International Journal of
Science and Engineering Investigations
vol. 2, issue 13, February 2013
ISSN: 2251-8843

Fabrication of Mini and Micro Dental Implants using Micro Investment Casting and Its Challenges

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Abstract-This paper describes a method of making titanium mini and micro dental implants with or without undercut by means of micro investment casting process. Micro investment casting allows fabrication of titanium implants with or without undercuts and free form surface geometry in micro scale dimensions. Due to titanium extreme reactivity at high temperatures, the process encounters some challenges that are discussed.

Keywords- *micro implant; micro investment casting; pattern; RP*.

I. INTRODUCTION

Micro implants were conceived based on decreasing the length and diameter of existing implants, allowing new areas to be used as orthodontic anchorage according to the bone thickness. Micro-implants have become very popular in the orthodontic community as skeletal anchorage devices. They are an excellent alternative to conventional orthodontic anchorage systems such as intraoral dental anchoring units and extra-oral headgear devices. Micro-implants are especially useful in adults with an incomplete dentition as well as in adolescents when noncompliance during treatment is likely. Other advantages include their relatively small size which results in minimal anatomical limitations, user-friendly protocol, immediate loading potential, adaptability to biomechanics in effecting orthodontic and orthopedic forces, high success rate, low cost and most importantly patient acceptability.[1] dental Micro-implants usually are tiny screws made of commercially pure titanium (99%) or titanium alloy (90%) like Ti-6AL-4V. Figure 1 and 2 shows some different views and types of micro implants.

Figure 1. Side view of micro dental implant.

Figure 2. Micro dental implants.

II. GEOMETRY AND DESIGN OF IMPLANTS

Micro threading on the endure implant collar preserves the cortical bone by reducing bone stress and axial stiffness while the 1mm polished portion at the top offers several options in collar positioning when placing the implant. The thread design and anatomical implant shape allow it to self-tap during insertion and minimizes excessive compression stress to the bone. Today most commercially available implants have thread profile in the low-milimeter and micrometer range. In addition to the threaded design, topographic modifications of the implant surface at the micrometer level are also applied extensively to enhance osseointegration. [3]

Some different geometry of micro dental implants demonstrated in figure 3, figure 4 shows typical design of a mini implants and figure 5 shows micro threads of micro implants.

Figure 3. Geometries of micro dental implant.

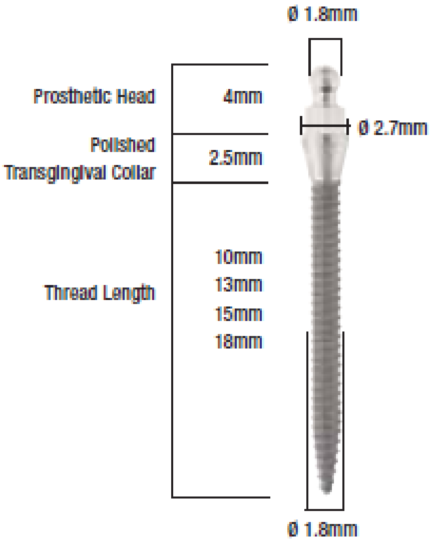

Figure 4. Typical design of a mini implant.

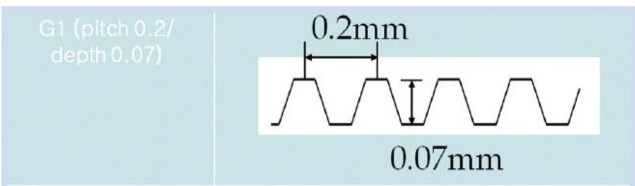

Figure 5. Threads of micro dental implants.

III. MANUFACTURING PROCEDURE

To obtain geometrical details in micrometer range, special manufacturing processes are required. Micro casting is one of the key technologies enable the manufacture of small structures in the micrometer range or of larger parts carrying microstructures by using a metal melt which is cast into a micro structured mold. Micro casting, is generally identified with the investment casting process, which is known as the lost-wax, lost-mold technique. The process has the advantages of reproducing complex shapes at relatively low cost, scalability from single items to large numbers of identical items, and low wastage of raw materials. However, certain defects in the final product may result from the casting process, such as porosity due to poor filling, shrinkage, or dissolved gases; chemical segregation and hence non-uniform properties due to the physical chemistry of solidification; and contamination due to mold-casting interactions.

Micro investment casting has been successfully applied for manufacturing of instruments for surgery and dental devices, instruments for biotechnology and miniaturized devices for mechanical engineering. Figure 6 shows the micro investment casting process steps. First a plastic or wax pattern is made and is coated with a nonreactive face coat intended to minimize the reaction between the ceramic shell and the molten metal during casting. Then the pattern is dipped in a ceramic slip repeatedly. The dipping and stuccoing process is repeated until the desired thickness is obtained, usually 6-8 times. It is essential to maintain a uniform wall thickness in the shell both for mechanical strength and for heat transfer during solidification. The extensive use of robots to manipulate these shells has led to advances in uniformity of the shells. After drying the ceramic mold is heated and sintered and the pattern will be lost during this process due to melting and burning. Finally the preheated ceramic mold is filled with metal melt by vacuum-pressure or centrifugal casting. After solidification, the ceramic mold is mechanically removed without destroying or influencing the cast surface. Depending on the casting alloy and the ceramic mold material, additional chemical cleaning processes may be sometimes necessary. Finally, the single parts are separated from the runner system. [4, 5]

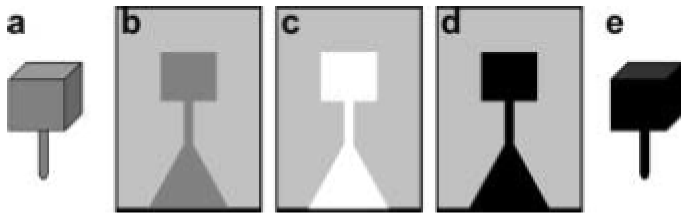

Figure 6. Micro investment casting process, a: plastic pattern, b: embedded in ceramic slip, c: hollow form, d: gold filled mold, e: cast part.

IV. MICRO CASTING OF TI ALLOYS

Titanium and its alloys are increasingly used as an implant material because of the combination of high specific strength, high corrosion resistance and good biocompatibility with the human tissue. Among other titanium based alloys Ti-6Al-4V ($\alpha + \beta$) alloy is actively used for the biomedical applications, such as hip, shoulder and knee implants, screws, plates, etc. [6]. However, due to its extreme reactivity at high temperatures, complex procedures such as vacuum- melting with water-cooled crucibles are required for handling the liquid metal. Consumable electrode vacuum arc or electron beam melting furnaces are commonly used. When titanium is cast into an investment shell, there is invariably some degree of reaction between the metal and the shell, resulting in a contaminated surface layer. Oxygen in titanium increases the hardness and brittleness of the alloy; other elements may result in inhomogeneous microstructure due to segregation during solidification, increasing the susceptibility to corrosion or decreasing the biocompatibility of the alloy. [7]

Therefore, production of implants by micro investment casting process has to be performed in vacuum and argon protective atmosphere, and use of specific shell molds is required. Nevertheless, examinations showed that inspite of the use of high vacuum, molten metal reacts with oxygen from the shell and creates a thin hard surface layer known as the »α case«. This surface phase is very hard and brittle and should be removed. [8] to decrease chemical reaction of molten metal with mold shell, the investment pattern can be coated with a nonreactive face coat like zirconite. Chemical milling can be used to eliminate hard layers and surface contaminations in titanium part after casting.

V. MACHINE

Vacuumed pressure casting and centrifugal casting are tow common approach to produce micro casting parts and special casting machines to performe dental implant casting based on these methods are available. Initial investigations show that centrifugal casting under vaccum is the most promising technique to produce qualified complicated microcast parts. [8] In centrifugal casting, the mold rotates and the melt fills the mold by centrifugal forces. Figure 7 shows a scheme of the process. The mold is fixed horizontally or nearly horizontally at one end of the centrifugal arm. On the other side, a counterweight is fixed to keep the balance of the rotation system. In most centrifugal casting machines the melt is first poured into the runner system and then the system starts to rotate, but there also exist some machines where the melt is poured into the already rotating system. Here the centrifugal forces are higher because the machine rotates already at top speed and no further acceleration has to be taken into account.[4]

VI. CERAMIC SHELL

Mold materials can influence the quality of Ti 6AL 4V castings. Common material for investment is phosphate bonded materials, but Stable high-temperature resistant oxides can serve as a barrier for reducing reactivity of titanium, such as MgO, zirconia, yttria, alumina and CaO.[9, 10]

casting pressure in vacuum pressure casting machines and speed of rotation in centrifugial casting machine should be enough for filling of mold and obtaining the sharp corners and edges of the workpiece and are dependent on temperature and geometry of the mold. Mari Koike [11] has shown that dental prosthesis, which has narrow cross sections containing very narrow regions (for example, clasps of a denture), can be cast successfully by utilizing high rotational speed during centrifugal casting.

Other important factor is the mold temperature before pouring that usually is adjusted about 450 degree of centigrade. Investigations show, the increased mold temperature of the investment resulted in an increase in the castability for the Ti–6Al–4V alloy.[9]

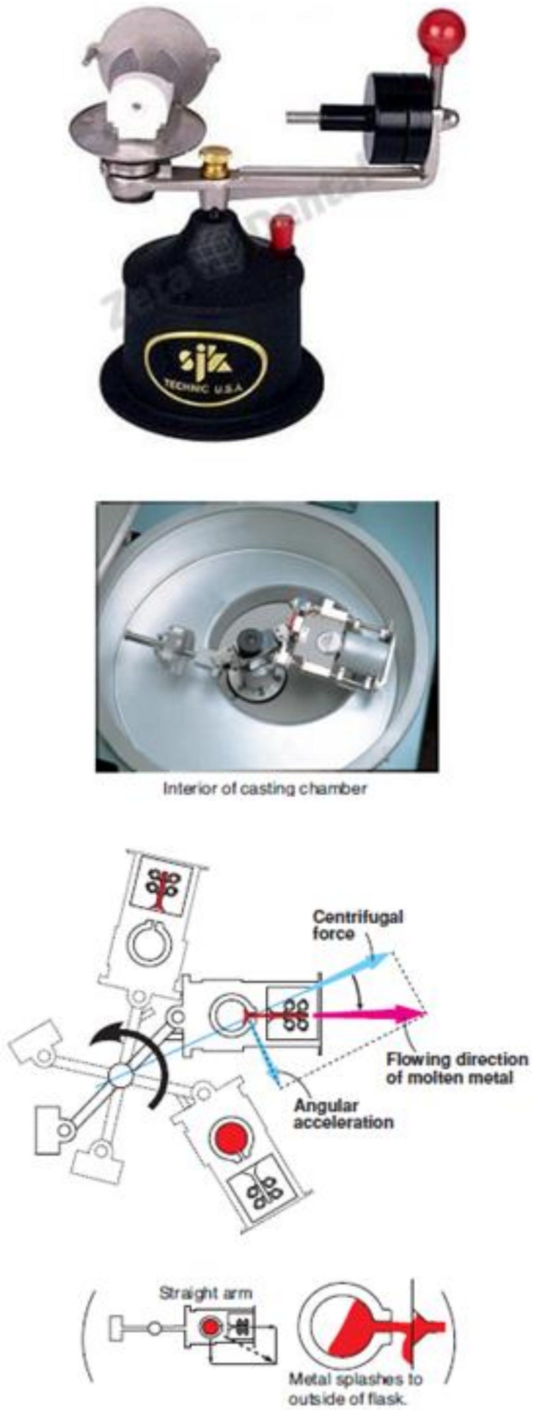

Figure 7. Machine & Scheme of the process of centrifugal casting under vaccum

VII. Making investment patterns for microcasting

In micro investment casting the patterns should guarantee a higher strength and are thus of advantage when assembling microstructures thus in contrast to the wax patterns used there, micro technology mostly works with plastic patterns which have much higher mechanical strength. The patterns usually are made of

Thermoplastic like PMMA or POM which shows much higher strength than wax made structures. The improved mechanical properties permit easier handling and assembling of the pattern during the manufacturing process. The feeding system can be made of wax.

Today's technology gives various processes for micro fabricating PMMA casting patterns like micro mechanical cutting, laser micro machining, micro injection molding, micro steriolithography and two photon polymerization. To select the suitable process, it is necessary to compare these processes based on availability, manufacturing aspects and economical points of view. Micro-cutting is one of the key technologies to enable the realization of micro-products. Similarly to the conventional cutting operation, in micro-cutting the surface of the workpiece is mechanically removed using tools, but the depth of cut is normally at the level of a micrometer or less. Laser micromachining has been widely applied in the fabrication, production and manufacturing of Micro Electro Mechanical Systems (MEMS). It uses photo thermal melting or ablation to fabricate a microstructure. In the production of micro-scaled products, laser ablation is able to generate structure sizes in the range of 10– 100 micro-meter, not only in metals and polymers like PMMA but also in hard and ultra-hard materials such as tungsten carbide and ceramics.

In micro injection molding, melted plastic is injected in micro mold. Microinjection molding (μIM) appears to be one of the most efficient processes for the large-scale production of thermoplastic polymer microparts like patterns for micro investment casting. To reduce the product development time and reduce the cost of manufacturing, the new technology of rapid prototyping (RP) has been developed, which offers the potential to completely revolutionize the process of manufacture. This technology encompasses a group of manufacturing techniques, in which the shape of the physical part is generated by adding the material layer-by-layer. Many of these techniques are based on either the selective solidification of the liquid or bonding solid particles. The most established and widely distributed technology is stereolithography with the direct layer-by-layer transformation of computer-aided design data into a 3-D mold using the photopolymerisation of reactive polymer resins with a focused UV beam.

A promising three-dimensional microfabrication method that has recently attracted considerable attention is based on two-photon polymerization with trashort laser pulses. When focused into the volume of a photoresistive material like PMMA, the pulses initiate two photon polymerization via two photon absorption and subsequent development (e.g. washing out the non-illuminated regions) the polymerized material reminds in the prescribe 3-D form. This allows fabrication of any computer generated structure by direct laser recording into the volume of a photosensitive material.[12]

In mass production the best process for pattern fabrication is microinjection molding. A complete review of this technique can be found in [13]. For one-off and batch production, micro cutting, laser machining, micro steriolithography and two photon polymerization technique respectively can be chosen. Complicate shapes with undercut may be producible only by steriolithography and two photon polymerization.[12]

VIII. Challenges in micro casting of titanium

One of the most important challenges in micro casting of titanium is the formation of reaction layer on surface of the part that usually has a thickness about 50 micro meters. This layer can be decreased by true selection of ceramic shell material and coating of pattern with suitable materials. To remove reaction layer, chemical milling and sand blasting can be used.[16]

Internal porosities made by casting also are a problem and Small amounts of porosity can decrease fatigue life and mechanical properties of the implant. To improve the fatigue properties, titanium castings are processed by HIP (hot isostatic pressing) to close off any internal porosity. Typical HIP processing is done under argon pressure of 15 ksi at 1750° F for 2 hours. It should be noted that HIP will collapse internal porosity but will not close off surface connected porosity. [14, 15]

The other challenge is complete filling of the mold. There is a great deal of experience based know-how in the design of the gates through which the molten alloy is introduced into the shell. The gates must be located to ensure that the shell cavity is filled before solidification is very advanced. The use of risers that provide supplemental molten metal helps this to be achieved. This is particularly important for titanium casting because of the lower superheat of the molten metal. These gates and risers are removed and recycled which results in significant cost saving.[15]

At last to cope the challenges about strength of implants under different kinds of loadings while using, modeling and analyzing with finite elements softwares such as other analysis that have been done by this type of softwares [17,18] can be done.

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