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Titanium Foam for Dental Implant Applications: A review

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Abstract The greatest challenge in making biocompatible metals implantable is anticipating the push protecting impact, which suggests that the metal and bone cells will not bond as well as they ought to. In any case, there are ways to overcome this problem. One way is to form the metal hardened, repressing the stress-shielding impact. Another way is to use porous materials, allowing the metal and the cells to bond better. Titanium powder is used to make titanium foam structures, which can help to stop bone growth and improve the attachment of dental implants. These applications involve load bearing in the aerospace and ship manufacturing industries in addition to trabecular implants in the biomedical industry which is the focus in this paper where biocompatibility and mechanical properties of titanium are extremely critical. Although implants are extremely rigid in comparison to the host bone, they still need to be designed meticulously to avoid stress-shearing or overloading the connected bone and promote bone regeneration. Additionally, several coating and roughening processes are applied toward enhance foam and bone attachment to the implant surface. This research intends to bring attention to the significance of porosity in the Titanium foam dental implant fusion with bone tissue, as well as the many production methods that are presently under investigation. For the best possible biological characteristics in Titanium foam, it has been shown that the preservative built-up approach is effective in controlling both the pore size and shape.

Keywords: biomaterials, dental implant, porous metal, osseointegration, titanium foam, trabecular implant.

1 Introduction

Research and development into spongy metals and metallic foams is currently very active.

Various researchers have considered and acknowledged the possessions of structure on the properties of cellular metals for biomedical applications. Dental implants are a surgical procedure used to restore a patient's health and ability to speak by replacing the tooth's root. They provide a stable foundation for a dental prosthesis because of their complete integration with the jawbone [1]. The shape, texture, and treatment of their surfaces, as well as the method by which they attach to the prosthetic, are used to classify these components. Dental implants available on the market range in length and diameter to accommodate different clinical treatment needs. Dental implants, for instance, can be anywhere from 3.25 to 6.0 mm in diameter and 5 to 18 mm in length, depending on the manufacturer. There was a rise in the recent past in concern in dental implants that are applied to care for millions of people annually all over the world [2]. The growing mandate for dental implants can be explained by several factors, including the ability to fully restore dentition, the rising average age of the worldwide residents, the rising total of mature people, and increased community recognition. Traditional tooth replacement options such as transferable dentures, fixed crowns, and bridges all come with their own set of challenges. For instance, after a tooth is extracted, the remaining bone gradually resorbs, reducing the bearing area that strengthens the removable prosthesis. This means that replacing missing teeth with end osseous titanium implants is easier and more practical than with traditional dentures [3].

Titanium foams have several desirable properties that are hard to achieve with any other kind of foam. Because of their unusual stress-strain response, which manifests primarily under compression, the mechanical properties of these materials are of paramount importance. These materials do not fail catastrophically when bent. Instead, compression causes cell collapse and densification, leading to plateau stress. The elastic modulus, which is lower than the actual modulus, is the cause of this deformation behavior because of cell collapse under initial loading (E). The disfigurement properties of these substances are affected by the comparative density and ductility of the build metal. Powder sintering, solid-state foaming and rapid prototyping are just a few of the methods that can be used to create porous metallic [4]. Powder sintering has gained popularity because it permits for the composition, mechanical properties, and shape of

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implants to be tailored to the individual patient [5]. Powder sintering has advantages over some other production methods. Simple and inexpensive, this method is highly desirable. Powder sintering can be used in tandem with space holder pore formation methods, which gives it an advantage over competing techniques. The combination of these two factors allows for greater porosity and finer regulation of scaffold pore size and distribution [6]. When metal powders are mixed with space holder particles, the latter are compacted and then removed prior to or during the sintering process. Sodium chloride, carbamide, magnesium, tapioca, and saccharose are all commonly used materials that are easily removed from the environment through evaporation or dissolution and are therefore suitable for use as space fillers.

1. Use of Titanium and Alloys for Medical Implants

There is evidence that titanium and its alloys have existed to present a wide range of biomaterials since the 1960s and can be used in the production of a wide range of medical devices. For the most part, this is because of the exceptional mechanical behaviors and superior corrosion resistance that these materials possess. Titanium's near-biological inertness and high tolerance in the human body's natural environment make it a good candidate for implantable medical devices. At room temperature, titanium is typically classified as a phase, and it transitions into a phase at temperatures above 883 °C [4]. Titanium lacks the necessary intensity for use in medical implants. Therefore, titanium alloys containing varying amounts of components like Al, Nb, Ta, Mn, Cr, Co, Ni, and Cu have been proposed to develop these properties. The transition temperature of titanium alloys is affected differently by each of these elements. Elements that raise the conversion temperature, like aluminium, are known as stabilizing elements, while elements that lower it, like vanadium, are known as stabilizing elements. For this reason, alloys are typically classified into one of three types based on their melting point [7].

2. Synthesis techniques for metallic cellular materials

There are several approaches to create metallic materials with cellular structures. Some approaches are like those applied for foamy aqueous or polymeric liquids, though others are devised to take benefits of metals unique features, such as their sintering activity or their ability to be electrically deposited. Corresponding to the situation in which the metal is processed, the various processes can be classed. This explains four of the processes depicted in Fig 1, each of which results in a distinct state of matter: one can begin with liquid metal, powdered metal form, vaporous metallic compounds, and a metal ion solution. Both liquid and powder metallurgy. Other techniques, such as electrochemical, rapid prototyping, and vapor deposition include manufacture foam [8]

2.1 Foam fabrication by liquid metallurgy

Blowing gas directly into the molten metal, introducing a component that crumbles for given temperature to distribute gas into the molten metal, infiltrating melt into the open-cell, cellular, decomposable material to obtain the droplet shape are all methods of generating pores in liquid metallurgy. Since metals must be melted in this process, only those metals with low melting point are synthesized. Even though metals with high melting points can likewise be manufactured in this manner, doing so requires a great deal of finesse due to the increased risk of oxidation at high temperatures.

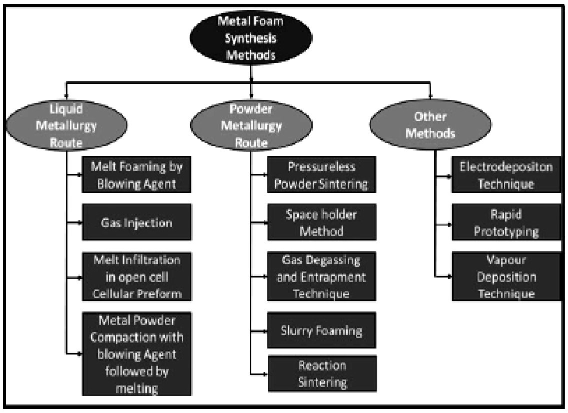

Fig 1 Methods of foam synthesis.

3.1.1 Metal-melt and space-holder based foam production

Components that hold empty space (space holder) can be either organic or inorganic. Introduced the melt to form porous structure of the metals via discharge in a suitable solvent or evaporation at minimal temperature that become an intrinsic part of the product once the melt solidifies. Salts, which can be extracted using a suitable solvent, are utilized as fillers [9]. Composable foam is produced using spacer like hollow alumina spheres and fly ash, which are trapped in the result. Once the melt solidifies, resulting in porosity because of the particles' hollow balloon-like nature [10]. Prior to mixing in the molten metal, the spacer is warmed to prevent the melting from hardening prematurely.

Preheating is crucial, particularly for the filler that has a high heat capacity and is treated at low pressure [11]. There may be an issue with the molten metal wetting the place holders owing to the high contact angle among them. The melt can't achieve the interstitial point of the place holder. To defeat this issue, the surrogate particles are covered with a suitable coating to lower the contact angle, a vacuum is generated, or the melt is subjected to high pressure to penetrate the interstices of the surrogate particles [12]. The stir cast, pressure, and vacuum infiltration processes can all be used to create syntactic foam. The stir cast, pressure, and vacuum infiltration processes can all be used to create syntactical foam. When the volume fraction of the cavity holder is tiny, the combination casting procedure is used. The procedure of pressure or vacuum infiltration is utilized for a significant fraction of the volume of the filler. Fig 2 depicts the overall pressure infiltration procedure for manufacturing syntactic foam. To achieve the supersaturated state of the melt, metal is melted using an electric heater at a temperature exceeding 3050°C of its melting point. By applying pressure, the mold containing hollow spheres is infiltrated into the molten material that has been drained. The molten substance permeates the interstices of the hollow spheres. Following solidification, foam enclosing a large portion of space by volume is formed.

3.2 Powder metallurgy to produce foam materials

Foam can be produced utilizing powder metallurgy. The primary distinction between liquid and powder metallurgy is that powdered titanium is utilized in powder metallurgy. The powder metallurgy process does not require the melting of this metal powder. Gas entrapment, slurry foaming, the space holder technique, bulk powder sintering, the metal powder combining with polymer binder method, reaction sintering, and other techniques are used to create the foam in this manner.

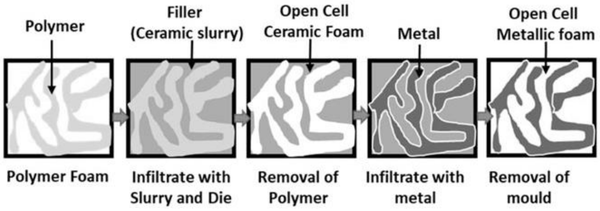

Fig 2 Procedure of foam performed using open cell polymer.

3.2.1 Foam synthesis using powder metallurgy technique

There is a significant technology to generate Titanium foam by powder metallurgy employing volatile materials as space holders. This approach has various advantages. The shape, size, porosity, and distribution of the pores in the foam material can simply be modified by varying the shapes, sizes, and volume fractions of spacers in the metal powder [13]. Fig 3 depicts the powder metallurgy approach for producing foam using a space holder. This approach has four key processes, which are as follows:

(i) Mixing: First, pick a suitable amount of titanium powder and spacer. The number of space holders would have proportional accordance to add porosity to the material. To obtain a homogenous mixture, the titanium powder and placeholder are well mixed. A tiny amount of polyvinyl alcohol is also added to guarantee proper bonding during compaction.

(ii) Compaction: The substance is compressed in a mold with enough pressure to form the appropriate shape and size green body. A stamp is used to control the shape and size of the image.

(iii) Pre-sintering: Pre-sintering is used to remove the spacer. The temperature and time of this stage are determined by the type of spacer utilized. If the placeholder is of evaporation nature, it evaporates through sintering; then, it is stripped in a suitable solvent.

(vi) Sintering: The burned section is sintered in a suitable furnace at the appropriate temperature for a sufficient period. The sintering process is utilized to retain the strength of the green compact owing to interparticle diffusion of the matrix powder.

Because of the diffusion, the bond strength between the particles increases, leading to an increase in overall strength of the model to be produced by a tiny shrinking in the volume of the sample. There are numerous materials that can be used as placeholders. Researchers employed ammonium bicarbonate [14], urea [15], sodium chloride [16], polymer granules [17], and magnesium as placeholders [18]. The material that can be utilized as a space holder should have certain features, such as no reactivity with the matrix powder, little or no residue after removal, ease of processing, and so on. The removal of the spacer is the general challenge of the spacer procedure. Any excess left over in the material in biomedical applications will have a negative impact on the human body. As a result, the spacer material should be biocompatible. It has been claimed that sodium chloride is a superior choice as a placeholder for producing the titanium foam implant using powder metallurgy since it is biocompatible and can be simply removed from the sintered material by leaking in water [19] study the value of employing sodium chloride as a spacer since it is inexpensive, has rapidly leachable characteristics in water, and is less hazardous to the human being's body. In latest years, there has been an upsurge in the use of ammonium bicarbonate and urea as spacer to generate titanium foam with regulated porosity, pore shape and size. Since the melting temperatures of ammonium bicarbonate and urea are low, they disintegrate fast through pre-sintering, making it difficult to manage the pore structure and porosity [20].

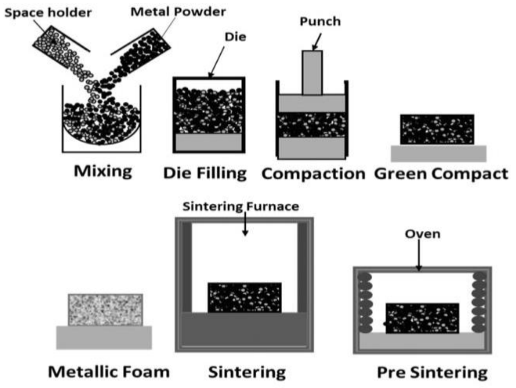

Fig 3 Producing of Titanium foam via powder metallurgy technique.

4. Investigation of several procedures for manufacturing titanium foam dental implants

There are now several processes for creating titanium foam constructions, each with its own set of advantages and limitations. The sequence of powder metallurgy (PM) with the space holder (SH) process has some advantages over other methods for fabricating porous Ti structures. PM techniques are less expensive and time-consuming to industrialize than fast prototyping techniques like SLM, 3D printing, as well as others. Titanium's high melting temperature and significant chemical reactivity with ambient gases and molding ingredients make solid foaming by powder metallurgy more favorable than liquid foaming procedures. Likewise, the resulting pores are arbitrarily distributed and come in a variety of proportions [21].

This could be viewed as a drawback when compared to alternative approaches that allow for more precise control of pore distribution. Yet, research indicates that bone implants with a unintentional pore distribution of varying diameters mirror the form of real bone and function substantially better in bone regeneration applications [21] shown that only foams with concave macropores promoted significant ectopic bone growth, not 3D printed scaffolds with convex prismatic macropores. Because of this, PM in combination with SH is a very appealing approach for producing porous metallic materials.

5. Titanium foam implant properties and characteristics

Titanium foam for dental implant applications is created using a variety of interconnected parameters such as geometry, alloys, surface qualities, and varied pore properties. Proper design and material selection result in the permanence of the implant bone boundary, the strength, speed of osseointegration and the success of dental implants. Although there is no one-size-fits-all implant design for dental functions, implant can be obtained to increase strength, interfacial stability, and load transfer. The subsequent is a summary of some of the most crucial factors for the success of dental implants, particularly foam scaffolds.

6. Titanium and titanium alloy osseointegration

Titanium and its alloys have been significantly hired for load-bearing dental implants due to their good biocompatibility along with high mechanical properties. They get a connection with bone tissue, despite reports of direct attachment to bone. Many coatings have fought for a long time to offer titanium and its alloys with bonding capacity, that impulsively bond to living bone. Although hydroxyapatite plasma spray coatings are extensively used in cementless hip replacement surgery, they have some drawbacks, comprising delamination of the coating layer from the substratum, complications in supervisory the structure of the coating layer, and degradation of the coating layer itself, which can statement remains and convert a source of third body wear [22]. The qualities of dental implant surfaces are extremely important in motivating the healing process prominent to osseointegration and definitive clinical success of the implant. Surface benefits of biomaterials are critical restrictions triggering cellular reactions near simulated substances.

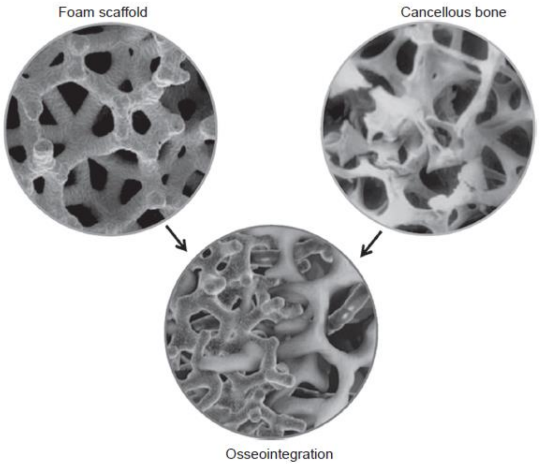

Fig 4 Implant bone interface cellular phenomena during healing.

Surface structures influence in what manner cells react to dental implants, and surfaces with different microstructures may assist further stable anchorage [23]. Proteins, bacteria, and cells can stick to implants, which are part of surface chemistry. Wettability and surface energy affect how proteins stick to an implant and make it easier for osteoblasts to stick to the surface. The way cells move on a surface that is hydrophilic is very different from how they move on a surface that is hydrophobic. On hydrophilic surfaces, the expressions of bone variation influence for osteoblasts are pushed forward [24]. So, companies that make dental implants have made rough surfaces that are high in hydrophilicity. This has led to better osseointegration than smooth surfaces.

7. Subsequent Surface Treatments for Titanium and Its Alloys

Surface engineering is a key part of making titanium orthopedic devices work many times longer than they would normally be able to. The main goals of surface treatments are to improve the implant's tribological performance, resistance to corrosion, and ability to fuse with bone. Surface oxidation, physical deposition processes like ion implantation and plasma spray coatings, and thermochemical surface treatments like nitriding, carburizing are all ways to change the surface of a material to make it harder and more resistant to wear and corrosion. This can be done with coatings. Too much work has been put into thickening and stabilizing the oxides on the surface of titanium to get the desired biological responses. Titanium's effect on living things is contingent on the surface's chemical make-up and the ability of titanium oxides to grip molecules and take in other components. Surface structure is a big part of how cells can change their shape, orientation, and how well they stick together. Oxidation is still the most common way to change the surface of titanium alloys. Heat treatment or electrolytic anodizing are usually used to make oxide layers on titanium.

8. Conclusion

Titanium and titanium alloys are some of the best biomaterials because they can be used in many ways. Because of their exceptional combination of low specific gravity, high melting point, and high resistance to corrosion, titanium alloys have found widespread use in a variety of applications. This is especially true in the medical field, where they are biocompatible and integrate well with bone. Components made of Titanium alloys are often in contact with different materials and media, under static or moving loads, and at different temperatures, in these kinds of applications. These interaction loads can break the thin oxide film that protects the titanium surface, and the titanium can withstand concentrated connections with the material on the other side and/or the environment around it. The ongoing research into how well biomaterials work with living things and how they can be improved. Adaptability helps by imitating the way the human body works in its natural state. The improvement of the quality of life for both older and younger people who need dental implants. Because of this, titanium foam structures are great options for making a big difference.

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