POLITECNICO DI MILANO

School of Industrial and Information Engineering
Department of Mechanical Engineering
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Applied Metallurgy Course

Technical Report

DENTAL IMPLANT: A MATERIAL SELECTION CASE STUDY

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1. INTRODUCTION

According to the National Institute of Health, a considerable number of patients suffer from *Edentulism*, a chronic oral infection that cause one or more missing tooth; actually, it is estimated that one over four American subjects have lost all their natural teeth over the age of 74 [1]. The common cause of teeth loss is gum disease: it begins with gum inflammation that turn into cavities causing tooth decay and physical injury or trauma, especially during sports. In addition to periodontal disease, other risk factors are Diabetes, Hypertension, Arthritis, smoking and poor nutrition.

That said, the total number of dental implants performed in the U.S. is expected to increase, as much as 23%, by the year 2026. As a matter of fact, dental implants are growing in popularity as the procedure is quickly, starting to eclipse other dental restoration procedures [26]. Moreover, research on dental implant materials and techniques has increased in the past years and it is expected to grow due to the recent expansion of the market [6]. The driving factors for this growth in the first place are:

- the increased elderly population worldwide;
- the growing prevalence of dental disorders;
- a rise in demand for cosmetic dentistry in North America and Europe;
- advancement of dental implant technology [27].

In this context, the selection of the proper material is crucial as biocompatibility must be satisfied. Precisely, biomaterials with high compatibility are metallic biomaterials, bioceramics, polymer biomaterials and biocomposites. They work on corporation with the body, supporting functions of living tissues and hindering possible inflammations and infections. During the last decades, metallic implants have become the most frequently used treatment. Excellent clinical results have been obtained with threaded titanium implants and nowadays they have been proven safe and effective in a considerable number of patients [1]. Therefore, Titanium is one of the most common biomaterials in oral and maxillo-facial surgery employed in the treatment of partial or complete teeth loss (Fig. 1). The technique is reliable and suppresses the use of fixed or removable dentures, which invariably alter the supportive adjacent teeth after a short or medium period.

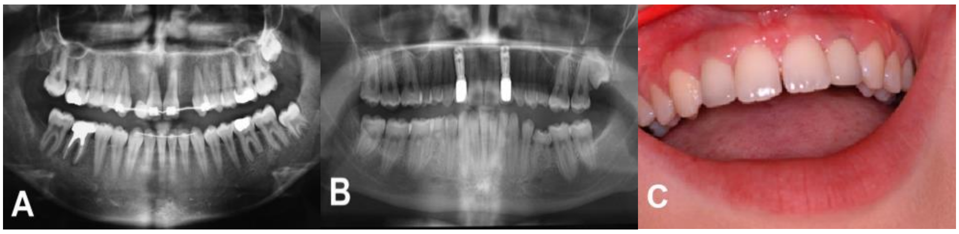

Fig. 1 - A. Panoramic radiograph before implant application. B. Panoramic radiograph after two implants placement. C. Frontal view of the definitive denture six years after implant placement [1].

1.1 BACKGROUND ANALYSIS

A dental implant is a prosthesis that interfaces with the bone of the skull through a biological process called osseointegration, during which materials such as titanium or zirconia form an intimate bond with the surrounding living bone (Fig. 2).

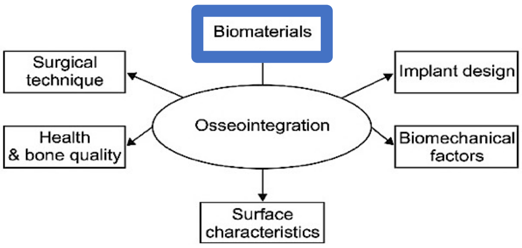

Fig. 2 - Factors that affects osseointegration [6].

Since in modern times monophasic implants are obsolete or employed in specific conditions, in Fig. 3 are shown the main four elements composing modern biphasic dental implants; this last type will be the one analyzed in the current work (note that the term *biphasic* is related to the implantation steps required) [9]. As highlighted in Fig.3, the component chosen for the current material selection case study is the endosseous part: the one in direct contact with the adjacent bone.

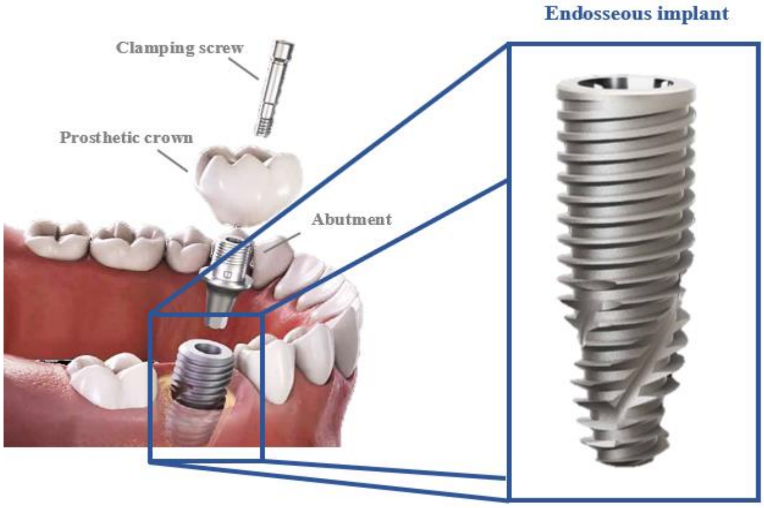

Fig. 3 – Schematic representation of dental implant components, focusing on the main element: the endosseous implant [catalogue of Neodent S.A].

The majority of biphasic implants that have been placed in patients have a similar shape: a hollow supporting the screw that receives, in a second time, a supra-prosthetic device. There are numerous variations in the overall shape of the implants pointed apex; more or less spaced threads, cylindrical or conical body [1].

The surface quality of an oral implant is one of the essential features for a successful early clinical outcome since a good surface roughness has been proven to improve the osseointegration process and the long-term biomechanical anchorage of the implant on the bone matrix. Several processes such as titanium plasma-spraying, particle blasting and acid etching, anodization of the implant surface and coatings (Hydroxy-apatite layer) have been proposed by manufacturers to produce the required rough surface on a dental implant.

1.2 SCOPE OF THE ANALYSIS

Nowadays, the branch of science concerning biomaterials is in great development in the medical field as biomaterials positively replace and support human body segments preventing adverse reactions. On this basis, the purpose of our research is to focus on three metallic biomaterials commonly used for the endosseous dental implant part and identify the best one according to the product requirements analysis based on a QFD approach.

2. MATERIAL SELECTION STRATEGY BY MULTI-CRITERIA ANALYSIS

In this section are delineated the main requirements that dental implants materials must possess, specifying the failure methods and damage phenomena involved, the implications of cost and receptiveness. As a result, the most used materials in the production of dental implant are listed. The properties of each material are analyzed, in order to highlight advantages and risks related to its employment. Eventually, a brief description of the technological cycle is carried out.

2.1 PRODUCT REQUIREMENTS

2.1.1 PERFORMANCE, P-TYPE CATEGORY

Materials suitable for dental implants must satisfy several specific criteria according to the standard ISO 10451 [10]. Precisely, the endosseous dental implant must be biocompatible and capable of functioning indefinitely without causing damages. Dental implants are subjected to occlusal loads when placed in function. Such loads vary dramatically in magnitude, frequency, and duration depending on the patient's parafunctional habits [5]. It's also requested a sufficient tensile and compressive strength to resist forces during function and an excellent fracture toughness and fatigue resistance to cycling loading. Moreover, a candidate material should have high resistance to corrosion and modulus of elasticity close to the one of the surrounding bones in order to avoid stress shielding.

- **Biocompatibility**

A material for dental implants must ensure the success of the osteointegration process with bone and soft tissues. The implantation of a biomaterial is an intrinsically invasive event that triggers the host response. Understanding and modulating this response allows to design dental implants in order to make them biocompatible, that is, being able to perform therapeutic function without causing undesirable effects on the recipient organism, giving rise to a favourable reaction in relation to the specific application. The mandibular and maxillary tissues of patients, that interact with the materials, should not suffer from any toxic, irritating, inflammatory, allergic, mutagenic or carcinogenic action. The biomechanics and the corrosive biological environment are decisive for biocompatibility [13]. Another contributing factor to biocompatibility is Bone Implant Contact (BIC [%]) which indicates how much implant surface is touching the bone on a microscopic level; high bone contact is required for implant stability as shown in Fig. 4 [18].

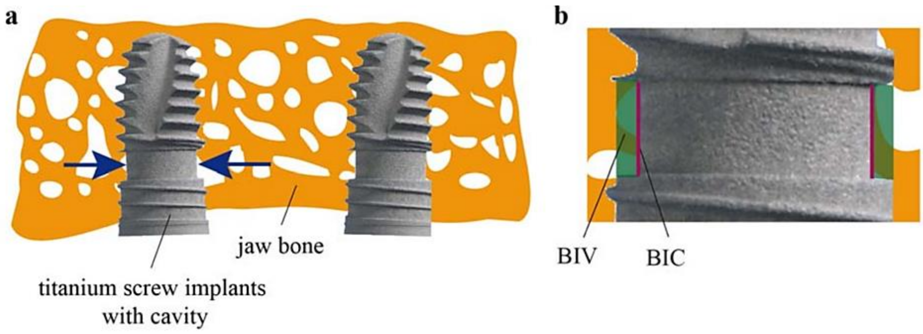

Fig. 4 a- Titanium implant inside jawbone, b- Region of new formed bones (BIC: bone implant contact, BIV: bone implant volume) [18].

- **Strength**

A dental implant is subjected to different loads throughout its life like compression, cyclic loads, bending, tensile stresses and even impacts. Precisely, there is an eccentric load applied which is given by the different angular position associated with the abutment component, as shown in the figure below (Fig. 5).

As a result, the endosseous component material must have sufficiently high tensile, compressive and fatigue strength properties. In addition, the yield strength and the ultimate tensile strength of the material determine the amount of load it can withstand before yielding or breaking, given the implant cross section. [5]. Moreover, to avoid brittle fracture a combination of fracture strength and ductility is requested [5].

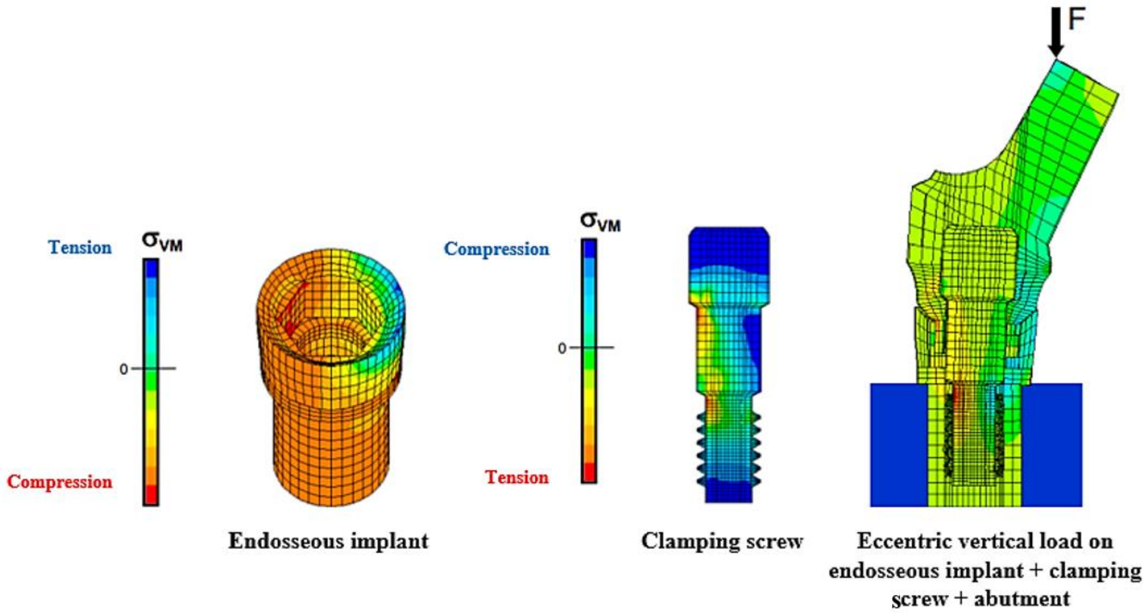

Fig. 5 - Finite element analysis concerning the distribution of stresses in the endosseous implant, clamping screw, and the whole implant [9].

- **Fatigue**

During mastication, the load varies in accordance with higher/lower efforts made by teeth. The effect of the variation of the applied load is detected with fatigue tests. As implants characteristic failure is provoked by fatigue fractures, we can delimitate fatigue strength the most relevant property, which is defined as the maximum cyclical load that the implant can withstand repeatedly without failure or functioning loss. Fatigue limits are difficult to find out since the implant is subjected to many different loading conditions, such as cantilever length and force direction. Fatigue limits are established to ensure that the implant, superstructures included, will function reliably for the patient in accordance with the ISO 14801 standard for dynamic loading test for endosseous dental implants.

- **Corrosion**

Corrosion can severely limit the fatigue life and ultimate strength of the material leading to mechanical failure of the implant. Corrosion, the gradual degradation of materials by electrochemical attack, is a concern particularly when a metallic implant is placed in hostile electrolytic environment provided by the human body. The oral cavity is subjected to changes in pH and fluctuation in temperature. The disintegration of metal is caused by the action of moisture, atmosphere, acid or alkaline solution and certain chemicals. Further, water, oxygen, chlorides, sulphur corrode various metals present in dental alloys. The chemical reactions occurring with non-metallic elements in the environment produce chemical compounds, the corrosion products; therefore, metal or alloy used within the human body should not form any product that may deteriorate the metal itself and be harmful [13].

Corrosion leads to a change in structural characteristics and loss of structural integrity. In addition, the particles lost are phagocytosed by macrophages, stimulating bone resorption and directly inhibiting osteoblast function, resulting in local osteolysis and loss of stability of the implant [13]. Actually, if highly corrosion resistant material is used for the implant, the superstructures are the main cause of release of metal ions.

As regards the endosseous implant, some materials spontaneously form an oxyde film on surface, reacting with oxygen and contrasting galvanic corrosion in the oral environment. Pitting corrosion and localized crevice corrosion can occur when the poor concentration of oxygen in the region is not sufficient to the formation of the oxide layer, thus leading to local loss of material.

- **Elasticity**

The material constituting the dental implant must have a Young Modulus (E) matching the bone's ones to better transfer stresses between the two; due to the fact that a dense cortical bone has a mean E = 16 GPa, a very stiff material may cause relative motion or disuse atrophy due to stress shielding at the bone-implant interface resulting in bone density reduction and stability loss.
We must add that force transfer is crucial for dental implants function. For this reason, many forms, diameters, shapes and lengths of the endosseous component has been tested to make it more efficient and predictable.

2.1.2 COST, C – TYPE CATEGORY

- **Raw materials**

Costs are mainly related to the price per kg of the specific material and its density, while transport costs are assumed constant.

- **Manufacturing**

The implant manufacturing phase strongly influences the final cost of the endosseous implant. The process usually includes turning, milling and threading, whose costs are affected by the machining speed, the yield strength and the hardness of the material (HV).

- **Maintenance**

A well manufactured and high-quality implant avoids excessive maintenance during its life lowering the frequency of medical examinations. This is reached by using metals with high corrosion resistance, high fatigue strength, right mechanical properties and low defects probability. Nevertheless, constant and periodic checks are always part of proper maintenance of dental implants to ensure its integrity and stability.
However, costs should have minor importance since a dental implant has to be coupled with the human body for a long period of time and it should have the highest quality as possible.

2.1.3 RECEPTIVENESS, R-TYPE CATEGORY

- **Reliability and service life**

The main concern of the customer is implant reliability in order to avoid sudden rupture or degradation of both implant and bone that can cause pain and the need of a replacement. It is mainly related to the fatigue strength of the material and its modulus of elasticity. Implant reliability at five years after surgery ranges from 95.5% to 99%, while at 10 years from 87.7% to 96.6% [14,15].
Another important concern is the implant service life which varies depending on the implant success rate. This latter is affected by several factors such as: age, implant length and diameter, bone quality, materials chosen and region of implant [16].

- **Sterilizability**

Sterilizability is a relevant feature in dental practice and prosthetic implants in general. Different methods are used by dentists in order to eliminate bacteria and living microorganisms, among them there are: steam autoclave, radiation or ethylene oxide.

- **Sustainability**

Nowadays, a very important objective is to develop production processes with low environmental impact in order to maintain an ecological balance.

This is mainly related to the CO2 footprint, the amount of CO2 emitted per kg of material produced, as well as the amount of water employed and the embodied energy for recycling.

2.2 QFD ANAYSIS: DESCRIPTION OF THE QFD ANALYSIS

The quality function deployment (QFD) is a method used to transform the customer requirements into product engineering characteristics. Precisely, in this analysis it is employed the QFD4Mat tool that is a QFD based software which allows one to choose the proper material for a generic application.
The customer specifications stated above (*Chapter 2.1*) are divided into three main categories: performances, costs and receptiveness. Each product requirement is then related to its material technical features [17]. During this phase, the parameters are directly quantified through a comparison of the physical properties.
For most of the cases, it is used a "table of conversion", in order to convert and evaluate different data coming from datasheets in a 1 to 5 scale. Selecting the material key features and choosing the direction of improvement (direct or inverse), the matrix gives a certain value that is inserted in the QFD.

The internal relationship between Technical-Key factors and Product Requirements is ultimately studied by the team, giving the most balanced and objective evaluation based on academic knowledge and bibliographic background. Thus, the relationships (Strong, Moderate, Weak and None) are multiplied by the "*Customer importance*", in order to return a "*Technical Importance Rate*", seized and weighted by the "*Relative Weight*" in percentage. Finally, looking at "*Normalized Final Weighted Score*" in the right part of the matrix, every material selection is associated with a value in 1-5 scale, and the material with the highest number is designated like the most suitable.

3. MATERIAL ASSESSMENT AND PROCESS SELECTION

3.1 MATERIAL SELECTION

This section presents the most used materials for dental implants which are chosen referring to literature articles and manufacturer's sites.
Summarising all the product requirements listed in the *2.1 Paragraph*, since titanium and titanium alloy have been widely used since 1960s, they are the election materials concerning dental implants [1]. As a result, our candidate's biomaterials for endosseous dental implant are shown below.

1. Cp Titanium Grade IV

Grade IV Commercial Purity Titanium is considered the gold standard in implant dentistry being a light metal with excellent biocompatibility, having corrosion resistance stronger than the other grades. It has also a relatively high stiffness which is important for biomechanical stability and load transfer mechanisms [6].

2. Ti-6Al-4V

The most common titanium alloy is Ti6Al4V, also referred as Grade V. It is an $\alpha - \beta$ alloy with 6% of Al and 4% of V: Aluminum increases the strength of the alloy and decreases its density while Vanadium inhibits corrosion by acting as an Al scavenger [4]. While the safety and success of Grade IV Ti is well documented as it guarantees superior characteristics of osseointegration, Grade V offers better physical properties and similarly outstanding biocompatibility [7, 90]. Ti6Al4V can be used since it is stronger and more fatigue resistant that pure Ti, having higher mechanical properties [2]. Even though this alloy has very good performances, it releases both Al and V; however, it has been shown that the emission of these elements is well below the one needed to have a toxic reaction [11].

3. Cp Titanium Grade II

Grade II Commercial Purity Titanium is similar to cpTi Grade IV. The differences are that it is softer and more ductile than the Grade IV. Despite having the same Young Modulus of the pure Ti, cpTi II has a lower mechanical strength due to the lower yield stress [12].

A summary of the candidates' material general properties chosen for the analysis can be appreciated in the following table, defined using *Granta Edupack*:

	Titanium, commercial purity, Grade IV)	**Titanium, α-β alloy, Ti-6Al-4V, Grade V**	**Titanium, commercial purity, Grade II**
COMPOSITION DETAIL			
Al (aluminum) (%)	0	5,5 - 6,75	0
C (carbon) (%)	0 - 0,08	0 - 0,1	0 - 0,08
Fe (iron) (%)	0 - 0,5	0 - 0,4	0 - 0,3
H (hydrogen) (%)	0 - 0,015	0 - 0,0125	0 - 0,015
N (nitrogen) (%)	0 - 0,05	0 - 0,05	0 - 0,03
Nb (niobium) (%)	0	0	0
O (oxygen) (%)	0 - 0,4	0 - 0,2	0 - 0,25
Ti (titanium) (%)	98,6 - 100	88 - 91	98,9 - 100
V (vanadium) (%)	0	3,5 - 4,5	0
Other (%)	0 - 0,4	0 - 0,4	0 - 0,4
PHYSICAL PROPERTIES			
Density (kg/m^3)	4490 - 4530	4410 - 4450	4510 - 4520
MECHANICAL PROPERTIES			
Young's modulus (GPa)	107 - 112	110 - 119	100 - 105
Yield strength (elastic limit) (MPa)	483 - 655	786 - 910	276 - 360
Compressive strength (MPa)	186 - 531	848 - 1080	170 - 210
Hardness - Vickers (HV)	195 - 205	337 - 373	155 - 165
Fatigue strength at 10^7 cycles (MPa)	306 - 356	327 - 381	245 - 296
IMPACT & FRACTURE PROPERTIES			
Fracture toughness (MPa.m^0.5)	50 - 55	84 - 107	55 - 60
MANUFACTURING PROPERTIES			
Machining speed (m/min)	11,6	27,7	27,4
Price (€/kg)	20,1 - 22,3	12,8 - 14,3	12,8 - 14,3
RELIABILITY & SUSTAINABILITY			
Sterilizability	Excellent	Excellent	Excellent
CO2 footprint recycling (kg/kg)	6,5 - 7,18	5,76 - 6,37	5,73 - 6,33
Water usage (l/kg)	187 - 207	104 - 115	103 - 114
Embodied energy for recycling (MJ/kg)	82,8 - 91,5	73,4 - 81,1	73 - 80,7

Tab. 1 – General properties of candidates' materials chosen for the analysis. Data taken from the Database Granta Edupack

3.2 TECHNOLOGICAL CYCLE: MANUFACTURING PROCESSES

There are two different manufacturing processes available nowadays to produce a dental implant, based on complementary concepts [1, 20, 21].

- **CNC**

The most widespread process concerns the use of a CNC machine, since all the required features can be performed using it. It requires a machine with at least 2 spindles to execute the proper features on both sides of the implant. The essential operations are the initial turning (roughing and finishing), the milling of the hexagonal pocket on the top and the threading of the part that will be inserted in the jaw. After these operations the surface is smooth and it should be blasted with hard ceramic particles at high velocity, reaching the required Ra (1-2 µm). The further procedure is cleaning the implant to remove residual particles and the lubricant oil used in the previous operations with an ultrasonic and vapor washing that employs specific solvents. After the surface treatments, the implant goes into a tank full of hot purified water and it is subjected to a series of further cleaning operations and then dried. At the end, implants are packed in sterile terms in special clean rooms and sent to gamma sterilization [21].

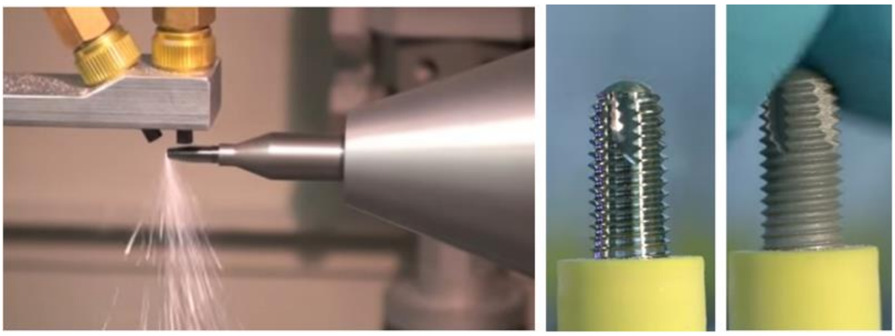

Fig. 6 - Sandblasting process (Dental Implant Surface, Comco Inc. – Youtube)

- **ADDITIVE**

The other process involved in dental implant manufacturing is the additive technique, more precisely the melting of powders. Additive manufacturing has allowed the fabrication of custom implants with microscale resolution. The technique uses data obtained from computed tomography or magnetic resonance imaging in order to reproduce the jawbone. The method, known as rapid prototyping or 3D printing, builds a structure by adding the material layer by layer, hence reduces wasting of material and time when compared with the milling. Metal implants are typically manufactured by electron beam melting (EBM) or selective laser melting (SLM), namely build solid components by melting layers of metal powder and following a 3D computer-aided design (CAD) file. In this context, the metallurgical processes involved in solidification are complex and produce fine-scale alloy microstructures with excellent mechanical properties, including high strength. Such characteristics occur due to the rapid solidification conditions of the alloy. In addition, the structures produced are porous and this is an important feature in reducing effective stiffness and, thus, concerns stress induction. Another beneficial property of the porous structures is providing anchor sites to the bone tissue and promoting accelerated osseointegration. With such trait, the implants could adequately transfer the stresses between bone and implant, increasing the life of an implant-supported restoration. Disadvantages of additive manufacturing of dental implants are the surface quality and dimensional accuracy obtained, chances of failure due to fatigue and equipment and materials costs [19].

4. RESULT AND DISCUSSION

Values 0-5 scale	
Absence	0
Very low	1
Low	2
Medium	3
Medium high	4
High	5

Relationship	Symbols
Strong	●
Moderate	○
Weak	▽
None	

		Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
		Category	P	P	P	P	P	P	P	P	C	C	R	R	R	R	R	
Product Requirements		Customer importance / Technical Key-Factors for Material and Process selection	Young Modulus (Mpa)	Fatigue stregth at 10^7 cycles (Mpa)	YS (Mpa)	Compressive strength (Mpa)	Fracture toughness (Mpa*m^0.5)	Percentage of Vanadium (%)	Percentage of Aluminum (%)	Hardness Vickers (HV)	Machining speed (m/min)	Price (€/kg)	Sterilizability	Density (kg/m^3)	CO2 footprint recycling (kg/kg)	Water usage (l/kg)	Embodied energy for recycling (MJ/kg)	
PERFORMANCES	Biocompatibility	5	●										●					
	Strength	4		●	●	●			▽									
	Fatigue	4		●		○	●											
	Corrosion	4						▽										
	Elasticity	3	●							○								
COST	Raw material cost	4										●		●				
	Manufacturing cost	5			▽					●	●			○	○	●	●	
	Maintenance cost	4		○														
RECEPTIVENESS	Reliability and service life	5	○	○														
	Sterilizability	5											●					
	Sustainability	5									▽				●	●	●	
		Technical Importance Rating	87	99	41	48	36	4	4	54	50	27	90	51	60	90	90	NORMALISED FINAL WEIGHTED SCORE
		Relative Weight	20.6%	23.4%	9.7%	11.3%	8.5%	0.9%	0.9%	12.8%	11.8%	100.0%	23.6%	6.1%	7.1%	10.7%	10.7%	
		Cp Titanium Grade IV	2.96	3.14	2.81	1.39	2.4	0	0	3.45	3.7	3.48	5	3.01	3.19	3.65	3.13	3.3
		Ti6Al4Va	2.88	3.35	4.58	5	3.96	5	5	1.59	1.57	2.04	5	2.96	2.62	1.73	2.75	3.1
		Cp Titanium Grade II	3.16	2.51	1.61	1.27	2.64	0	0	3.97	3.74	3.48	5	3.03	3.19	3.62	3.12	3.2

Fig. 7 - QFD Matrix

4.1 THE BUBBLE MAP SOLUTION

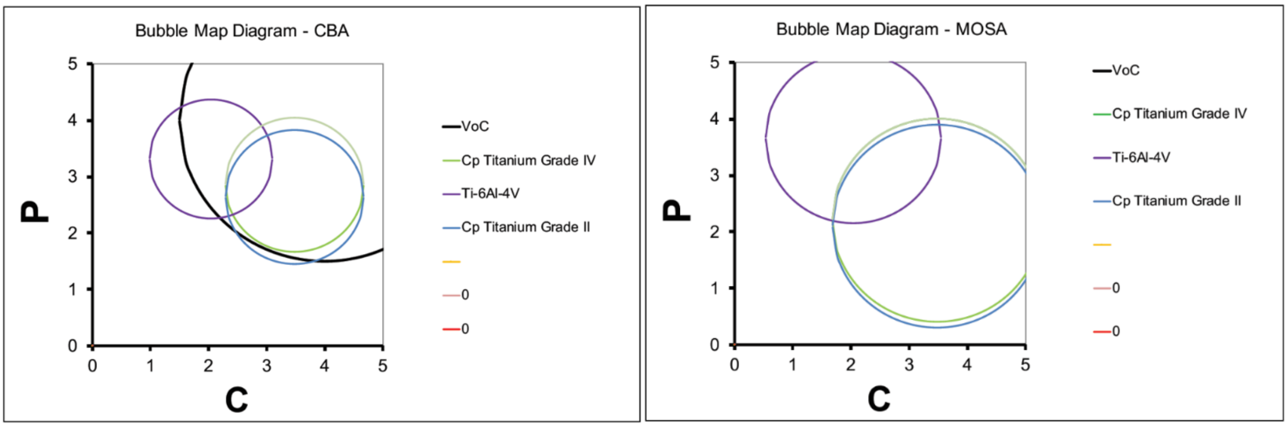

Fig. 8 – a) Bubble Map Diagram – CBA   b) Bubble Map Diagram – MOSA

As shown in the QFD matrix, resulting from the analysis conducted (Fig.7), it can be verified that all the 3 candidate materials exhibit a good combination among all the factors and adherence with the application chosen; besides Cp Titanium Grade IV, with a final score of 3.3, proves to be the most suitable biomaterial for our material selection case study: the endosseous dental implant. It can be noticed that all the selected materials are titanium based, that's why their "*Normalized Final Weighted Score*" ranges in a close interval between 3.1 ÷ 3.3. While outstanding physical properties of Grade V Ti (Ti6Al4V) are easily quantified and collected on *Granta Edupack* database, Grade IV Ti biocompatibility supremacy, that guarantees superior characteristics of osseointegration, is not easy document. As a matter of fact, we haven't found quantitative indexes concerning biocompatibility properties for all the three materials involved in the analysis; otherwise, we would have proven that Cp Titanium Grade IV stands out from the others with an even higher final score. Indeed, nowadays the most used material is Cp Titanium Grade IV as it is stated in literature.

Moreover, in Fig. 7 it can be appreciated the two resulting Bubble Maps (Performance vs Cost diagrams): they show how the different materials employed manage to reply to the customer's needs. The best combination between performances, costs and receptiveness parameters is reached by the material candidate with the associated bubble closer to the Voice of Customer circle, which represents the ideal response in order to satisfy the market requirements. So, in terms of strategic analysis, the ideal situation is when the PCR bubble representing the supply-side (denoting the material response by its key-features) completely matches the demand-side (the bubble representing the product requirements weighted by relative importance assigned by customer) [17]. This is the case of Grade IV Titanium, our final choice for the endosseous implant.

5. CONCLUSIONS

The scope of this project is to find out the most suitable material among several candidates for a specific application: dental implants; in particular we have focused on their endosseous components. Starting from a customer point of view, which can be considered both dentistry and patient, the main requirements that dental implants materials must possess are pointed out and then divided into three main categories: performances, costs and receptiveness. Therefore, the technical key factors for our specific application are collected from literature, manufacturers' sites, or material databases (*Granta Edupack*) in order to match with the corresponding product requirement. As a result, by means of QFD4Mat tool that is a QFD based software, it allows us to choose the proper material among the candidate materials selected: Cp Ti grade II, Cp Ti grade IV and Ti-6Al-4V. From the QFD matrix shown in Fig. 7 and the Bubble Maps in Fig. 8, it is clear that having obtained for Grade IV the highest score of 3.3, it can be considered the election material for the endosseous component of dental implant, combining better features in terms of cost, biocompatibility, strength, fatigue, elasticity and corrosion; moreover, this is in accordance with what stated in literature.

Besides that, we need to underline that the "*Normalized Final Weighted Score*" ranges in a close interval between 3.1 ÷ 3.3, therefore, they can be all possible material that fits since we are talking about of the same base material: Titanium.

Referring to possible developments in terms of cutting-edge materials, investigations of novel titanium alloys developed for orthopaedics show that they offer few advantages as dental implants. Different alloying elements have been used to replace Al and V in the Ti-6Al-4V alloy. One example is the use of niobium (Nb) and Zr resulting in the alloy Ti-13Nb-13Zr. This offers the highest strength-to weight ratio and a reduced young's modulus (77 GPa), making Ti-13Nb-13Zr optimal for orthopaedic implants. Moreover, a Ti-13Nb-13Zr core can provide excellent mechanical properties (compressive strength of 1289.7 MPa) with a porous outer layer of HA (hydroxyapatite) to improve the implant osseointegration (micro and macro-pores between 100–400 μm) having also a resulting young's modulus similar to the bone (14.9 GPa) [25]. Ti-13Nb-13Zr's possible dental applicability is still under investigation [7].

Another innovative solution for dental implants is the use of polymers, such as PEEK. It is able to resolve some problems occurring in Ti alloys, like breakdown of the oxide film on implant surface and the consequently exposure of metal to electrolytes. As PEEK has Young's modulus near to the cortical bone, hence it exhibits stress shielding less than the Ti material. It possesses good chemical resistance, high mechanical properties, biocompatibility and they are very suitable with modern imaging technologies. Very limited clinical trials have been done using PEEK as dental implant, so it is too early to conclude that PEEK can replace Ti implants in future. Further research and a greater number of controlled clinical trials on PEEK implant is required in near future. [22].

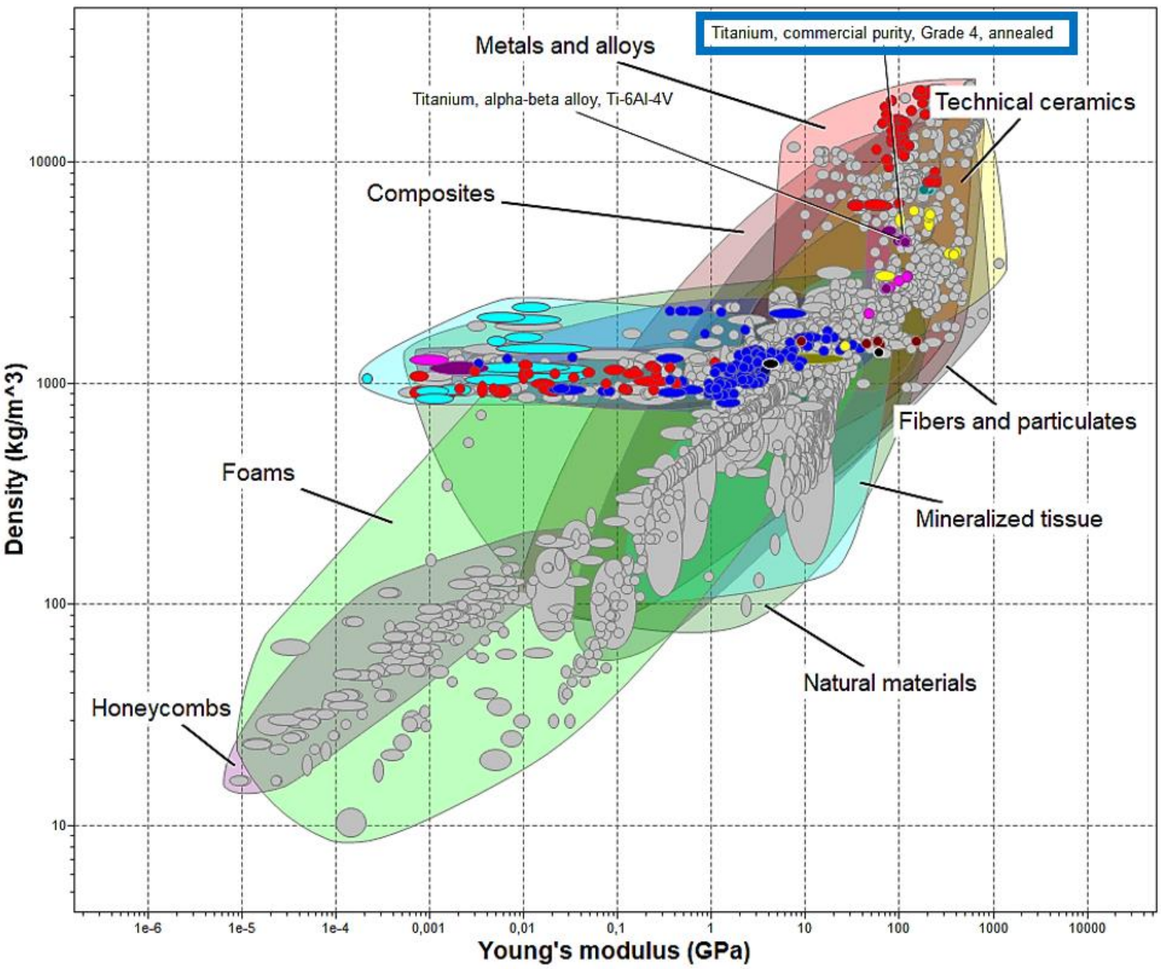

Fig. 9 – General overview Diagram matching Young Modulus and density property; our best candidate material is highlighted. (Granta Edupack)

6. LIST OF FIGURES

7. LIST OF TABLES

8. SOFTWARE

Excel (*Microsof* 365): Version 18.0
Granta Edupack (*Ansys*)

9. BIBLIOGRAPHY

1. Dental implants: A review – Guillaume – Morphologie (2016) 100, p. 189—198 - http://dx.doi.org/10.1016/j.morpho.2016.02.002
2. Dental Implant Materials: Commercially Pure Titanium and Titanium Alloys – McCracken – Journal of Prosthodontics, Vol8, No 1 (1999)
3. Interventions for replacing missing teeth: different types of dental implants (Review) – Esposito - Cochrane Database of Systematic Reviews (2014) - DOI: 10.1002/14651858.CD003815.pub4.
4. Materials for endosseous dental implants – Wathana - Journal of Oral Rehabilitation (1996) 23(2), p. 79–90 – DOI: 10.1111/j.1365-2842.1996.tb01214.x
5. Misch's contemporary implant dentistry – Resnik – Fourth edition (2021) – ISBN: 978-0-323-39155-9
6. Current trends in dental implants – Gaviria – J Korean Assoc Oral Maxillofac Surg (2014), 50-60 - http://dx.doi.org/10.5125/jkaoms.2014.40.2.50
7. Titanium and its alloys in dental implantology | Implante Institute - https://implante.institute/artigos/titanium-and-its-alloys-in-dental-implantology/612
8. Titanium Alloys for Dental Implants: A Review – Nicholson – Prosthesis (2020) – DOI:10.3390/prosthesis2020011
9. Notes of the Course "Progettazione di Endoprotesi" – La Barbera (2021)
10. ISO 10451:2010 (en) – Dentistry (Contents of technical file for dental implant systems)

11. Titanium Alloys for Dental Implants: A Review - John W. Nicholson - Prosthesis 2020, p. 100-116; https://doi.org/10.3390/prosthesis2020011
12. Titanium and its alloys in dental implantology - https://implante.institute/artigos/titanium-and-its-alloys-in-dental-implantology/612#
13. Corrosion in titanium dental implants: literature review – Adya – The journal of Indian prosthodontic society (2005) - https://j-ips.org/article.asp.Adya
14. Evaluation of implant success: A review of past and present concepts. – Karthik, K., Sivakumar, Sivaraj, & Thangaswamy, V. – Journal of pharmacy & bioallied sciences, 5(Suppl 1), S117–S119. (2013)– https://doi.org/10.4103/0975-7406.113310
15. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. – Albrektsson T, Zarb G, Worthington P, Eriksson AR. – Int J Oral Maxillofac Implants. 1986 Summer;1(1):11-25. – PMID: 3527955.
16. Factors Affecting the Survival Rate of Dental Implants: A Retrospective Study. – Raikar S, Talukdar P, Kumari S, Panda SK, Oommen VM, Prasad A. – J Int Soc Prev Community Dent. 2017 Nov-Dec;7(6):351-355. – doi: 10.4103/jispcd.JISPCD_380_17. Epub 2017 Dec 29. PMID: 29387619; PMCID: PMC5774056.
17. Material selection by a hybrid multi-criteria – D'Errico – Springer international publishing (2015) – ISNB: 978-3-319-13029-3
18. Comparison of bone-implant contact and bone-implant volume between 2D-histological sections and 3D-SRMCT slices. – Bernhardt, R., Kuhlisch, E., Schulz, M., Eckelt, U., & Stadlinger, B. – European Cells and Materials, 23, 237-248 (2012). – doi:10.22203/ecm.v023a18
19. Fabrication of dental implants by the additive manufacturing method: A systematic review-Thaisa-The Journal of Prosthetic Dentistry (2019) - https://doi.org/10.1016/j.prosdent.2019.01.018
20. Articles-Site of sptmak -visited on 08/11/2022- https://sptmak.com/category/makaleler/
21. Manufacturing processes and surface modification techniques of dental implants, Chapter 16 - Yurttutan, Mehmet (2020)
22. PEEK materials as an alternative to titanium in dental implants: A systematic review- Sunil Mishra (2018) - DOI: 10.1111/cid.12706
23. Leghe di titanio introduzione- Site of TAG- visited on 26/10/22- https://www.tag.it/leghe-di-titanio-introduzione-caratteristiche-applicazioni/
24. Fabrication and characterization of Ti-13Nb-13Zr alloy with radial porous Ti-HA coatings for bone Implants, Volume 209 -Yuanhuai He (2017) - https://doi.org/10.1016/j.matlet.2017.08.098
25. Surface modifications and their effects on titanium dental implants- Jemat, A., Ghazali, M. J., Razali, M., & Otsuka, Y. - BioMed Research International (2015) - https://doi.org/10.1155/2015/791725
26. https://www.trendstatistics.com/health/dental-implants-facts-statistics/ (15/12/2022)
27. https://www.jungimplantplano.com/post/dental-implant-statistics-from-around-the-world (15/12/2022)