DESIGN OF A CLAY EXTRUSION SYSTEM FOR LOW COST 3D PRINTING

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ABSTRACT

The rapid prototyping by manufacturing of molten deposition (FDM) in 3D printer, has evolved rapidly in terms of printed materials such as polymers, metals and composites. Through this project, we have designed a clay extrusion system (ceramic) that allows us to print objects in three dimensions quickly, either as a prototype, artistic products, among others. A literature search was made about types of clay extruders and their main components, the clay extrusion system was designed according to the printing variables (clay plasticity, exit velocity, mass flow and others), according to the design was followed by calculations and selection of materials for the extruder equipment. For the process of dragging the clay to the outlet nozzle, a screw or worm was selected in stainless steel, which was carried out stress analysis using the finite element software ANSYS® WORKBENCH. The output of the clay extruder is coupled through a hose to the extruder of the 3D printer, where the output speed of the material is regulated according to the type of product, drying, room temperature, relative humidity among others.

Keywords: 3D printing, Clay extrusion, rapid prototyping, extrusion system.

1. INTRODUCTION

Learning and applying 3D printing studies the development of bodies and forms difficult to perform conventionally. In mechanical engineering, it is of vital importance to use modern design methodologies and finite element analysis, for the well development of machine elements generating better, more competitive, safer and more efficient mechanical systems. For this reason, 3D printing has a lot of applications to modern engineering, so it has allowed to develop this system, using different methods varying the materials used and geometries, such as clay, concrete, among others.

3D printing can be used in a wide range of tasks, such as designing and testing prototypes, also finished products in a shorter time. In mechanical engineering, prototype designs are continuously generated in academic class activities and final course projects by students and teachers. However, students show limitations in understanding the abstract concepts represented by such designs [1].

Previously it was not easy to obtain pieces with strange geometries, which involved a difficult batch production. 3D printing helps any user by means of coordinates, codes or a CAD model to produce the desired part in some material. There is a great variety of 3D, classified according to the printing capacity, type of material and products to be printed. There are many brands, models and sizes. However, for the printing of ceramic material or clay there is still few information.

Clay is the chemical wear product of "feldspar" one of the most common minerals in the earth’s crust. Clay tends to be malleable when wet, hard and brittle when dry. There are many kinds of clay, each with slightly varied characteristics. Some combine with mineral oxides and can acquire a rainbow of colors. For the construction its most interesting characteristic is the adhesion. It is the glue of the mixture [2].

In construction, clay has been very well-used as a primary adhesive or structural material for more than 10,000 years, together with other readily accessible materials. It was compressed to form finally very resistant bricks with which all types of buildings were made. Currently, the use of clay in construction is emphasized in the elaboration of artistic structures for finishes.

Medicinally you will also find a great variety of clay use as it is mixed with other natural components such as red, white, black, pink and green clay contain components that help to alleviate or combat some medicinal problems.

Artistically, the clay by its adhesion and viscosity allows to form all kinds of artistic figures such as vases, vessels, sculptures and pieces or accessories of high relief for architectural use.

One of the objectives of the project is to guarantee a wide working space, allowing the operator to have a wider range of work than other printers allow. An important factor was the nozzle change, which allowed printing with different shape and relief, reducing the number of extruders, to optimize the design since the first design that was obtained had three phases of extruder.

In this paper, we show the experimental results of thermal conductivity at an average temperature of 350C, in extruded red clay blocks, made in Cucuta and its metropolitan area. We also evaluated the influence on said thermo-parameter physical variables such as mass, density, porosity and the fraction of air present in the blocks [3].

2. METHODOLOGY

In the design process, a conceptual design methodology was used [4], in order to manage integrated methods for a more competitive mechanical system. The identification and analysis of the need for the problem is essential before the design of the device is started, as there is often insufficient data to determine the importance and define the problem.

Once the system was defined to design in somewhat abstract terms, reviewing applied standards, limitations such as expected results, costs, available technologies and other considerations, a study of the state of the art and technique was carried out, mainly looking for patents close to the idea of the proposed design, in order to generate ideas to solve the problem. Using the 635 method, which is based on 6 people generate 3 ideas of the device to be designed in 5 minutes, the ideas are passed to the person on the side repeating the exercise, in the end 108 ideas were obtained. The design group generated several solution alternatives which were evaluated using selection criteria corresponding to the design criteria proposed by the group, such as ergonomics, safety, easy manufacturing and construction, novel, cost, among others.

2.1 Preliminary Design

Based on the selected alternative of the system design, we proceeded to evaluate the functionality together with the safety analysis, evaluating the efforts under the theory of von Mises, of the elements that integrate the extrusion system.

2.1.1 Design of the extruder system

Following the design parameters established by the authors, the general system was divided into three basic subsystems: mechanical subsystem, electronic subsystem and computer subsystem.

3. RESULTS

The extrusion system for the injection of the material was chosen because of its efficiency, good output pressure and constant flow.

3.1 Extrusion System

In the extrusion system, the mechanical and technological properties of the clay are previously analyzed, successively other design variables that are pressure, flow and output speed of the material. With the design and calculations carried out, the materials of the extruder system and all its components are selected. This was designed from the housings, where a PVC tube of 6 inches (152.4 mm) was chosen for 31.49 inches (800 mm) long, this hound is attached to the square hopper, 70 mm from the centre of the hopper a hole of 20 mm was made to insert in it a 12V solenoid valve of ¾ In (19.05 mm) to carry out a general wash by maintenance. At the rear end was installed a 6 in PVC lid which has a 1 in hole (38.1 mm) in which will be the spindle shaft or screw without end, at the front end is the nozzle of the extruder which was printed in PLA, this was fastened to the extruder's shirt by means of round head M4 rivets.

3.1.1 Spindle or screw endless system (subsystem)

The spindle is designed in stainless steel, it is 1010 mm long, has a diameter of 1 ½ in (38.1 mm), Winch angle of 13°, a blade passes of 73 mm, channel depth of 52 mm, clearance or tolerance between liner and 1 mm blade, at the front end this ends in spiral match of 75°, this to generate higher output pressure and at the rear end has a length of 40 mm by 25 diameter. Also, at the top of it, there is a hole for a wedge (ISO 2491 AA 5x3x20.) This is to contain and generate the spindle motor by means of a pulley for a belt drive with a motor rotating at 1750 rpm with a 40:1 reducer of 43.75 rpm with a power of ¾ hp, see Figure-1.

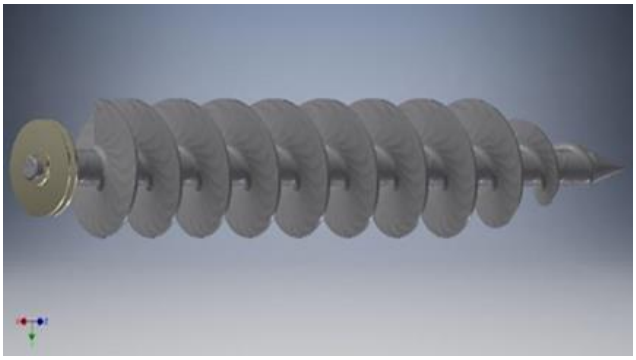

Figure-1. Isometric image of spindle with pulley and wedge. Source: Authors

3.1.2 Structure of the extruder

For the structure of the extruder, it was used a rectangular steel profile 20-40 of 1200 mm length by 320 mm height to each profile welded 2 sheets of 10-gauge steel with MIG or GMAW welding. Sheet 1 is 732 mm long by 360 mm wide and sheet 2 is 428 mm long by 360 mm wide. For the mobility of this structure, 6 double castors with 100 kg brakes were installed at the bottom, secured with zinc-plated Bristol M4 type screws (DIN 439-2), fastened with M4 nuts (DIN 439-2) and a 1 in bent tube was welded to the structure (25,4 mm. For the mobility of this structure, 6 double castors with 100 kg brakes were installed at the bottom, secured with zinc-plated Bristol M4 type screws (DIN 439-2), fastened with M4 nuts (DIN 439-2) and a 1 in bent tube was welded to the structure (25,4 mm).

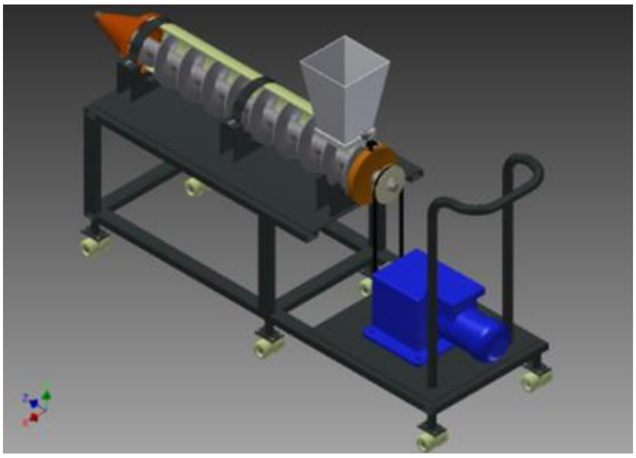

Figure-2. Isometric image of the extruder with structure and engine. Source: Authors

3.1.3 Nozzle system (subsystem)

For the extruder nozzle was designed from a PVC cap of 4 in (101.6 mm), was printed on PLA the sleeve or shell of the nozzle, it was adjusted by means of round head M4 rivets, on the lid were opened 2 holes, 1 for the spindle axis to which it is connected by an axle transmitter to the servomotor (Nema 13), which is attached to a 10-gauge metal structure by means of 4 zinc-plated Bristol M2 type screws (DIN 439-2), fastened with M2 nuts (DIN 439-2). The other hole is used for a PVC terminal that is internally adjusted to be able to connect from the printer to the nozzle by means of a 35 mm hose that is connected to a 35 mm to 15 mm coupling, see Figure 3.

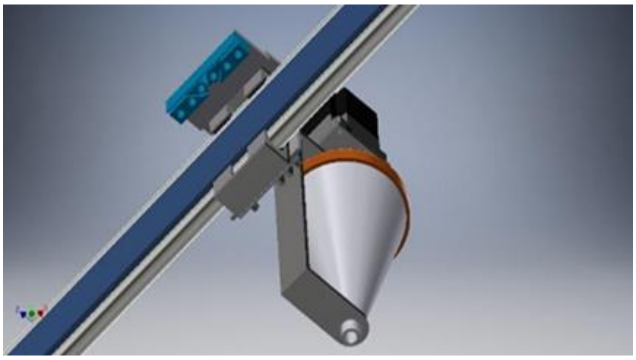

Figure-3. Isometric image of the extruder nozzle with structure and servomotor. Source: Authors

3.2 Simulation by Finite Elements

From the spindle of the CAD model the spindle was saved in a format (.stp) to be imported into the software of the FEA, the WORKBENCH was used.

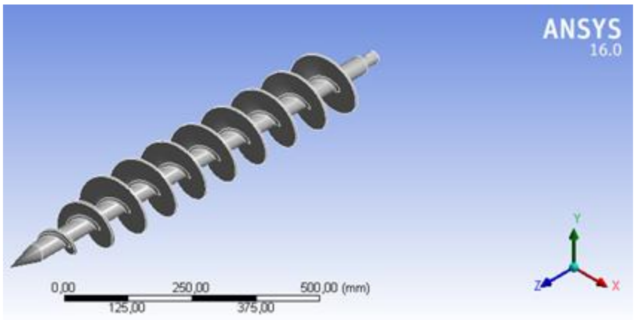

Figure-4. Spindle imported into finite element software. Source: Authors

A search was carried out for the mechanical properties of the material, Stainless Steel 304, as it is very commercial, with a tensile strength of 580 Mpa with an elastic limit of 290 Mpa and modulus of Elasticity E= 200 Gpa with a ratio of Poisson ν=0.3. These data are important to feed the material model into the finite element software, in which it was taken as linear and isotropic.

The element type uses SOLID 186 for the three-dimensional modelling of solid structures. The element has plasticity, hyper elasticity, tension stiffness, creep, high deformation and great deformation capacities.

For the simulation a pressure load equivalent to 2.5 Mpa distributed on each side of the screw was proposed, this pressure to deform the clay depends on the amount of moisture that the clay has, according to experimental data (Navarro), for 26.5 % of water, the pressure is 1 kg/cm 2 equivalent to 0.1 Mpa and for 23% water, the pressure is 25 kg/cm^2 equivalent to 2.5Mpa.

Considering that the selected red clay has a water percentage of approximately 20%, it was chosen to do the stress analysis with the highest pressure (2.5Mpa), being more conservative, see Figure-5.

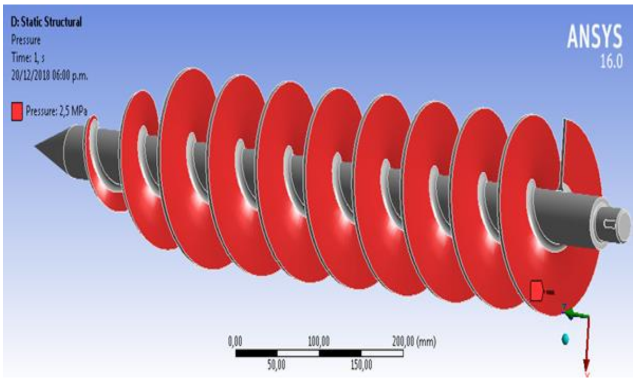

Figure-5. Pressure distributed on the spindle. Source: Authors.

The maximum von Mises effort found in the simulation is 40 Mpa, see Figure 6, and a maximum displacement of 0.017 mm.

The displacement value is very satisfactory as the spindle structure must be sufficiently rigid to avoid displacement, and not interrupt operation or unbalance the system.

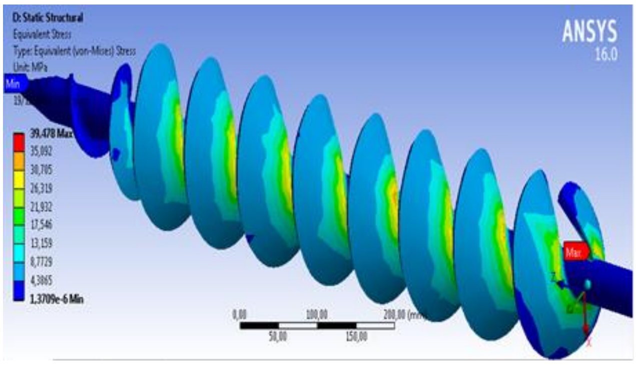

Figure-6. Von Mises' efforts in the spindle, detail. Source: Authors

Making an approach in the area of concentration of the greatest effort, it was noticed that it is applied in the root, inside part of the spindle, see Figure-7.

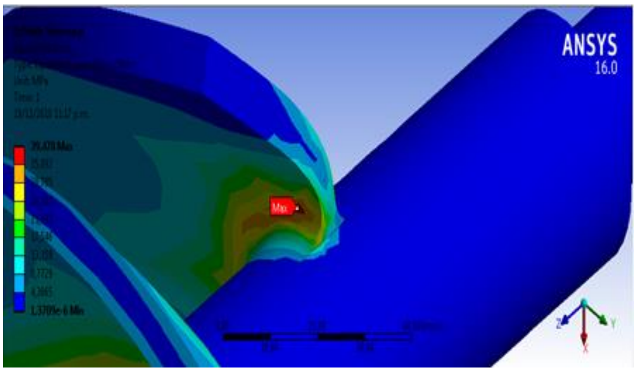

Figure-7. Von Mises' efforts in the spindle, detail. Source: Authors.

3.3 Analysis of Spindle Fatigue

The properties of the material Stainless Steel 304, are resistant to creep $S_y = 290\ Mpa$ and a last resistance of $S_{ut} = 580\ Mpa$. As there is no information about the fatigue or fatigue resistance limit of Stainless Steel 304, it is estimated as:

$$S_e^{'} = 0.5\ S_{ut} \qquad (1)$$

Adjusting the limit of fatigue resistance by means of correction factors.

The spindle is considered to be under combined stress, load correction factors [5]: k_c=(1 Flexión@0.85 Axial@0.59 Torsión)

Taking the most critical value is torsion. For the size factor k_b, the spindle is larger than the fatigue test sample and is not round, so an equivalent diameter should be calculated based on 95% area (A_95) subjected to stress.

In order to obtain a conservative design, a k_e reliability factor is used for the 99.9% desired. The corrected fatigue resistance limit is calculated,

$$S_e = k_c \times k_b \times k_a \times k_e \times S_e^{'} \qquad (2)$$

For alternating effort and average effort, you have:

$$\sigma_a = \sigma_m = \frac{(\sigma_{max} - \sigma_{min})}{2} \qquad (3)$$

Using the modified Goodman Fault Criterion,

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{n} \qquad (4)$$

Resulting in a fatigue safety factor of $n = 3.6$. If Soderberg's fatigue failure criterion is used:

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_y} = \frac{1}{n} \qquad (5)$$

A safety factor of $n = 3.3$ is obtained. Since Soderberg's failure criterion is more conservative than Goodman's, see Figure-8, the Soderberg line ranges from the corrected fatigue resistance to the creep resistance and the Goodman straight line starts equal in the corrected fatigue resistance and ends in the last resistance, having more margin of error compared to the other criterion. However, both criteria are the most conservative of the theories of failure shown, indicating that the safety factor is good for having taken into account the most critical conditions and a reliability of 99.9%.

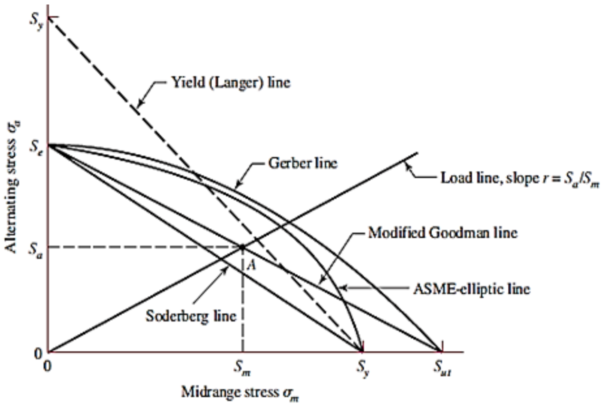

Figure-8. Fatigue failure criteria. Source: [5].

CONCLUSIONS

Based on the characterization of clay, it was designed an extruder that generates the mixture of clay and water at a constant pressure and sends it to the extruder nozzle of the 3D printer. The extrusion system designed and the selected materials are low cost and affordable in the local market.

A conceptual design methodology was used, demonstrating a great contribution in the generation of ideas to obtain better designs.

The spindle is well dimensioned and with a good material as it was made analysis by finite elements of the main element (spindle), in order to guarantee the safety of the mechanical system.

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