New Metallic Alloys Used for Dental Implants Manufacturing

Diana-Irinel Băilă

Abstract—Trauma, degeneration and diseases often make surgical repair or replacement necessary. When a person has a joint pain, the main concern is the relief of pain and return to a healthy, normal and functional life style. This usually requires replacement of skeletal parts that include knees, hips, finger joints, elbows, vertebrae, teeth and repair of the mandible. Biomaterial is available and suitable for inclusion in systems which augment or replace the function of body tissues or organs. From as early as a century ago, artificial materials and devices have been developed to a point where they can replace various tissues of the human body. These materials are capable of being in contact with body fluids and tissues for prolonged periods of time, with little or without any adverse reactions. In this paper, there are presented new biomaterials that can be used to manufacture dental implants and restorations, like Fe alloys, Co alloys, Ti pure and Ti alloys, Ti-Ta alloy, Ni-Ti alloy, zirconium alloy.

Index Terms—Dental implants, biomaterials, iron alloys, Co alloys, Ti alloys.

I. INTRODUCTION

In function of structure and properties of the metallic implant, the materials are selected according to the manufacture process.

With exception of noble metals such as gold (which do not represent a major fraction of implant metals) the majority of used alloys are different chemical combinations with other elements, as in the case of metal oxides.

The most used alloys are rutile TiO$_2$ and ilmenite FeTiO$_3$ [1]-[3].

The purity grade of the titanium product is very important for dental implants [1].

In the production of the most common grades of commercially pure (CP) titanium, these grades differ in oxygen content by only tenth of a percent, yet these small differences in oxygen content have an important impact regarding the mechanical properties: yield, tensile and fatigue strength of titanium.

In the case of multicomponent metallic implant alloys, the raw metal product will usually have to be further processed both chemically and physically [1]-[6].

Processing steps include remelting addition of specific alloying elements and controlled solidification from the melt. Thus, it is obtained an alloy that meets sure chemical and metallurgical specifications.

A metal supplier will typically further process the bulk raw metal product (alloy and/or pure metal) into stock bulk shapes, such as bars, wires, sheets, rods, plates, tubes or powders [6].

The materials used for dental implants have evolved significantly in the last 50 years.

![Fig. 1. Processing steps of a typical dental implant [1].](image)

Over time, the first materials were the metal from the austenitic stainless steels, Co-Cr alloys or at the titanium base, currently considered to be biocompatible, followed inert ceramic biomaterials and bioactive biomaterials, with their advantages and disadvantages.

One of the major disadvantage is that the use of synthetic materials in hard tissue cause the bone retracted to the implantation area, but this is happening in few years [7], [8].

Figure 1 illustrates the processing steps of a typically dental implant, from mining the metal to fabrication and launch on the market.

About the material’s characteristics, the Young modulus exceeds 350 MPa in case of ceramics and 200 GPa for stainless steels and alloys Co-Cr even Ti has the modulus over 100 GPa, in case that the mature human bone has a module between 7 and 30 GPa [1], [9]-[12].

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The chemical composition of metals used for implants are presented in Table I.

### TABLE I: CHEMICAL COMPOSITION OF METALS USED FOR IMPLANTS [1]

<table>
<thead>
<tr>
<th>Biomaterial</th>
<th>Nominal composition elements</th>
<th>Tensile Strength [MPa]</th>
<th>Elongation [%]</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Fe alloys</td>
<td>Fe-18Cr-2.5Mo</td>
<td>480</td>
<td>30</td>
<td>Cast and wrought forms</td>
</tr>
<tr>
<td></td>
<td>Fe-18Cr-14Ni-2.5Mo</td>
<td>150-1350</td>
<td>10-40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fe-Zr-10Ni-3Mo</td>
<td>24-1100</td>
<td>10-35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fe-15Ni-2.5Mo</td>
<td>490-860</td>
<td>4-40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fe-22Cr-13Ni-5Mo-2.5Mo</td>
<td>690-1035</td>
<td>12-35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fe-23Mn-21Cr-1Mo</td>
<td>827-1379</td>
<td>12-30</td>
<td></td>
</tr>
<tr>
<td>Co alloys</td>
<td>35Co-35Ni-20Cr-10Mo</td>
<td>241-1580</td>
<td>3-60</td>
<td>Cast and wrought forms</td>
</tr>
<tr>
<td></td>
<td>Co-28Cr-6Mo</td>
<td>655-1192</td>
<td>8-20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40Co-20Cr-16Fe-15Ni-7Mo</td>
<td>1240-2275</td>
<td>1-65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co-20Cr-15W-10Ni</td>
<td>190-896</td>
<td>20-45</td>
<td></td>
</tr>
<tr>
<td>Ti and Ti alloys</td>
<td>99Ti (grade I-IV)</td>
<td>240-550</td>
<td>4-30</td>
<td>Cast and wrought forms</td>
</tr>
<tr>
<td></td>
<td>Ti-6Al-4V</td>
<td>860</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-6Al-4V (ELI)</td>
<td>825-860</td>
<td>8-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-6Al-7Nb</td>
<td>800</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-13Nb-13Zr</td>
<td>560-860</td>
<td>8-15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-12Mo-6Zr-2Fe</td>
<td>931</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-15Mo</td>
<td>690-724</td>
<td>12-20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ti-3Al-2.5V</td>
<td>621-862</td>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td>99Ta</td>
<td>172-517</td>
<td>12-30</td>
<td>Deposit and wrought forms</td>
</tr>
<tr>
<td>Zirconium alloy</td>
<td>Zr-2.5Nb</td>
<td>450</td>
<td>15</td>
<td>Wrought forms</td>
</tr>
<tr>
<td>Nickel Titanium alloy</td>
<td>45-57Ni-Ti</td>
<td>551</td>
<td>10</td>
<td>Wrought forms</td>
</tr>
</tbody>
</table>

This will certainly impose that future research in this area should be oriented towards obtaining new biocompatible materials which have a Young's modulus much more similar to that of bone [1], [9]-[12].

The chemical composition of metals used for implants are presented in Table I.

### II. IRON ALLOYS USED IN DENTISTRY

The outcome of biomaterials and medical devices implantation is not always optimal, many times owing to suboptimal tissue-biomaterials interactions for bio-compatibility.

Implants can be retrieved after in vitro studies or at either reoperation or necropsy/autopsy of animals or humans, and they may or may not failed.

The correlation of biomaterials surface chemistry with performance is a critical step.

**Fig. 2.** SEM realized on probe Fe-Cr (x1000).

**Fig. 3.** SEM realized on probe Fe-Cr (x4000).

**Fig. 4.** SEM realized on probe Fe-Cr-Ni (x1000).

Fig. 2 and Fig. 3 present electron microscopy on the stainless steel Fe-Cr probe and it can be remarked the presence of homogeneous martensitic structure and fines grains of δ ferrite and small black inclusions of Si oxides.

The classic Fe-Cr-Ni alloy is used frequently in dentistry and presents good mechanical resistance, but the time to obtain the dental crown is too long because of rectification operations.

Thus, all the patients lose more time to obtain an adequate dental crown.

In Fe-Cr-Ni alloys (microscopy probes in Fig. 4 and Fig. 5)
may appear some tensions after classical sintering process.

In the last years, the implant research guided the development of new and modified implant designs and materials, assistance in decisions of implant selection and management of patients.

Also, it was the base and permitted many studies of the mechanisms of biomaterials-tissue interactions.

Preclinical tests of modified designs and materials are crucial to developmental advances.

These investigations usually include in vitro functional testing and insertion/implantation of the implant in the intended location in an appropriate model, followed by noninvasive and invasive monitoring, specimen explantation and detailed pathological and material analysis.

Animal investigation may permit more detailed monitoring of implant functions and enhanced observation of morphologic detail, using frequently tests of laboratory parameters and allow in situ observation of fresh implants at desired intervals.

Animal tests present facility observations of specific complications in an accelerated timeframe.

The animal models that faithfully duplicate the relevant human anatomy, physiology and pathology are not often available.

III. COBALT BASED ALLOYS

Co based alloys include ASTM F75 and F90, forged Co-Cr-Mo alloy ASTM F799 and multiphase MP35N alloy ASTM F562.

Alloy powder Co-Cr (ST2724G) is used in medicine for realization of dental crowns, analogues implants (Fig. 6), dental bridges and implants [9]-[11].

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic limit (0.2%) RP 0,2</td>
<td>817 MPa</td>
</tr>
<tr>
<td>Break elongation</td>
<td>9.7%</td>
</tr>
<tr>
<td>Vickers hardness</td>
<td>375 HV5</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>228.7 GPa</td>
</tr>
<tr>
<td>Volume mass</td>
<td>8.336 g·cm⁻³</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>&lt;4 μg/cm²</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>14.5×10⁻⁶ K⁻¹</td>
</tr>
</tbody>
</table>

Mechanical properties of alloy powder Co-Cr are given in the Table II below.

The chemical composition of Co-Cr alloy (ST2724G) is as follows: 54.31% Co; 23.08 % Cr; 11.12% Mo, 7.85% W, 3.35% Mn, Si and Fe < 0.1%.

Powder of Co-Cr is a tolerable material in medicine and the powder alloy Ti-6Al-4V is tested as biocompatible material.

IV. TITANIUM BASED ALLOY

Dental implants differ greatly by the material from which they are made, shape and geometry, number and shape the end turns, and connection.

The two most common titanium-based implants are commercially pure (CP) titanium (ASTM F67) and Ti-6Al-4V alloy (ASTM F136). F67 alloy present 98.9-99.6% Ti.
Fig. 8 presents a 3D model for a mandible realized by 3D Printing. Fig. 9 and figure 10 present a SEM analysis of mandible fracture Ti-20%HA. Fig. 11 presents a EDS analysis of mandible fracture Ti-20%HA [11].

Table III presents the mechanical properties of Ti alloys.

<table>
<thead>
<tr>
<th>Ti alloys</th>
<th>Young’s modulus [GPa]</th>
<th>Yield strength [MPa]</th>
<th>Tensile strength [MPa]</th>
<th>Fatigue Endurance Limit strength (at $10^7$ cycles) [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>F67</td>
<td>110</td>
<td>485</td>
<td>760</td>
<td>300</td>
</tr>
<tr>
<td>F136</td>
<td>116</td>
<td>896</td>
<td>965</td>
<td>620</td>
</tr>
</tbody>
</table>

Osteointegration is the growth and healing of bone implant inside and outside ensuring much greater surface contact between implant and bone body than normal titanium implants.

Metallic implant with trabecular structure has become the treatment of choice when solving difficult cases and greatly increasing the success rate.

Its structure similar to human bone spongy (porous), interconnected porosity and bone growth potential among these pores are a unique combination of features that contribute to osteoconductivity the metal implant with trabecular structure, which leads to the formation of vascular bone on and in implant surface.

Another new alloy of titanium and zirconium is a material intended solely for dental implants. Ti-Zr alloy is fifty times more resistant than the current material, titanium.

The results of the experiment conducted in the clinical trial showed that the implant from Ti-Zr was integrated much better bone structure than titanium.

Another potential advantage met is the potential use in bone structure, where normally the process of implantation is complicated, requiring an augmenter processes. Interest in searching for high-performance materials appeared with titanium.

V. CONCLUSIONS

Through our research, we identified the major problems being the metallurgical principles underlying structure-property relationships, design, production and proper utilization of the implants.

The alloys Co based and Ti based present very good mechanical properties, being resistant to corrosion tests and
are biocompatible materials.

These materials can be used successfully to manufacture dental implants, orthopaedic hips, knees, oral/maxillofacial implants, stents and heart valves.

Any metallic implants will differ after the manufacture process, metallic alloys and its properties.

Functional, aesthetic and health compromises have been correlated with the loss of oral dentition.

Actually, there exists a multitude of dental implant designs and intraoral restorations, depending on their background, the patient population being treated and recognized needs for improved treatments.

For dental implants manufacturing there are necessary to be realized in vitro tests of durability and biocompatibility, then preclinical investigations of implant configurations on large animals.

For investigation of bioactive materials/implants and combination and potentially tissue-engineered medical implants in which the interactions between the implant and the surrounding tissue are complex, research based on implant retrieval and evaluation continues to be critical.

A robust sterilization validation method embodies in national and international standards and they are the foundation for the strong patient safety record of terminal sterilizations.

Some biological materials may have undesirable responses to the techniques used and then may require special sterilization methods.

After prototype device have been designed and fabricated, biologic tests in vitro and in animals are normally used to gain more information for eventual regulatory approval and introduction of such an implant into clinic.

Many actual and future researches determine a development of different metallic alloys composition with very special properties like Ti-Ta alloy and Ti-Zr alloy.

REFERENCES

Bâilă Diana Irinel is a lecturer in University Politehnica of Bucharest. She holds courses for the following subjects: manufacturing processes, manufacturing equipments.

She got the Ph.D in industrial engineering with thesis title “Theoretical and experimental research on the assimilation of new biocompatible materials processed by RP (rapid prototyping) technology” from Technical University of Cluj-Napoca, The Faculty of Machine Building in 2009. She is a member in 7 research contracts. Her 10 papers have been published in ISI journals with impact factor.