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Design and Development of Low Cost Prosthesis

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Abstract:	It does include the most sophisticated developments in expensive prosthesis, but manufacture under low cost conditions. INTRODUCTION Unfortunately, those countries, which need prosthesis, do not have economical support for acquiring them. Therefore, we propose a low cost prosthesis to overcome daily life. It also includes the recycling of plastics and manufacturing in situ, without depending on foreign technology. METODOLOGHY It was a practical procedure where tools used resemble those in the final user facilities. We will show during the presentation the stages of the research. The hardness of the final product and some other mechanical properties were studied as well.

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8th Manufacturing Engineering Society International Conference

Design and development of low-cost prosthesis

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Abstract

In this paper we propose a proven manufacturing procedure for a low cost prosthesis, the procedure developed takes into account the living in Refugee Camps. The research procedure involved to get info about the resources available and to design the best economical manufacturing strategy to achieve a practical hand prosthesis. The main aim is that anyone in those countries can develop, even repair, their own prosthesis. That will contribute with a quite interesting psychological benefit, too. This is also a sustainable product dealing with the recycling of leftovers.

Peer-review under responsibility of the scientific committee of the 8th Manufacturing Engineering Society International Conference

Keywords: hand prosthesis; low cost manufacturing; sustainability.

1. Introduction

Life in countries of the first world is facilitated because of technology and development, which allow not only communications and breaking global barriers but getting a good health system as well as it provides a comfortable life. It is not so complicated to improve the life quality with a prosthesis if needed.

In developing countries, they are not able to amortize the cost of a hand prosthesis that could be around 6000 $. It could be though that it may be manufacture by 3D additive manufacturing, but the final cost will be around 3500 $ or in the best case around 100 $ [2]. In addition to obtain this last kind of prosthesis, they would depend on developed countries.

This Project has the goal of obtaining the development of a low cost hand prosthesis based on accessible resources in developing countries and those in conflict, such as clay from the land, ash from wood, rustic oven, plastic bottles … All these things could originate a hand prosthesis.

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Fig.1: Final product

Fig.2: Reusing bottles in the refugee camp of Doro (South Sudan)

2. State of art

The existence of conflicts in some countries left/leave a great amount of injured people, having as an example Vietnam where civil war left a lot of amputated and antipersonnel mines that currently continue buried in different points of the country. We should keep in mind the extension of the problem to solve.
In 2009, the World Health Organization estimated that 650 million people worldwide have disabilities, the vast majority of whom live in low-income countries. The burden of disability is disproportionately borne in lower-income countries where the rate in the adult population is 18% compare to 12% in high-income countries.
While low-income countries account for 84 percent of the global population, they bear 90 percent of the total disease burden. [7]

Based on this, a research about the resources in the disadvantaged places is done, and a study of plastics and its presence is conducted searching sustainability and recycling. Among all the residues all over the world, plastics will be the worst heritage for future generations, because it takes even one million years to disappear. Then we decided to focus on a technical solution that will also face with a sustainable strategy.
Therefore, our proposal deals with a worldwide concern that may be even implemented in developing countries.

In low-income countries there are already some uses for the plastic (Fig.2), but they show off sporadically and not very often. So, we decided to find another re-use for them. Knowing that plastic bottles body is made of polyethyleneterephthalate and caps are composed of high-density polythene, plastic type 1 and type 2, we studied the viability of the project.[10]

We were researching to find a base for our design, discovering that there are another experiences around the world, as the Jaipur feet. It couldn't be denied that India people developed a process of designing low cost feet. Learning from this experience, we are proposing a new procedure with new materials and without electrical ovens. [8]

3. Design

Our design is based on the best prototypes in developed countries, with main functions that may be reached as catching things with pliers operation.
From a real hand we can distinguish different parts. Therefore, we decided to develop a first proposal made of four fingers and a palm, one of the fingers shorter than others in order to acquire the role of the thumb.
In order to obtain the prosthesis, we need to get a mould where caps can be introduced so that they can be heated and melted.
Once this get dry we will have a prototype.

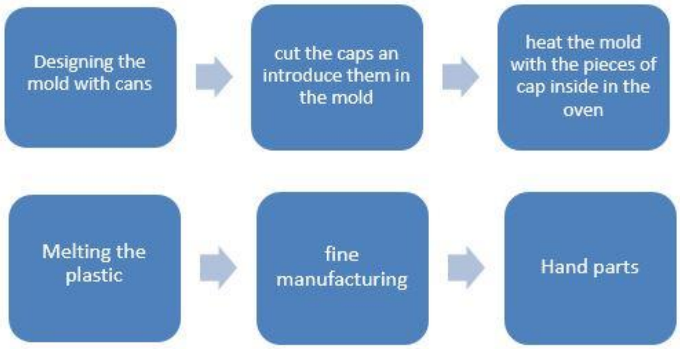

Fig.3: Process

3.1 Moldmaterials

Nomenclature

σbr = σzmax= Breaking strength [Mpa]
Mfmax= Mz= maximum bending moment [Nm]
F= force [N]
Izz= moment of inertia [kg/m4]
B= number of bottles [units]
D= diameter [mm]
M_p= mass of the palm [grams]
M_f= mass of the fingers [grams]
ΔM= loss of water mass [%]
ρ = density [g/cm^3]
Tª = Temperature [ºC]

3.1.1 Clay

This time, it was designed using three packages of 500 grams of dough for moulding, some water and a Tupperware with a cover for each part of the mould.
Once the dough was located inside the covers, the palm of the right hand sculpts the zone getting enough depth to resemble the reverse of the left symmetric hand (Fig.5).

The edges of the hole in the clay were not well defined, so it would be difficult to fit together both parts of the mould. Then, we repeat it using a cardboard with a hole some bigger than the hand because it shrinks (Fig.6).
The process was repeated trying to obtain the zone around the hole smoothed.

As we will use it, we prove how the moulding dough reacts under high temperatures. After being the mould into an oven for 5 minutes under 180ºC, it starts to become darker and some crevices appear.
Therefore, it was not good enough.
It would be recommended to test with the dough available in situ, before deciding to move to metal as the end solution.

3.2 Material for the prosthesis

At the time to use a suitable material for the project, bottles of plastic are handy staff for people worldwide.
The plastic caps of type 2 made of high-density polythene were provided by family, friends…, that means, quite easy to afford to it.

The aim of this fabric is reaching the temperature where it is malleable.
After the trials, type 2 plastic revealed to be the best material to use, because of the type 1 plastic low efficiency which constitute the body of the bottle, so the rest of the project was focused on it.
High-density polythene approximately mechanic properties are [11]:

$$E = [1.07; 1.09]\ GPa \ ; \quad \nu = [0.41\ ; 0.427] \ ; \ \sigma_{br}\, compression = [18.6\ ;\ 24.8]\ MPa$$

$$\sigma_{br} bending = [30.9\ ;\ 43.4]\ MPa \quad ; \quad \sigma_{br} traction = [22.1\ ;\ 31]\ MPa$$

But this should be tested because of the process the material suffering.

Fig.4: Clay mold Fig.5: Shape cut

4. Proposed manufacturing process

4.1 Melting the plastic

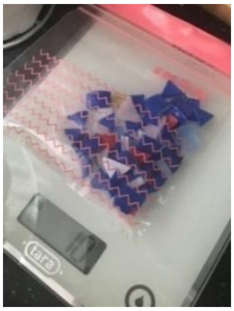

Figure 6: Small pieces for fingers 10 grams Figure 7: mould with plastic pieces into the electric oven. Figure 8: Part to press

A small oven was bought to be located in a ventilated area. As in the final country user they could use rustic ovens to execute this function, the temperature at which the electric oven was used was kept the same.

1. Cutting process/Preparing the material. The scraps cut with scissors in twelve little pieces each one, were introduced in a cupcake mould made of aluminium (Fig.9). First, the oven worked at 160ºC for 15 min, observing some vapour in the beginning, later we used a wood stick until plastic got the more compressed possible (Fig.10), so the air inside was removed and the scraps were moved to disappear.
It may be placed inside the oven for another 15 minutes under 180ºC. Then the plastic, once pressed will be more viscous. If it is not enough to acquire the appropriate quality, it may be needed 15 minutes more under 180ºC.

After, it hardens reacting chemically different to the other time, when trying to change the container it gets tough in the wood stick because of the fast cooling.

Fig.9: melted plastic

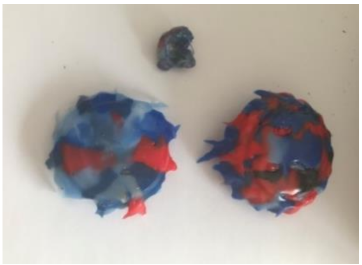

Fig.10: Back face of the check

Fig.11: palm composition of 13 grams

These were the results: The finish surface is smooth, bright and tough, as well as soft to the touch which makes it handy and comfortable (Fig.12).
This time the plastic is weighed in a kitchen scale before and after to check the loss of water.
$M_p = 13\ g$ (Fig.13); $M_f = 10\ g$ (Fig.8); $\Delta M = 1{,}6\%$ therefore negligible.

4.2 Metal mould

Tins are quite common so, we decided to base our design on them. The recycling of cans is very useful because of the aluminium properties. One of the most important characteristics is that their properties don't change although they are subjected to heat, so it can be introduced in the oven withouth any kind of concern.

$\rho = 2{,}6989\ g/cm^3$ → lightness; $\sigma_{br} traction = [230\ ;\ 570]\ MPa$ → good resistance quality; $T^{a} fusion = 660\ ºC$

Fig.12: Cutting the can

Fig.13: putting moulds in the oven

In this case, gloves, scissors and pliers, will be used to get the basis of the can and the central cylinder obtaining a 9 x 8,5 sheet.
It would be bend until obtaining a little box where the scraps are introduced.
The design of the mould was made bending flaps towards outside, directly using pliers.
Old examples made with plastic were introduced in the first design in order to prove if it could be remelted getting a good recycling result. So we can emphasize that in case the prothesis felt and got broken, it could be repair reusing the material.

4.3 Hand parts

As a 3D printer, the final palm will be done by layers, and it is not needed to be pressed.

When the plastic dries, it contract. This event allows to remove easily the parts from the mould.
There were more difficulties with the fingers because of the slenderness and the small folds where some of the fingers got hooked, compare with the palm.

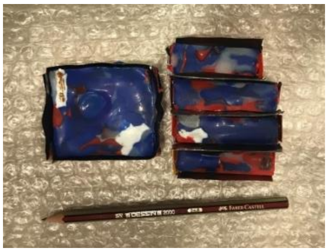

Fig.14: hand showing

Fig.15: Plastic fingers

The solution for the last incident is locating the flap in the external zone.

The fourth and smaller finger will be the thumb because it is the more important to permit the tweezers effect in order to catch things. [3]

5. Mechanical test

Once the first prototype of hand was done, it was the moment to test the material.
The FREMAP Hospital collaborate with this, there the bending test was done with typical and easy process.
This test was made with two metal brackets where locate the test tube and a double hook with two bags to be fill with bottles to apply effort.

We will consider an uncertainty of the 10% of the measurement.

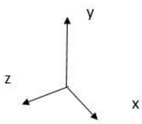

Fig.16: Axes

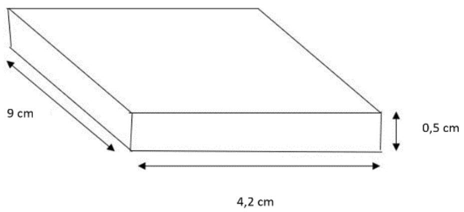

Fig.17: Test tube

Weigh of 17 grams, a surface of 88,8 $cm^2$and a volume of 18,9 cm^3.
The density is 899,5 kg/m^3.

For bending in HDPE, $\sigma br = [30{,}9; 43{,}4]\ MPa$ as we showed in the state of art.

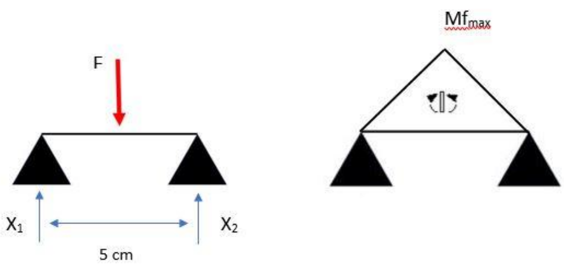

Fig.18: Checking

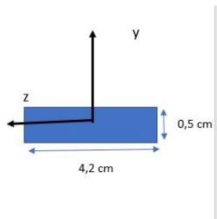

Fig.19: Checking perspective

$$Mfmax = \frac{F}{2} * 2{,}5 * 10 - 2 = 0{,}0125 * F \quad (1)$$

$$\sigma_{zmax} = \frac{M_z * y}{I_{zz}} = \frac{0{,}0125 * F * 0{,}0025}{\frac{1}{12} * 4{,}2 * 10^{-2} * (0{,}5 * 10^{-2})^3} = 71428{,}6 * F \quad (2)$$

$$30{,}9 * 10^6 = 71428{,}6 * F1 \qquad \mathbf{F_1 = 432{,}59\ N} \quad (3)$$

$$43{,}4 * 10^6 = 71428{,}6 * F2 \qquad \mathbf{F_2 = 606{,}19 N} \quad (4)$$

Knowing that F=m*a and concretely in this case F=m*g, being g=9,81m/s^2

M_1= 44,1 kg y**M_2= 61,79 kg**

B_1= 88,2 = **89 units**
B_2= 123,58 = **124 units**

This time the tube is limited in both sides in order to get that this does not move during the test. (Fig.17)

At the time that the load is being insert in the bags, it is represent by a steel reel to weld of 15 kg in each bag and 32 bottles, which means 16 kg, distributed between both until the test tube brakes.

Therefore it stands 46 kg before breaking, but it starts bending with around 20 kg.

$$\sigma br = \frac{M_z * y}{I_{zz}} = \frac{0{,}0125 * (46{,}61 * 9{,}81) * 0{,}0025}{\frac{1}{12} * 4{,}2 * 10^{-2} * (0{,}5 * 10^{-2})^3} = \mathbf{32{,}66\ MPa} \quad (5)$$

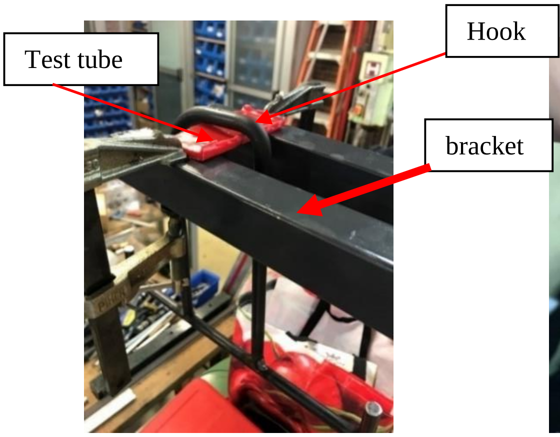

Fig.20: bending test

Fig.21: breaking

Fig.22: hardness centaur universal machine

Then a hardness test was done with a centaur universal machine and using a pyramidal end the Vicker test was studied. The process consist of the application of a force of 10 kp for 15 seconds and then it stayed for 30 second due to the plastic property.
In addition, three diagonal measurements were done with a projector in order to obtain an average:

D=2,2945 mm

$$Area = \frac{D^2}{2 * sin(136)} = \frac{D^2}{1{,}854} \quad (6)$$

$$HV = \frac{1{,}854*F}{D^2} = \frac{1{,}854*10}{2{,}2945^2} = 3{,}52kp/mm2 \quad (7)$$

6. Results

The result of the research is a hand prosthesis prototype of low weight and cost and the mechanical characterization of it. Therefore, they will be ready to be joint with some holes and clips, the dimensions are:

- Palm: 6 x 5,2 x 1,3 cm
- Fingers: 5,8 x 1,5 x 0,5 cm
- Thumb: 4,6 x 1,4 x 0,7 cm

This prosthesis stands around 20 kg before bounding and 40kg before breaking.
$\sigma br = 32{,}66\ MPa$; $HV = 3{,}52kp/mm2$

After the formation process, some tests were made to confirm the capacity of standing at least 40 kilograms keeping in mind that it starts to bend before, when the load is around 20 kilograms. Looking at the current prosthesis in developed countries the materials used are titanium with a Vickers hardness of 940 MPa and aluminium 167 MPa while HDPE Vickers hardness is 34,5 MPa. As you can see, HDPE is not as hard as other materials, however its quality beats the 3D printing material due to the less compactness in the last one.

7. Conclusion

In conclusion, the project, based on the developed study, showed that the development of the mould with clay could be accomplished provided that the plastic is introduced in the mould directly when it is inserted in the oven, as long as clay stands the temperatures without crevices happening.

That way, the main conclusion would be the recycling of soda cans giving them a second use, shaping and heating inside high-density Polythene (HDPE) until it reaches a malleable point. HDPE is usual and easy to find, furthermore it owns good properties as thermal or chemical resistance and low permeability which allows having a long-life cycle.

A worldwide technique that makes developing countries happier and healthier.

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9. Acknowledgement

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