Researches on the Simulation with Inventory Program and Implementation of an Ankle Prosthesis in the Aluminium Alloy EN AW 6082 and Anodizing Process for the Proshesis Components

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The objectives of this paper are to simulate the design under the kinematic conditions of the human walking cycle and to make of an ankle prosthesis from the aluminum alloy 6082. It was considered that the ankle prosthesis is must absorb the shock caused by weight in the moment of stepping and must provide smoothness to the movement. The ankle functions such as strength and suppleness are considered. Since the ankle prosthesis is personalized, it must become an integral part of the body and therefore must be accepted by the patient.

Keywords: ankle prosthesis, aluminum alloy 6082, anodizing aluminum

To minimize in the size and weight of the ankle prosthesis, it was simulated prototype in which most of the components are passive elements and the engine has a limited contribution. The virtual prototype has been optimized to be as light and compact as possible, able to withstand to the forces and moments of force exerted by the drive system and body weight. The ankle prosthesis prototype and the ankle prosthesis wrist are shown in fig. 1.

Fig. 1. Prototype of the ankle and ankle joint manufactured in lab Seletron SRL

Experimental part

Simulation of ankle prosthesis parts

The ankle prosthesis sole should fulfil several conditions:
- to ensure stability for the person using the prosthesis,
- to simulate the movements of the fingers, so in length, it continues with another section which simulate the movements of the fingers,
- to be narrower that the healthy foot, taken as a dimensional witness, because it must be inserted into a shoe.

The disadvantage is that the sole of ankle prosthesis is not as mobile as the soles of the foot.

Simulation with INVENTOR software of ankle prosthesis parts

In the following figures are presented stages of modelling with the INVENTOR program [1]: the ankle prosthesis (fig. 2) the sides of the ankle prosthesis (fig. 3) and in the assembly of these parts (fig. 4).

Applying forces that simulate the actions of various factors on the ankle prosthesis

The connection points between the prosthesis components were studied and the forces which are simulating the actions of various factors on the ankle prosthesis were applied, (fig. 5) [2,3].

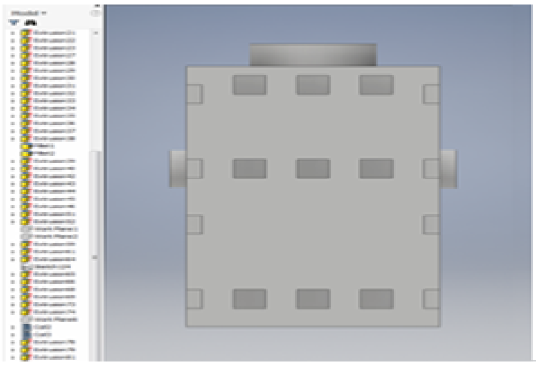

Fig. 2. Simulation of the ankle prosthesis foot

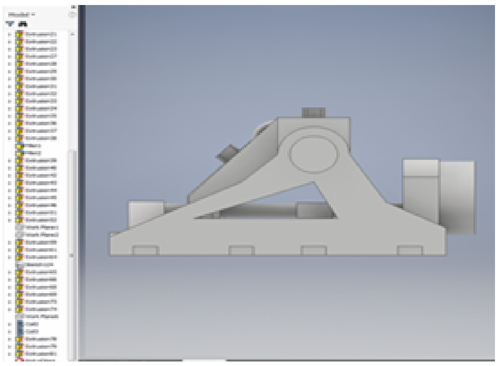

Fig. 3. Simulation of the ankle prosthesis

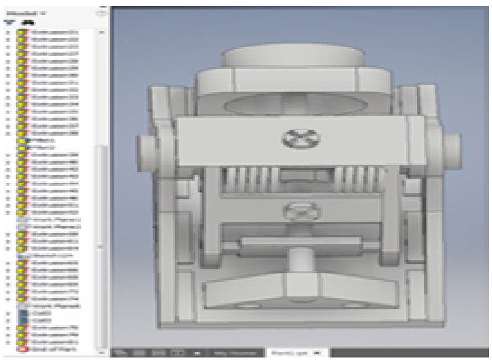

Fig. 4. Simulation of the joint of the prosthesis soles, of the ankle prosthesis and of the other parts that make up the ankle of the prosthesis

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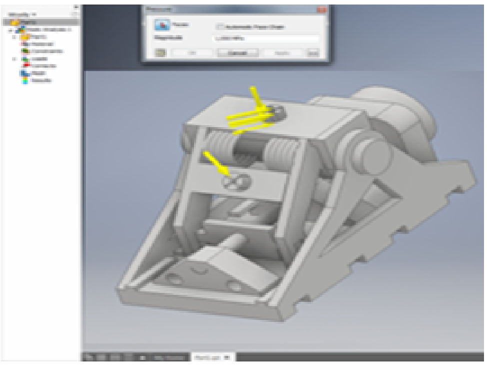

Fig. 5. Simulation of the application of forces which acts as different external factors upon the ankle prosthesis

Ankle prosthesis material selection from simulation

For simulation of the ankle prosthesis body, from the INVENTOR [4] program, the library, was chosen the aluminum alloy plate 6082, (fig. 6), which is a medium strength alloy with excellent corrosion resistance. The alloy has the highest strength in the 6000 series [5].

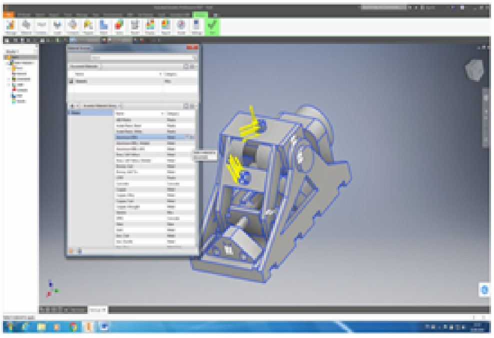

Fig. 6. Simulation of choice of aluminum alloy 6082

The alloy 6082 is known as a structural alloy. In the form of plates, 6082 is the most commonly used alloy for machining. The EN AW 6082 alloy belongs to Class 6xxx and contains aluminum, magnesium and silicon. The chemical composition of the chosen alloy, EN AW 6082, [5], is shown in table 1.

Element	Percent
Silicon (Si)	0.70 - 1.30
Magnesium (Mg)	0.60 - 1.20
Manganese (Mn)	0.40 - 1.00
Iron (Fe)	0.0 - 0.50
Chromium (Cr)	0.0 - 0.25
Zinc (Zn)	0.0 - 0.20
Others (Total)	0.0 - 0.15
Titanium (Ti)	0.0 - 0.10
Copper (Cu)	0.0 - 0.10
Other (Each)	0.0 - 0.05
Aluminium (Al)	Balance

Table 1
CHEMICAL COMPOSITION OF THE ALUMINIUM ALLOY EN AW 6082 [5]

Values in the table are expressed in percent.

Technical or commercial aluminum has a purity of 99.5 ÷ 99.8, the remainder of 0.2 ÷ 0.5 being impurities, in particular Fe and Si, which have a negative effect on plasticity and corrosion resistance.

These impurities determine the tendency of cracking at solidification, due to the AlFeSi ternary chemical compound, which has as a result in the formation of large closed loops and superficial cracks.

The applicability of the aluminum alloy EN AW-6082 Si1MgMn [5] is shown in table 2.

The physical properties of the aluminum alloy 6082 are shown in table 3, [5].

To improve the mechanical characteristics, this alloy is generally used in the treated state. The treatments are thermal and electrochemical. After thermal treatment, the alloy is characterized by a high mechanical resistance, good corrosion resistance, weld ability, good mechanical

Composition	Al 0,9Mg 1.0Si 0,7Mn
Applicability	High loading structures for truck or trolley frames, for boilers or bicycles, boat construction, hydraulic systems, flanges, digging equipment, pylons, towers, motorboats, masts and triads in boat construction, metal scaffolding, frames for tents, etc.
Characteristics	Corrosion-resistant, good welding, excellent for mechanical machining, increased T4-formability, medium-hard alloy. Alloy with somewhat greater hardness than 6061
Precautions and warnings	Not recommended for complex sections
Possible products forms	Sheets, sheets, rectangular bars, round bars, wires, pipes, profiles after drawing

Table 2
THE APPLICABILITY OF THE ALUMINUM ALLOY EN AW-6082 [5]

Property	Value
Density	2700 kg / m^3
Melting point	555 °C
Thermal point	24 x 10^{-6} /K
Elastic modulus	70 G Pa
Thermal conductivity	180 W/m·K
Electrical resisstance	0.038 x 10^{-6} Ω·m

Table 3
GENERAL PHYSICAL PROPERTIES OF THE ALUMINUM ALLOY EN AW-6082 [5]

processing characteristics and suitable for surface finishing by anodizing.

The mechanical properties of the EN AW-6082 aluminum alloy for a 6.00 mm - 12.5mm plate, required for finite element analysis are shown in table 4 [5].

Table 4
THE MECHANICAL PROPERTIES OF THE ALUMINIUM ALLOY EN AW-6082 [5]

Property	Value
Proof Stress	255 Min Mpa
Tensile strength	300 Min Mpa
Elongation A50 mm	9 Min %
Hardness Brinell	91 HB

Anodizing the ankle prosthesis components

In figure 7 and figure 8 are shown the components of the ankle prosthesis made of the aluminum alloy plate 6082.

Anodizing is a surface treatment for aluminum parts and is carried out for anticorrosive protection purposes, being done by controlled electrochemical oxidation of the aluminum alloy. Anodizing is a process that changes the surfaces. The result is a cover film of metal oxide that will increase on the surface of the treated part. The process of creating this protective oxide layer is reached electrolytic [6].

Fig. 7. Manufacture of ankle prosthetic components

Fig. 8. Executing ankle prosthesis components

Aluminum has usually a fine layer of natural oxide (alumina) on its surface. This layer is subject to deterioration due to its fragility determined by both its reduced thickness and its non-homogeneity. The anodizing process allows the control of the thickness of this oxide layer, resulting a homogeneous and resistant coating. Anodizing aluminum gives the metal the possibility of retaining its natural appearance and the resulting pores in the oxide layers can provide a better surface for the adhesion of paints and glue.

This method increases the corrosion resistance of the metal parts through an oxide layer formed on their surface.

The various methods of anodizing are generally characterized by the type of electrolyte solution used. Chromic acid (also known as Type I) was used in the first commercial anodizing factories in 1920 [6]. The most common electrolyte solution for anodizing, used at the present, are produced using sulphuric acid (known as Type II or III, depending on the process used) [4].

To ensure the forming of a considerable oxide layer, conditions such as: electrolyte concentration, acidity, solution temperature and current intensity must be controlled.

Harder and thicker films can be produced by dilute solutions at low temperatures with higher voltage and current intensity.

Film thickness can range from less than 0.5 micrometers for bright decorative and 150 micrometers for architectural applications.

While anodizing (anodizing) of aluminum allows the metal to retain its natural appearance, pores in the oxide layers can provide a better surface for adhesion of paints and glue [6].

The most common anodizing processes (such as aluminum sulphuric acid) produce a porous surface that can easily accept paint. The number of colors in the paint is almost infinite; however, the colours resulted on the treated aluminium tend to vary function on alloy base [6].

Practically, the process consists in aluminium immersing a plate in an electrolyte bath. Applying electricity to aluminium, the parts become anodizing despite the cathode type, in a complete circuit that sinks into the electrolyte bath [6].

When a current between 6 and 12 V and amperage over 1 A passed through an acid solution, the hydrogen is released from the cathode and the oxygen forms the anode surface meaning the aluminium plate.

Electricity and acid bath work together to open surface texture and crystalline structure and build the thickness of the natural oxide layer. In the same process, the surface increases its hardness, which is crucial for most applications of anodized aluminium (anodised).

The action of the acid is balanced with the oxidation rate to form a 10-150 mm diameter nanoporous layer as can be seen at the electronic microscope [6]. These pores, which allow electrolyte solutions and current to reach the substrate of aluminium, continue to increase the thickness of the oxide layer through to auto passivating process. However, the same pores will later allow the air or water to reach the substrate and corrode it if they are not locked [7].

To prevent this process, they are filled with coloured paints or corrosion inhibitors before used in the assembly. Because dyeing is only superficial, the oxide layer below can continue to provide corrosion protection even if small scratches can break the paint layer. To stain the anodized layer are used special dyes.

The finishing of the anodizing treatment is done by clogging the pores by hydrating process of the formed oxide layer [8]. Once the pores are latched, a better corrosion resistance is achieved.

The 6000 series alloys (magnesium and silicon alloys) behave very well at anodizing, the appearance of the anodized obtained layer being very homogeneous.
The pieces made of this alloy can be blasted to the surface a matt appearance. At a thickness of anodized layer over 30μm, the surface of the parts becomes dark gray [9].

Anodizing aluminium improves hardness or corrosion resistance, but accidental rubbing can damage large areas of anodized parts. Anodized parts have a longer life than non-anodized parts. The deposited aluminium oxide layer on the surface also has dielectric properties[7].

Alumina obtained by anodizing aluminium (AAO) in an acid solution is a self-organized structure with an order network of pores with the same size. The ordered in porous

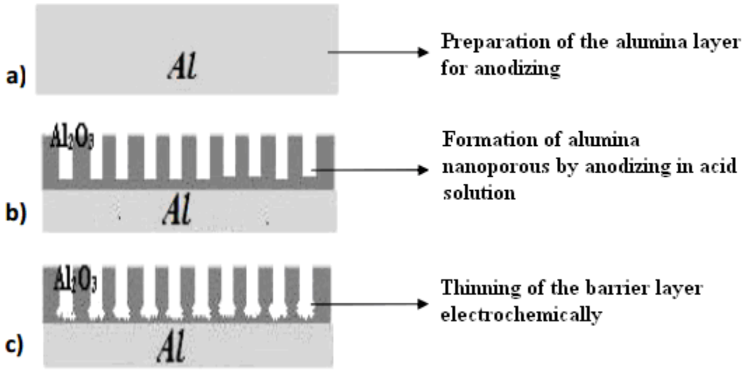

Fig. 8. The schematic process of alumina layer formation by a single anode [12]

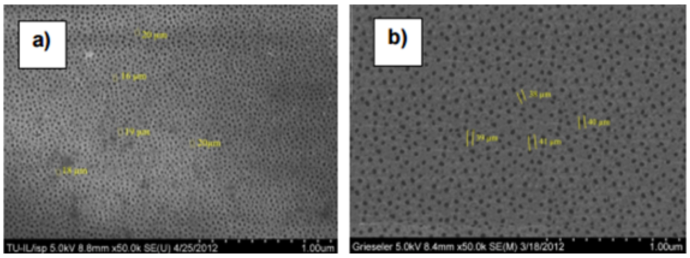

Fig. 9. SEM images of the alumina membrane obtained from: a) sulfuric acid b) oxalic acid [12]

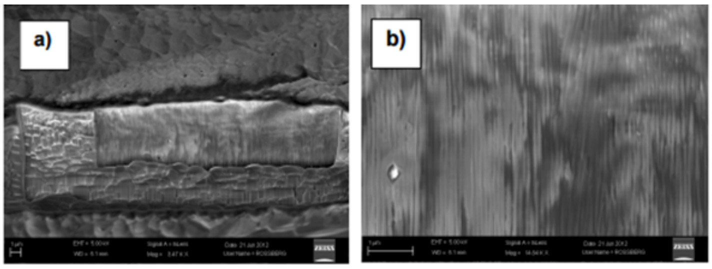

Fig. 10. FIB images of the alumina membrane obtained in oxalic acid in cross-section at different scales [12]

alumina originates in its unique structure, consisting of tight packing of cells, each cell containing a straight-pillar porch in its centre [8].

Commercial alumina membranes have a thickness of 60 μm, pores with a diameter of 20-200 nm, pore density 1011-109 pores / cm^2 [10].

Nanofibre networks of different materials have been manufactured using alumina membranes as templates [11].

The template method consists of filling metal alumina membranes by different electrodepositing methods.

There are several ways to fill nanopores, to get metal nanowires, and the electrodepositing method in the alumina membrane is a general and versatile method, which is successfully used to obtain nanowires with superior magnetic and optical properties.

Obtaining metal nanowires involves several steps, but two of them are essential: membrane creation and pores filling.

The schematic of the process for obtaining the alumina membrane is illustrated in figure 8. In this way the aluminium anodizing steps are easier to follow [5].

The anodization process was carried out experimentally using an Al substrate and two different electrolytes: oxalic acid and sulphuric acid.

Throughout the anodizing experiment the temperature is kept constant at 18°C [5].

In order to identify the diameter of the pores of the obtained membranes and the distance between them, a morphological characterization is made using [SEM and FIB] microscopy. SEM images can be recorded on the surface of the membrane as well as in cross section by means of FIB microscopy (fig. 9) [12].

The FIB micrographs pinpoint as accurately as possible the shape and distribution of the pores on the surface of the alumina membrane as well as in cross-section.

The nanoporous forms obtained in the two electrolytic media are hexagonal, fact confirmed also by FIB images in figure 10 [12].

The anodizing treatment is completed with hydrating the formed oxide layer to clog the pores. Once the poles are latched, a better corrosion resistance is achieved.

Conclusions

The ankle joint is a particularly important point in leg's anatomy by its role in performing the movements of the lower limb. Due to the biomechanical behaviour of this joint, any modification that occurs at her's or leg level may have major consequences on the stability and ability of the inferior limb and therefore for the entire body.

Through simulation, the characteristic dimensions of the ankle-foot system have been determined. The ankle prosthesis was designed to mimic the behaviour of a healthy ankle. The ankle prosthesis was designed to mimic the behavior of a healthy ankle.

Anodizing is a process of strict precision and high standards [13].

During anodizing treatment, by the action of aggressive solutions in electrochemical baths, the crystalline structure may be highlighted. The presence of the anodised layer on the surface of the aluminium parts prevents electricity from passing. The porosity of the anodized surfaces allows a very good adhesion in electrostatic painting or when two surfaces are glued.

Aluminium surface treatments can hide certain material defects. The irregularities of the sanded surfaces can recur after the degreasing and pickling of the parts (the surface micro-defects which are filled during grinding give an apparent uniform aspect of the surface, and when the surface is cleaned by degreasing and pickling, the dust is removed from these small recesses and micro-surface defect being highlighted) [12].

In anodizing process, to achieve the anode it is essential to have an electrical contact points on the surface of the aluminium piece. In these contact points the oxide layer does not form, and white traces appear.

Also, in the area of the welding cords, the parts suffer an important thermal treatment and the metal microstructure is affected. Thus, the material shows differences in appearance between the basic metal of the aluminium parts and the welded area. In this area, appearance is darker compared to the rest of the aluminium parts. Moreover, the welded area may have an uneven appearance [12].

The contact area of the parts will be chosen to preserve the aesthetic appearance of the prosthesis.

During the anodizing process, a thin layer of aluminium oxide is created and fully integrated on the outer surface of the profiles, giving them impressive characteristics such as:

*Appearance: u*nique look that highlights the metallic nature of aluminium

Color stability: long lasting colour preservation, because the anodized

surfaces have resistance at very high light and UV rays, and they are only slightly affected by weather conditions.

Durability: both during manufacture, handling, installation and use:

- corrosion resistance, ideal for use in difficult environments such as coastal areas, in the environment affected by large pollutants, etc.;

- abrasion resistance, because the anodized colour is integrated inside the aluminium and is not just a layer above it;

- scratch resistance, because the anodizing both with painting process creates a raw ceramic coating on the aluminium surface.

Easy Maintenance: due to all the above-mentioned durability attributes of the parts, the required maintenance is minimal.

Health and Safety: an anodized product is chemically stable, it does not decompose, it is non-toxic and completely recyclable.

Simply rinsing or light soap cleaning will give the surfaces of the prosthesis the original appearance, while more abrasive solutions can be used for more difficult deposits.

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