3D printing as a tool for predicting the mechanical-functional behavior of components and mechanical systems.

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Abstract. Rapid prototyping is a technology that can automatically construct physical models from Computer Aided Design (CAD) data or is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data. This technic allows to minimize the possible human mistakes caused by a bad operator intervention, and represents a significant saving thanks to its accuracy, providing excellent visual aids for communicating ideas with co-workers or customers apart from design testing. The rapid prototyping area, where 3D models are converted into real models through different systems of manufacture, explores the possibilities offered by this technology for an engineer to design systems and devices before its final construction. As result it is observed an ostensible reduction in mechanical systems development times and its components; since functionality and usability of with rapid prototyping these corrections can be made. This document provides information about the use of Rapid Prototyping for specimens’ preparation and general configurations for construction of functional models.

1. Introduction.
With the purpose of enhancing the teaching of the mechanical design, and thus facilitate the construction of knowledge and lead students to development of professional competences, were investigated modern technologies that are applied in the industry and that can be deployed as a new pedagogic strategy for the subjects of mechanical design.

Today the industry allows you to produce rapid prototypes to scale, in plastic PLA, from a Design of 3D modeling in CAD system.

The development of specific skills in students [1] leads to find an equivalence and association of concepts between the way of teaching the mechanical design and the design process that is done in the industry. In the processes of mechanical design, the production of prototypes is a practice that is becoming more and more entrenched. Why is spreading this activity? There are several reasons: accessible costs, existence of varied offer of software design by 3D modeling parametric, which based their logic in design through the geometry of the shapes and their parameters that can be varied according to need.

The student will be able to tour the design process through to analyze a specimen to understand the physical phenomena which act on it, enabling the development of reasoning physical - mathematician, and the understanding of these phenomena, or generate their own designs, simulate mechanically, to then be produced as a possible solution to a problem of real life.

The technology of Rapid Prototyping, thanks to its integration with the CAD and the development of New materials, opens infinite possibilities as a teaching resource in the teaching-learning process of mechanical engineering.
2. Process Methodology
This work will be developed in the following instances:
1) Study on the techniques of Rapid Prototyping, stages of the process and applications.
2) Manufacture of specimens to be analyzed
3) Conduct of stress tests to determine the behavior of each one of the configurations made
4) Realization of sampling by scanning electron microscopy.
5) Assessment of the behavior of each one of the configurations studied.
6) Proposal of pedagogic implementation for industrial purposes of a design exercise using the rapid prototyping.

2.1. Study on the techniques of Rapid Prototyping, stages of the process and applications
The process of rapid prototyping is the continuation of the modeling CAD. The product designer can quickly get a physical model of the design of a piece in place of a digital model or a drawing.

The prototype virtual, which is a modeling in computer of the design of the piece in a CAD software, may or may not be suitable for viewing the part. Using one of the technologies of Rapid Prototyping available, can be create a physical piece solid in a relatively short time, being able to examine visually and physically the workpiece, and then perform a series of tests and experiments to evaluate their advantages and disadvantages [2].

There are different technologies identified generically as rapid prototyping. They can be classified into two basic categories:
1) Processes of removal of material and
2) Processes of adding of material. The latter can be divided in turn according to the form of the starting material in the process of Rapid Prototyping:
   a) Based on liquids,
   b) Based on solid, and
   c) Based on powders.

   The common approach in all current techniques of Rapid prototyping by adding material includes the following steps [3]:
   1. Geometric modeling. Consists in modeling the piece in a system of CAD to define the overall volume. The solid modeling is the preferred technique because it provides a mathematical representation complete and accurate picture of the shape of the piece. For the rapid prototyping, the most important thing is to distinguish the interior (earth) on the part of its exterior and the solid modeling provides this distinction.

   2. Tessellated of geometrical model. In this step, the model of CAD is converted to a format in which their surfaces are approximated by triangles or polygons. The triangles or polygons are used to define the surface, at least in an approximate way, and have their vertices arranged in such a way that you can distinguish between the interior of the object of its exterior. The format of Tessellated common that is used in the rapid prototyping is STL (Standard Triangle Language), which has become the de facto standard as input format for almost all the systems of rapid prototyping.

   3. Division of the model on layer. In this step, the model in the form of STL file is divided into horizontal layers parallel with a separation very close. These layers are used by the system of Rapid Prototyping to build the physical model. By convention, the layers are formed in the orientation of the x-y level, and the procedure of creating layers occurs in the direction of the z axis as can be seen in Figure 1.
In this work, we will address the modeling by Fused Deposition Modeling (FDM).

It is a process of Rapid Prototyping in which a filament of polymer is stretched over the surface of the existing part from a head of work to complete each new layer. The work head is controlled in the x-y level during each layer and then moves up a distance equal to one layer in the z direction. The starting material is a filament robust fed from a spool to the work head that heats the material to a temperature 0.5°C above their melting point before stretching on the workpiece surface (Figure 2). The material stretched solidifies and welded to the surface of the part that this colder in about one-tenth of a second. The form of work is similar to a plotter 3D (Figure 3). If you need support, uses a media separable easily from the material of modeling parent.
In the case of study, both the starting material as the support will be a thermoplastic polymer called acid polyacrylic (PLA), which is obtained from maize starch (U.S.) or cassava (mostly in Asia), or sugar cane (rest of the world), taking properties similar to those of polyethylene terephthalate (PET) and is used for the manufacture of packaging, but that in addition is biodegradable, deteriorate easily in water and carbon monoxide.

2.2 Manufacture of specimens to be analyzed
For the study of characterization, have been printed 15 specimens in a printer Markertbot of modeling by FDM, divided into three groups (low, medium and high) as print resolution. In Figure 4 you can see the weight in grams of each one of them; where each layer has a layer height of 0.3 / 0.2 / 0.1 mm, respectively; where a lower height will be better print quality.

![Figure 4. Test specimens for the characterization](image)

The print resolution is directly proportional to the print time; at a higher resolution, the longer the time that lasts the printing; this must also be taken into account at the time to generate the print models and the function to fulfill. For the case study, each test piece lasted printed between 30 and 45 minutes.

2.3 Conduct of stress tests to determine the behavior of each one of the configurations made
15 printed specimens were subjected to a stress test to take them to their breaking point; starting with the of lower resolution (Figure 5), which reaches a point of break with 0.044 KN/mm²; to the of higher resolution (Figure 6), which reaches its point of break with 0.047 KN/mm².
Later, to every specimen a study was done to him in the electronic microscope of sweep SEM. The electronic microscopy of sweep or SEM is based on the beginning of the optical microscopy in which the light bundle is replaced with an electrons bundle [4]. In the above-mentioned study, it was possible to characterize of microscopic form the morphology of each of them, to understand how to major impression resolution, major layers quantity is observed, what it does to the most resistant specimen in the tension essay.

### 2.4 Realization of sampling by Scanning electron microscopy

In the figure 8 one can observe the disposition of the layers of the test tubes of half resolution. In the figure 7 one can observe the disposition of the layers of the test tubes of half resolution.
Figure 7. Characterization of the specimens of low density in the SEM scanning electronic microscope

Figure 8. Characterization of the specimens of half density in the SEM scanning electronic microscope
In the figure 9 one can observe the disposition of the layers of the test tubes of high resolution.

![Figure 9. Characterization of the specimens of high density in the SEM scanning electronic microscope](image)

In photographs taken by the microscope SEM of printing at low resolution you can appreciate the deposition of 6 layers; in the medium-resolution there are also 9 layers; while in the high resolution presented 12 layers. Which is the reason for which makes it more resistant the measuring cylinder to increase the print resolution.

2.5 **Assessment of the behavior of each one of the configurations studied**

Making a comparison between the different types of print resolution, with regard to the effort applied that resist before fail and the characterization carried out in the test specimens in the microscope SEM; it can be inferred that can be modeled and print prototypes, preliminary or final; functional or formal; that could be useful in the study of a piece and / or product, applying the concepts of mechanical design, with the possibility to study it and submit it to different tests according to interest concerned. This means that when it is necessary to perform a conceptualization morphology of the piece, that practice would be to make a print at low resolution (Figure 10); when you perform a study of functional type in terms of movement and assembly, ideally make a print with a medium resolution (Figure 11); finally, if the need is to determine the behavior of a piece and / or assembly with some mechanical loads, and interaction repetitive, it is therefore more appropriate to perform printing in high resolution (Figure 12).
Figure 10. Hydraulic jack printed at low resolution to appreciate the relationship between parts and present it as a formal model

Figure 11. Manual mixer of food that will be subjected to interaction with the user and other materials, printed with medium resolution

Figure 12. Hook crane that will be subjected to small mechanical loads, as demonstration to the students of design applied 2, printed in high resolution

It is important to emphasize that the printing speed and the consumption of material is directly proportional to the print resolution; therefore, for a same model printed in a low resolution, the quantity of material consumed could be 70%, and the time spent would be a 60% if compared with the same model printed in high resolution.

2.6 Proposal of pedagogic implementation for industrial purposes of a design exercise using the rapid prototyping

The new paradigms educational, as the focus of the student-centered learning and training based on competencies, which at present is an international trend in the design of plans of engineering study [1], requires of the teacher the implementation of new pedagogic strategies and resources directed to the achievement of significant learning in students, forming the future engineers that society demands today.
In regard to the Mechanical Engineering, the introduction of CAD systems, from some 25 years ago, meant a radical transformation of the "way of thinking and doing" in all areas relating to mechanical design and graphic communication. The graphics technology of CAD systems not only impacted on the design of curricula but that imposed a new geometry digital. The possibility of 3D solid modeling on the basis of the 3D geometry of the objects and, from that modeling, obtaining the views automatic in the plane or projections, reversed the traditional sequence of the design process, from 3D to 2D, which meant a major paradigm shift in the area of graphic representation [5]; it made possible a direct interaction, fast and economic of the students with the mechanical elements designed (Figures 10, 11 and 12).

The production of prototypes in the process of mechanical design is a practice that tends to become widespread in the industry. Technological tools such as CAD-CAM (design and manufacturing assisted by computer), or the CNC (computerized numerical control) produce models or prototypes directly from the interface design in a computing environment CAD 3D; therefore, the display multi-sensory (visual-Touch) constitutes a source of information and understanding of the reality that provides great help in the process of mechanical design and representation and graphic interpretation. In the development of pieces or complex objects can be much more information the model put it in the hand that watching simply on the monitor of a computer. The student will be able to analyze the geometry of its form, check its physical behavior and mechanical, experience movements and possibilities of assemblies. It is here where research and teaching must be found, since it is necessary to investigate to teach and to teach investigating.

3. Conclusions

The incorporation of technology of Rapid Prototyping, comes from the productive process in the industry, in the teaching-learning process in the area of mechanical design, enables the transfer of experiences of the industrial activity in the classroom, and therefore constitutes an educational innovation that is also in line with the current concept of training based on competencies.

As well as the solid modeling 3D facilitates the design of complex shapes and their graphical representation, Rapid Prototyping enables easy implementation of a formal model or a functional model, and power ability deductive and spatial reasoning of the student. The cost of production of models by Rapid Prototyping is no longer a limiting factor for its use extended in fields such as education, because today this technology is much more accessible than in its beginnings, some 20 years ago.

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