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IMPLEMENTATION OF MECHANICAL ELEMENTS AND MATERIALS FOR KNEE JOINT PROSTHESES

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ABSTRACT

This article aims to highlight the importance of the materials used in the manufacture of prostheses, through the knowledge of their characteristics and mechanical properties in order to use them on the manufacture of links and sockets. The most commonly used materials in the prosthetics industry are: titanium, polymers, synthetic polymers, among others, which provide adequate pressure distribution, and a high shocks absorption capacity and elasticity, this facilitates their relationship of the human body.

Keywords: exoskeleton, prostheses, mechanical properties.

1. INTRODUCTION

The development of prostheses has become one of the most used techniques for the repair of upper or lower limbs in people, these are artificial devices that replace a part of the body that is missing to improve or replace totally or partially a limb, helping with the psychological development of the patient by allowing them to have a perception of totality through the recovery of mobility, improvement on physical appearance and sensibility [1].

Lower limb prostheses have been designed throughout history to provide a better quality of life for people with disabilities caused by amputations or genetic affectations.

There are two kinds of lower limb prostheses:

- Endoprosthesis (joint prostheses, knee - hip)
- Exoprosthesis (lower limb prosthesis). [2]

2. PROSTHESIS DESIGNS

Conventional or exoskeletal: they are aesthetic prostheses laminated in polyester resin material, rigid in skin color with fiberglass reinforcement, adaptable to any type of foot, Figure-1.

Figure-1. Exoskeletal prosthesis for below-knee amputee. Fountain: [3]

Modular or endoskeletal: Currently, modern prosthetics conceives modular prostheses as the most functional for all levels of amputations. The mechanical components are designed in such a way that they can be incorporated into the aesthetic sleeve.

The ankle and knee joints, hip joints and adapters can be detached from the piece and can be easily interchanged, Figure-2.

Figure-2. Endoskeletal prostheses. Source: [4]

3. MATERIALS FOR PROSTHESES PRODUCTION

In the manufacture of prostheses for lower limbs, different materials are used; these are selected according to factors such as the chemical composition or the function it fulfills within the prosthesis.

The use of materials varies and is constantly evolving. Currently, aluminum and its alloys, structural steel, titanium and its alloys, chromium, plastics, polymers and resins, fiberglass, among others are used. [5]

Gustav Hermann suggested using aluminum over steel to make artificial limbs lighter and more functional. In 1912, Marcel Desoutter, a famous English aviator, lost his leg in a plane crash and made the first aluminum prosthesis with the help of his brother Charles, who was an engineer. [6]

Aluminum and its alloys are used mainly for the manufacture of tubes and connections, although they have also been used for the manufacture of ball joints.

Additionally, it has great advantages where we find diamagnetism, high resistance to corrosion and

oxidation, its use also depends on the type of alloy it presents, since there are two types of alloys, those of forging and those of smelting, which makes its heat treatment determine its properties[7], Table-1 indicates the properties of aluminum and its alloys.

Table-1. Properties of aluminum and its alloys.

Aleación	Resistencia a la tracción (kpsi)	Limite Elástico (kpsi)	Elongación (%)
Forjado con tratamiento térmico			
1100-O >99%	13	5	40
1100-H18	24	22	10
3004-O 1.2% Mn-10% Mg	26	10	25
3004-H18	41	36	9
4043-O 5.2% Si	21	10	22
4043-H18	41	39	1
5182-O 4.5% Mg	42	19	25
5182-H19	61	57	4
Forjado sin tratamiento térmico			
2024-T4 4.4%Cu	68	47	20
2090-T6 2.4%Li-2.7%Cu	80	75	6
4032-T6 12% Si-1% Mg	55	46	9
6061-T4 1%Mg-0.6% Si	45	40	15
7075-T4 5.6 Zn-2.5%Mg	83	73	11
Por fundición			
201-T6 4.5%Cu	70	63	7
319-F 6% Si-3.5%Cu	24	18	2
356-T6 7%Si-0.3Mg	33	24	3
380-F 8.5% Si -3.5%Cu	46	23	3
390-F 17%Si-4.5%Cu	41	35	1
443-F 5.2%Si	19	8	8

Structural steel: Structural steel is defined as the alloy of iron, carbon and small amounts of other elements such as silicon, phosphorus, sulfur and oxygen, which provide specific characteristics.

Structural steel was one of the most used materials in the manufacture of prostheses due to its high resistance, however, it has been replaced by titanium and aluminum due to their strength and weight ratio, and also because of its nickel content, which it is a carcinogenic agent which due to the effects of corrosion can be dispersed throughout the body; is currently used for links and has a great advantage that is its low cost in the market [8], Table-2 indicates the properties of structural steel.

Table-2. Propiedades del acero structural.

PROPIEDADES DEL ACERO ESTRUCTURAL	
Módulo de la elasticidad	29 kpsi
Módulo de Poisson	0.3
Peso especifico	0.282 lbf/in^3
Coef. Expansión térmica	1.2x10^{-5} 1/ºC
Conductividad térmica	5.2 Btu/hr in ºC
Calor especifico	0.18 Btu/lb ºC
Límite de esfuerzo	
Limite elástico a la tensión	36.28 kpsi
Resistencia ultima a la tensión	66.76 kpsi
Limite elástico a compresión	36.28 kpsi
Resistencia ultima a la compresión	0 kpsi

Titanium and its alloys: Titanium is a transition material, which has many similarities with silicon and zirconium, which makes it a favorite element within prosthetics, due to its resistance and low weight, it is used in the production of femoral stems, for the replacement of the femoral head, transmitting all the weight of the body to the femur, this material has succeeded in replacing steel in all prosthesis components, additionally it has excellent resistance to corrosion, good properties at high temperatures, although its high price makes for a great disadvantage [7], Table-3 indicates the properties of titanium and its alloys.

Tabl-3. Propiedades del titanio y sus aleaciones.

Grupo Ti	Resistencia a la Tracción (ksi)	Limite Elástico (ksi)	% Elongación
Ti comercial puro 99.5% Ti 99.0% Ti	 35 80	 25 70	 24 15
Aleaciones Ti Alpha 99.5% Ti	125	113	15
Aleaciones Ti Beta 99.5% Ti	187	176	5
Aleaciones Ti Beta 99.5% Ti	150	140	8

Fuente: [7]

Chromium-cobalt alloys: These are alloys that are used in different elements of the prosthesis, mainly in the femoral head (hip), this material contributes to improve the friction surface; additionally, it is widely used due to its resistance to corrosion.

Polymers: These materials have two uses, the first is for the manufacture of the articular surface of the prosthesis, for this it must have low coefficients of friction, and good resistance to wear and tear when in contact with other surfaces, since metals or ceramics are regularly used; This is also used for the fixation between the interface between the structural component of the implant and the bone tissue.

Polypropylene: It is a semi-crystalline thermoplastic material, called homopolymer, it is characterized by being rigid plastic with very good resistance to fatigue, in Image 3 you can see one of the main applications of polypropylene.

Polyethylene: low density is used in the prosthetics industry, due to its flexibility, as well as being soft, light, transparent, inert, waterproof and inexpensive [8], Table 4 indicates the properties of polyethylene.

Figure-3. Femoral prosthesis with polyethylene friction surface. Source: [9]

Tabl-4. Propiedades polietileno.

	BAJA DENSIDAD	ALTA DENSIDAD	BAJA DENSIDAD
Peso molecular (lbf/mol)	74.9	1102	4408
Densidad (slug/mol)	6.16×10^{-5} -6.3×10^{-5}	6.3×10^{-5} -6.5×10^{-5}	6.3×10^{-5} -6.46×10^{-5}
Resistencia a la tracción (kpsi)	1.1	3.3 – 5.8	0.43
Elongación	150	400-500	200-250
Modulo de elasticidad (kpsi)	13.9 – 37.73	59.5 – 179.9	__

Fuente: [10]

Copolymer: It is the result of mixing polypropylene with ethylene, it has better resistance to cracks than polypropylene, it is generally used for support due to its ability to transmit force and its high resistance to impact, it is also used in leg sockets due to the fact that when heated it can be adapted to the shape of the leg mold, which provides greater accuracy when producing prostheses [7], Image 4 shows one of the main applications of the copolymer and Table-5 indicates its properties.

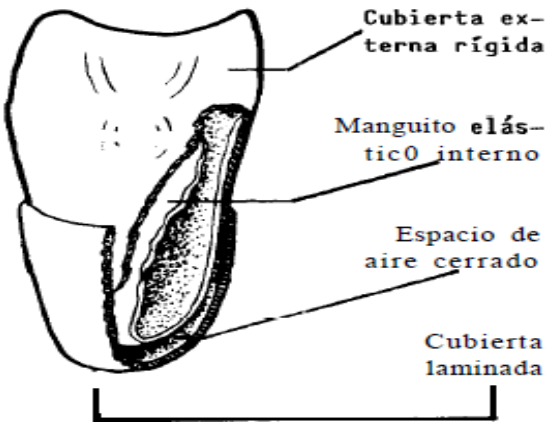

Figure-4. Encaje de pierna. Fuente: [8]

Table-5. Propiedades del Copolimero.

Propiedades	PP Copolì-mero
Módulo elástico en tracción (ksi)	101.6 - 203.2
Alargamiento de rotura en tracción (%)	450-900
Carga de rotura en la tracción (ksi)	0.589 - 0.799
Modulo de flexión (ksi)	60.95 - 203.2
Resistencia al impacto Charpy (Btu/in^2)	5.5×10^{-3} - 24.4×10^{-3}
Dureza en shore D	67-73

Fuente: [7]

Synthetic Polymers:

Silicone: It is a material made mainly of silicon, it is inert and stable at high temperatures, it is currently used for restorations of upper limbs, it is an elastomer which presents plastic and non-linear deformation when force is applied.

Restorations are often given more realism and durability, this is due to the fact that different textures are achieved, their useful life is 3 to 5 years; has great acceptability to the human body.

Silicone is used in prosthetics as an aligner due to its mechanical properties that do not allow it to easily tear or irritate the skin. [7], In Table-6 the properties of silicone are indicated, in Graph 1 the stress-strain curve of the material is shown.

Table-6. Propiedades del Silicón.

Propiedades	Silicón
Resistencia a la tracción (psi)	4,000
Módulo de elasticidad (psi)	1200
Densidad (slug/in^3)	1.7×10^3
% elongación	0

Fuente: [7]

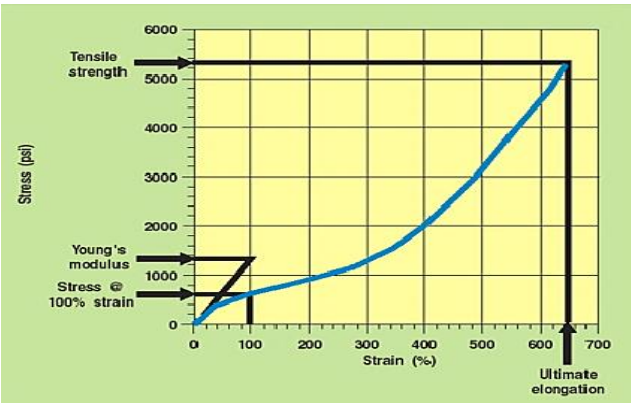

Figure-5. Curva típica del esfuerzo - deformación del silicón. Fuente: [7]

4. MATERIAL COSTS

Table-7 shows a price comparison of the main materials used for the manufacture of prostheses.

Table-7. Costos de materiales protésicos.

COMPONENTE	PRECIO*
Platina de aluminio de 1” x 1/8” x libra	3190
Resina semirìgida x libra	4110
Resina epoxica x libra	24250
Silicón de 490 C/catalizador	45000
Titanio de densidad 4.51(g/cm^3)x libra	7312
Platina de acero de 1” x 1/8” de densidad 7.87(g/cm^3)x libra	1828
Hule de látex 1 l	2450

* Costo en pesos colombianos

5. CONCLUSIONS

Adequate knowledge of the mechanical properties of materials has allowed the prosthetics industry to select suitable materials for the production of prostheses and implants, considering the durability, wear, and tear that they have along their life cycle; this has led to minimizing the risks that come up with the daily use of prostheses.

In accordance with the technological advancement in the manufacturing of prostheses, the materials and designs currently used guarantee the comfort and functionality of the lower-body prostheses, allowing the demand of users to increase.

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