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Titanium and Titanium Alloys for Biomedical and Industry Applications

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ABSTRACT

This paper refers to recent advancements and trends in the titanium and its alloys industry, especially focused in biomedical area.

Bone Prosthesis

The principles of design, selection of biomaterials and manufacturing criteria for orthopedics implants are, basically, the same as for any other product that must be dinamically stressed. However, even the replacement of human tissues with materials similar in shape and density seems tempting, in fact this is much difficult task to undertake. That is because the living tissue has some extraordinary caracteristics including the capacity of remodeling both micro structural and macrostructural under the different directions loads.

The functional and design capabilities of a metallic implant material are important with respect to the metal's ability to be formed, machined, and polished. An implant metal must be capable of being utilized with state-of-the-art metallurgical techniques. In addition, the implant device must remain functional during its expected performance life; it must not be degraded with time in the body through fatigue, fretting, corrosion, or impact loading. Titanium and its alloys meet all of these requirements.

The ASTM (American Society for Testing and Materials) defines a number of alloy standards with a numbering scheme for easy reference (see the tables below).

Table 1 – *Minimum mechanical properties of titanium and its alloys*

	Ultimate Tensile Strength [Mpa]	Yield Strength [Mpa]	Elongation [%]	Reduction of Area [%]
Grade 1	241	172	24	30
Grade 2	345	276	20	30
Grade 3	448	379	18	30
Grade 4	552	483	15	25
Ti-6Al-4V ELI	862	793	10	25

Grade 1-4 are unalloyed and considered commercially pure or "CP". Generally the tensile and yield strength goes up with grade number for these "pure" grades. The difference in their physical properties is primarily due to the quantity of interstitial elements. They are used for corrosion resistance applications where cost and ease of fabrication and welding are important.

Table 2 – *Principal titanium alloys and their composition*

% / **Grade**	Al	V	Sn	Pd	Mo	Ni	Ru	Cr	Zr	Nb	Si	Co	Fe
Grade 5	6	4											
Grade 6	5		2.5										
Grade 7				0.12-0.25									
Grade 7H				0.12-0.25									
Grade 9	3	2.5											
Grade 11				0.12-0.25									
Grade 12					0.3	0.8							
Grade 13, 14, 15						0.5	0.05						
Grade 16				0.04-0.08									
Grade 16H				0.04-0.08									
Grade 17				0.04-0.08									
Grade 18	3	2.5		0.04-0.08									
Grade 19	3	8			4			6	4				
Grade 20	3	8		0.04-0.08	4			6	4				
Grade 21	3				15	2.7					0.25		
Grade 23	6	4											
Grade 24	6	4		0.04-0.08									
Grade 25	6	4		0.04-0.08		0.3-0.8							
Grade 26, 26H, 27							0.08-0.14						
Grade 28	3	2.5					0.08-0.14						
Grade 29	6	4					0.08-0.14						
Grade 30,				0.05								0.3	

31													
Grade 32	5	1	1		0.8				1				
Grade 33, 34				0.015		0.4	0.025	0.15					
Grade 35	4.5	1.6			2						0.3		0.5
Grade 36										45			
Grade 37	1.5												
Grade 38	4	2.5											1.5
Grade													
Grade													

Grade 5 is the most commonly used alloy. It has a chemical composition of 6% Aluminum, 4% Vanadium, remainder titanium, and is commonly known as Ti6Al4V, Ti-6AL-4V or simply Ti 6-4. Grade 5 is used extensively in Aerospace, Medical, Marine, and Chemical Processing.

Grade 6 contains 5% Aluminum and 2.5% Tin. It is also know as Ti-5Al-2.5Sn. This alloy is used in airframes and jet engines due to its good weldability, stability and strength at elevated temperatures.

Grade 7 contains 0.12 to 0.25% Palladium. This grade is similar to Grade 2. The small quantity of Palladium added gives it enhanced crevice corrosion resistance at low temperatures and high Ph.

Grade 7H contains 0.12 to 0.25% Palladium. This grade has enhanced corrosion resistance.

Grade 9 contains 3.0% Aluminum and 2.5% Vanadium. This grade is a compromise between the ease of welding and manufacturing of the "pure" grades and the high strength of Grade 5. It is commonly used in aircraft tubing for hydraulics and in athletic equipment.

Grade 11 contains 0.12 to 0.25% Palladium. This grade has enhanced corrosion resistance.

Grade 12 contains 0.3% Molybdenum and 0.8% Nickel.

Grades 13, 14, and 15 all contain 0.5% Nickel and 0.05% Ruthenium.

Grade 16 contains 0.04 to 0.08% Palladium. This grade has enhanced corrosion resistance.

Grade 16H contains 0.04 to 0.08% Palladium.

Grade 17 contains 0.04 to 0.08% Palladium. This grade has enhanced corrosion resistance.

Grade 18 contains 3% Aluminum, 2.5% Vanadium and 0.04 to 0.08% Palladium. This grade is identical to Grade 9 in terms of mechanical characteristics. The added Palladium gives it increased corrosion resistance.

Grade 19 contains 3% Aluminum, 8% Vanadium, 6% Chromium, 4% Zirconium, and 4% Molybdenum.

Grade 20 contains 3% Aluminum, 8% Vanadium, 6% Chromium, 4% Zirconium, 4% Molybdenum and 0.04% to 0.08% Palladium.

Grade 21 contains 15% Molybdenum, 3% Aluminum, 2.7% Niobium, and 0.25% Silicon.

Grade 23 contains 6% Aluminum, 4% Vanadium.

Grade 24 contains 6% Aluminum, 4% Vanadium and 0.04% to 0.08% Palladium.

Grade 25 contains 6% Aluminum, 4% Vanadium and 0.3% to 0.8% Nickel and 0.04% to 0.08% Palladium.

Grades 26, 26H, and 27 all contain 0.08 to 0.14% Ruthenium.

Grade 28 contains 3% Aluminum, 2.5% Vanadium and 0.08 to 0.14% Ruthenium.

Grade 29 contains 6% Aluminum, 4% Vanadium and 0.08 to 0.14% Ruthenium.

Grades 30 and 31 contain 0.3% Cobalt and 0.05% Palladium.

Grade 32 contains 5% Aluminum, 1% Tin, 1% Zirconium, 1% Vanadium, and 0.8% Molybdenum.

Grades 33 and 34 contain 0.4% Nickel, 0.015% Palladium, 0.025% Ruthenium, and 0.15% Chromium .

Grade 35 contains 4.5% Aluminum, 2% Molybdenum, 1.6% Vanadium, 0.5% Iron, and 0.3% Silicon.

Grade 36 contains 45% Niobium.

Grade 37 contains 1.5% Aluminum.

Grade 38 contains 4% Aluminum, 2.5% Vanadium, and 1.5% Iron. This grade was developed in the '90 for use as an armor plating. The iron reduces the amount of Vanadium needed for corrosion resistance. It's mechanical properties are very similar to Grade 5.

In the 1950s and 1960s the Soviet Union pioneered the use of titanium in military and submarine applications (Alfa Class and Mike Class) as part of programs related to the Cold War. Starting in the early 1950s, Titanium began to be used extensively for military aviation purposes, particularly in high-performance jets, starting with aircraft such as the F100 Super Sabre and Lockheed A-12.

In the USA, the Department of Defense realized the strategic importance of the metal and supported early efforts of commercialization.[14] Throughout the period of the Cold War, titanium was considered a Strategic Material by the U.S. government, and a large stockpile of titanium sponge was maintained by the Defense National Stockpile Center, which was finally depleted in 2005. Today, the world's largest producer, Russian-based VSMPO-Avisma, is estimated to account for about 29% of the world market share.

Titanium is recognized for its high strength-to-weight ratio.[6] It is a light, strong metal with low density that, when pure, is quite ductile (especially in an oxygen-free environment),[19] lustrous, and metallic-white in color. The relatively high melting point (over 1,649 °C or 3,000 °F) makes it useful as a refractory metal.

Commercial (99.2% pure) grades of titanium have ultimate tensile strength of about 63,000 psi (434 MPa), equal to that of some steel alloys, but are 45% lighter. Titanium is 60% heavier than aluminium, but more than twice as strong as the most commonly used 6061-T6 aluminium alloy. Certain titanium alloys (e.g., Beta C) achieve tensile strengths of over 200,000 psi (1380 MPa). However, titanium loses strength when heated above 430 °C (800 °F).

Titanium is the ninth most abundant element and the fourth most abundant structural metal in the earth's crust. Reserves of the principal titanium ores, rutile and ilmenite, are dispersed throught the world. Within its own boundaries, the United States has reserves far greater than will be needed for the rest of the century and beyond. In fact, titanium is one of the few critically important elements (along with molybdenum and zirconium) for which more than 100 percent of the demand for the next 20 years can be met by American domestic resources. On the other hand, only a small portion of the domestic demand for alloying elements such as chromium, nickel, and cobalt can be met by domestic resources.

Table 3 – Demand for alloying minerals versus reserves in the United States

Commodity	Available from U.S. Resources, %
Chromium	6
Cobalt	0
Nickel	14
Titanium	over 100

On the world market, titanium is currently produced in England, Japan, Russia, and China, and construction of new titanium facilities is planned in several other countries.

It is very important to keep in mind that an idea should and must be put into an growing environment. As the seed must be put in a proper soil and fertilized in order to grow. We cannot look at scientists, managers and businessmen as distinct entities. Instead of this, they should work together like a living organism. Growing faster mean harmony between elements.

We believe orthopedics will emerge as the single most promising source of future investor returns in healthcare, given the confluence of demographics, technology and global expansion. While other healthcare sectors such as cardiovascular devices, cancer or biotech may have been more lucrative in the past, what the American Association of Orthopedic Surgeons (AAOS) calls the "Decade of Orthopedics" provides the best opportunity for future investor profits in healthcare.

A number of elements will create this opportunity for the next ten years:

- Increased life expectancies, which is a powerful demand driver that uniquely favors orthopedic devices.
- Technological innovation, which will change the entire complexion of the industry.
- Attractive industry economics and profitability.
- Combined, these elements will cause the industry to grow more than twofold, from $30 billion per year to $65 billion in the coming decade, resulting in as much as $40 billion of potential investor profits.

This combination of factors supports sustained, attractive industry valuations.

We must understand that science and innovations are keys to SUCCESS.

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