et al. (2010) 3D object is created with 3 steps; includes image acquisition, image post-processing, and 3D printing. In Yaoyang Xiong et al. (2012) a total of 16 porous Ti implant prototypes were produced by 3DP.The porosity of sintered Ti implants decreased and surface hardness increased. In Ali Reza Asa et al (2013) results shows that Compressive strength of FDM axial build direction is equal 42.37Mpa. Which is 12.4% greater than the strength of the FDM for the transverse building direction.

3.4. Advantages

In .M. Terakubo et al. (2005), Simple 3D titanium objects were formed by continuous stacking and welding of titanium beads under computer control. And Ali Reza Asa et al (2013) Helps to understand the mechanical properties of materials made of FDM and 3D printer. Florencia Edith Wiria et al. (2010) justified that as a bone-engineering material, the titanium implant prototypes present good mechanical properties and biocompatibility. Similarly, Jana Markhoff et al. (2015) proved that titanium is an adequate material to bridge large bone defects. One advantage with 3D printing is that it eliminates much of the expensive and highly skilled labor associated with traditional manufacturing ,Richard van Noort (2012). The advantage of 3D printing of titanium alloy includes surgical planning. Implant and tissue designing, human organ (nose, ear) produce, dental device, dental laboratory Medical research etc. Titanium has superior properties like high specific strength, chemical inertness and low thermal conductivity, M. Terakubo et al. (2005). On the other hand, the Ti implant fabricated by 3DP reduced the elastic modulus of pure bulk Ti to closely match that of natural bone, Yaoyang Xiong et al. (2012).

4. LIMITATIONS

There are few limitations of both 3D printing and titanium alloys. The application of titanium alloy in 3D printing industry is still limited compared to other materials due to the cost of raw materials and difficult processing, M. Terakubo (2005). F. Rengier et al. (2010) also said the same thing. According to this paper, 3D printing cannot produce a large object and the major limitation lies within time and cost spent in the generation of the 3D object. On the other hand, the challenge for the dental material research community is to combine the technology with materials that are suitable for use in dentistry which represents the still improvement phase of the 3d object (Richard Van Noort 2012). Apart from this there are other some limitations. If anybody can produce anything with 3D printing then they may use it for destructive reason like: making army arms, bombs, and weapon, making unethical drugs copying others idea and design etc

6. CONCLUSION

Commercially pure titanium has been successfully investigated to fabricate porous dental implant prototype and both the fabrication and cell culture results have been satisfactory (Florencia Edith Wiria 2010). So maybe with in next few years it would be possible to use titanium alloy properly in additive manufacturing. Since the machining time of titanium alloys is high and the cost is also high, in 3D printing future work could be more focused on cost and time optimization. Scientist is now using post-processing method while producing the large part in 3D printing F. Rengier (2010). So in near future we hope it would be possible to create a large object using 3D printing with less machining time.

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