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Individual implants of a loss of palate fragments fabricated using SLM equipment

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ABSTRACT

Purpose: The aim of the article is to present the new conception of design and manufacturing individual implants of a loss of palate fragments using Selective Laser Melting equipment.

Design/methodology/approach: The designed virtual model of scaffolds have been produced in a process of selective laser melting (SLM). For their preparation titanium alloy powder - Ti6Al4V of suitable granulation and shape has been used. Thus obtained scaffolds have been observed in a scanning electron microscope. The structure of the pores is compatible with the shape of a designed unit cell. The outcarried EDS analysis has confirmed the chemical composition of the tested material.

Findings: In the framework of research innovative porous biomimetic materials called scaffolds with the well-defined regular structure of open pores have been used. Virtual implant models have been made using Computer Aided Materials Design. They have the geometrical dimensions corresponding to a fragment of a loss of a human palate. Porous and regular structure with defined geometric dimensions and shape are designed in the form of the unit cell, which has then been subjected to the multiplication process.

Practical implications: The scaffolds fabricated in the SLM process create conditions for their application as implants of a loss of palate fragments.

Originality/value: Implants for the whole palate or its part, required due to mechanical injuries, tumorous diseases or cleft palate are original at the basis of a literature review.

Keywords: Biomaterials; Scaffolds; Implants; Loss of palate; Porous structure; Ti6Al4V; SLM

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MANUFACTURING AND PROCESSING

1. Introduction

Biomedical engineering is one of the sciences continuously seeking new solutions and new materials having influence on rescuing and improving the quality of human or animal life. Scaffolds have been intensively developed in this field at present [1-5]. Scaffolds are biomimetic, porous materials whose task is to replace and mimic the biological functions of bone or soft tissue [6-9]. The material expected to replace a missing bone should have the set of specific characteristics [10-16]. Such objects do not only have geometrical dimensions corresponding to the piece of a human body being replaced, but also a structure in the form of open pores with specific geometrical dimensions and shape. This has an effect on the growth of bone/soft tissue in open scaffold pores. Open object pores allow to access the nutrients necessary for the growth of cells. Such materials can be used in an organism over a long-term period as they are biocompatible [17-22].

A literature review reveals that no implants exist currently for the whole palate or its part, required due to mechanical injuries, tumorous diseases or cleft palate. Prostheses made of plastics and/or metals biocompatible with a human organism are currently is use. Such solutions are not comfortable, durable and aesthetic. The authors of the article have made an attempt to create an implant scaffold with specific geometrical dimensions of an object and with a specific shape and geometrical dimensions of open pores. The article depicts the subsequent production stages of innovative implants. The application of Computer Aided Materials Design (CAMD) methods [23-25] necessary to design a virtual model of an implant with specific geometrical shapes is presented in the first place. An innovative porous implant was manufactured using Ti6Al4V powder at the first stage by Selective Laser Melting (SLM), with its shape and geometrical dimensions corresponding to the shape and geometrical dimensions of a piece of the palate loss of a patient for whom it is individually designed. The scaffolds produced were then subjected to macro-, micro- and spectroscopic examinations. Metallographic examinations were carried out at the last stage [16,26-29].

2. Computer aided materials design

The designing of virtual implant models was preceded by a clinical stage during which plaster casts of the palate piece loss were made for a patient. CAMD methods were employed at the next stage, which allowed to create a virtual model of a solid implant of a piece of palate (Figs. 1 and 2). A unit cell with the dimensions of 500x 500x500 μm and a solid hexagon shape with small cubes on each of its side walls was created with CAD software (Fig. 3). A virtual palate scaffold model with a specific shape and pore dimensions (Figs. 4 and 5) was created by multiplying a unit cell with 3D Marcarm Engineering AutoFab software.

Fig. 1 View of 3D virtual model of solid palate implant; bottom view

Fig. 2. View of 3D virtual model of solid palate implant; top view

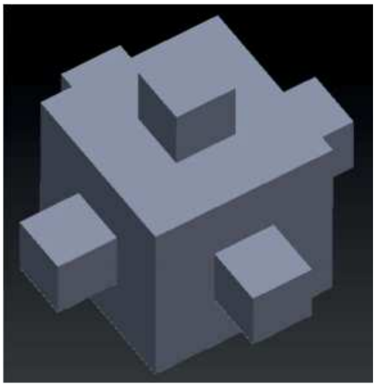


Fig. 3. Newly designed cube-shaped unit cell with six small symmetrically contiguous cubes

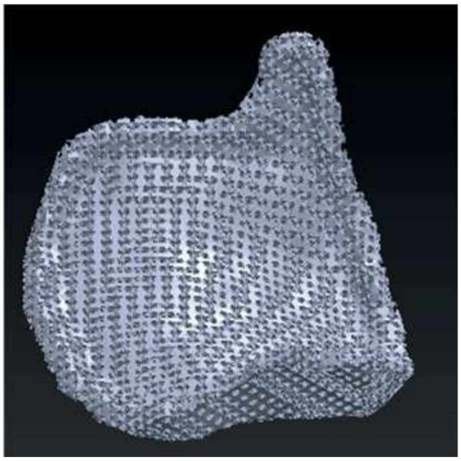


Fig. 4. Scaffold model created by means of 3D Marcarm Engineering software; bottom view

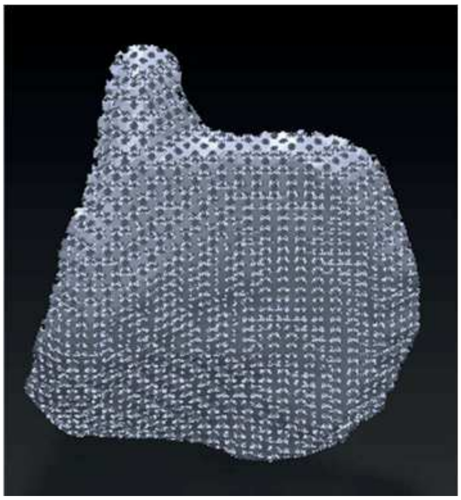


Fig. 5. Scaffold model created by means of 3D Marcarm Engineering software; top view

3. Materials and methodology

Spherically shaped Ti6Al4V powder which, in line with the valid standard, is dedicated to medical applications, was a material used for producing innovative porous implants of a palate piece. The grain size is within the range of 15-45 µm. According to the manufacturer's specifications, the powder used for producing scaffolds by the SLM method contains the following chemical elements: Al 6.35%, V 4.0%, C 0.01%, Fe 0.2%, O 0.15%, N 0.02%, H 0.003%, others 0.4%.

The selective laser melting (SLM) process was preceded by the stage of designing a virtual implant model with the specific geometrical dimensions corresponding to a loss of a patient's palate piece and with a particular structure. Files with an .stl extension with a virtual scaffold design were transferred to a machine executing an SLM process. The device recognises the extension automatically, hence direct data transfer to the machine software is possible and the related triangulation process in which a model is transformed into a net of triangles. A virtual three-dimensional implant model was placed in a virtual working chamber on a platform under the angle of 45° and props were added to secure the model against collapse under its own weight during the process and to make it easier to remove the model from the platform after the selective laser sintering process. The so prepare virtual model with props is split into layers, in relation to which a melting process is performed point after point and layer after layer. The following parameters of the process carried out in a protective atmosphere of argon were applied: laser power of 100 W, scanning speed of 1000 m/s, laser beam size of 60 µm. The process was executed without preheating the working platform of the device, but, prior to the process, Ti6Al4V powder was heated at 200°C to remove any moisture likely to exist in the powder.

4. Results and discussion

Figures 6 and 7 show the result of performing a laser selective sintering process in the form of a metal scaffold produced from Ti6Al4V powder removed from a working platform, by mechanically cutting off the propos connecting the object with the device's working platform. Any powder grains were cleaned off with compressed air from with the produced innovative porous implant of a palate piece. Macroscopic observations allow to state that the manufactured innovative implant has open pores, and geometrical dimensions of the actual object correspond to geometrical dimensions of a virtual model.

Surface topography of the metal scaffolds produced was viewed with a scanning electron microscope Supra 25 SEM, as shown in Figs. 8 and 9. It was observed that the studied material has a porous, regular latticework-shaped structure. Unmelted powder grains exist on the surface of the produced scaffolds, which were partly melted into the scaffold structure while depositing the particular layers of the material in the SLM process.

Fig. 6. Scaffold produced in SLM process; bottom view

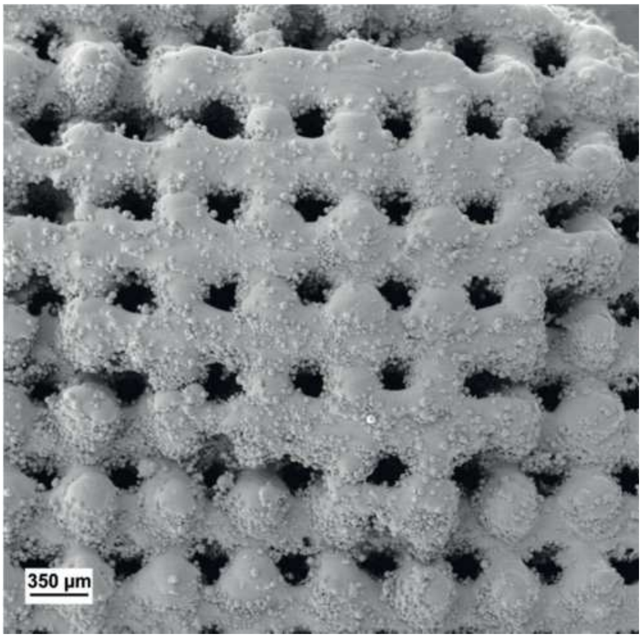


Fig. 8. Scaffold produced with Ti6Al4V powder in SLM process, SEM, Mag. 60x

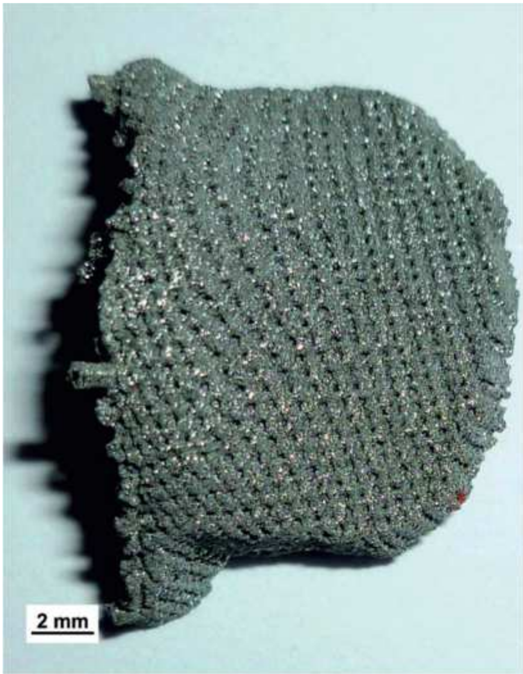


Fig. 7. Scaffold produced in SLM process; top view

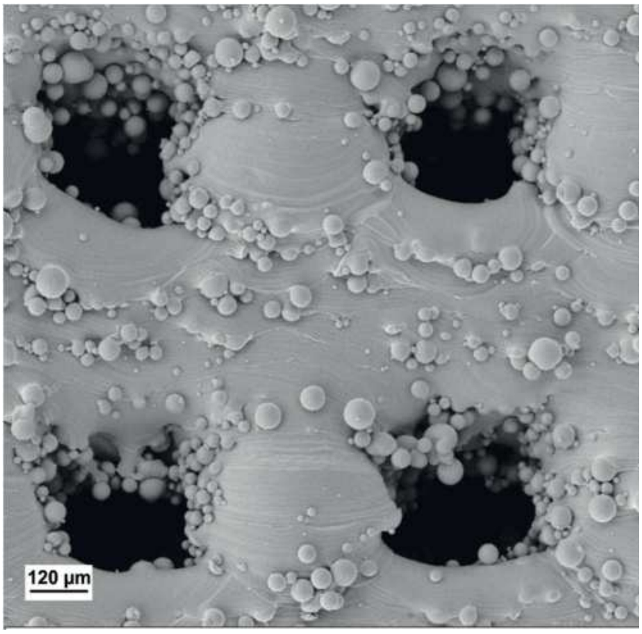
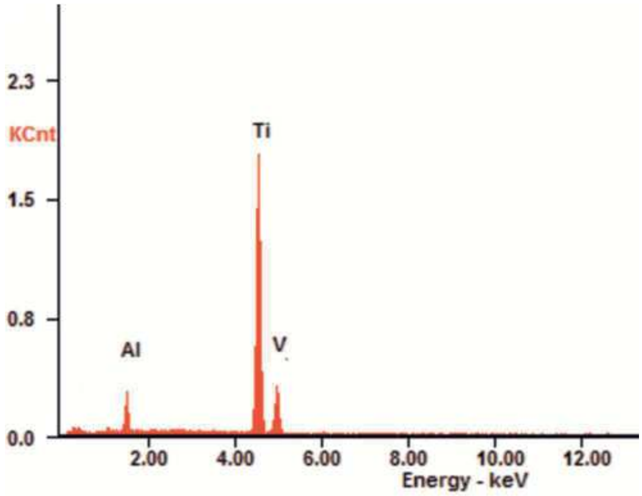
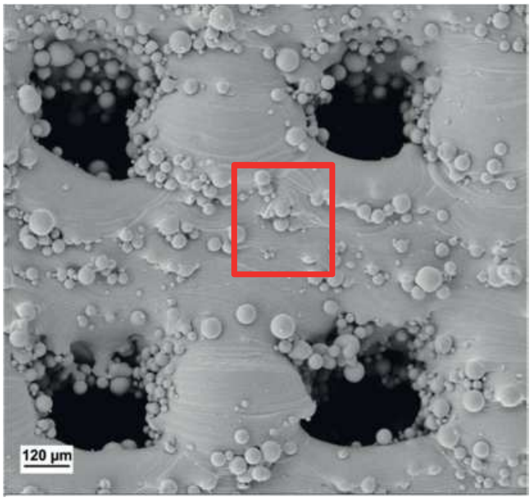


Fig. 9. Scaffold produced with Ti6Al4V powder in SLM process, SEM, mag. 250x

a)



b)



c)

Element	AlK	TiK	VK	Matrix
Wt %	06.7	88.7	04.2	Correction
At %	07.6	86.2	04.1	ZAF

Fig. 10**.** Qualitative (a) and quantitative (b) chemical composition analysis from the microarea (c), SEM, magnification of 250x made by EDS

The unmelted spherical powder grains contribute to increased surface roughness and to the reduced size of pores. It was confirmed that the pores of the scaffold produced are open, which was one of the designers' key assumptions. A fault and unevenness on the surface of the studied object, shown in Figure 8, result from its complex geometrical shape corresponding to a loss of a patient's palate piece. Figure 8 shows also small cubes projecting from the surface, and their irregular shape is due to the fact that unmelted Ti6Al4V powder grains have stuck to the scaffold surface. A regular shape of a base cell would probably be exposed in case of chemical etching in acid. A metal melting effect was observed during the melting of Ti6Al4V powder grains (Fig. 9).

An Energy Dispersive Spectrometer (EDS) fitted to a scanning electron microscope was employed for a qualitative and quantitative analysis of the chemical composition of the scaffold. Figure 10 presents the outcomes of a qualitative and quantitative analysis of chemical composition in the chosen microarea – with the magnification of 250 times – of the produced scaffold. The qualitative analysis results clearly reveal the presence of titanium, aluminium and vanadium, which are the principal components of the alloy used for scaffold fabrication in the SLM process. A quantitative analysis confirms that the percentage fraction of elements in the implant produced matches the specifications given by the Ti6Al4V powder manufacturer.

5. Conclusions

Modern Computer Aided Materials Design systems (CAMD) permit to design, on a Make-to-Order (MTO) basis, craniofacial implants matching the geometrical dimensions of a loss of bone or soft tissues of a particular patient. A virtual 3D solid implant model can be converted, with special software, into a virtual 3D porous implant model, and a designer can individually design the shape and geometrical properties of scaffold pores by creating any unit cell, as exemplified in this article. The authors have proved that it is feasible to manufacture an implant of a palate piece with Ti6Al4V powder for an individual patient with specific geometrical dimensions and structure. A scaffold manufactured using Ti6Al4V powder has visible powder grains, which have not been fully melted in the process of selective laser melting (SLM). It is possible to remove excess powder by using an etching process with hydrofluoric acid [29]. All the pores of the implant produced in all the planes are open, which was the authors' key objective. The assumptions of the design process provide that the dimensions of open pores are 200x200 µm, and the size of one elementary cell is 500x500 µm. At present, the authors of this article have also been working to optimise a manufacturing process of an innovative biomimetic composite consisting of a metallic/ceramic scaffold, onto the whole surface of which, or onto parts of which, a thin polymer layer corresponding to a patient's soft tissues is deposited.

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