Global Scientific JOURNALS

GSJ: Volume 8, Issue 8, August 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

PROTOTYPING SHAPES USING MATERIAL DEPOSITION AT ROOM TEMPERATURE

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KeyWords
CAD/CAM processes, Material blend, CNC toolpath generation, Extruder device, Extrusion at room temperature, Layered manufacturing, Rapid prototyping,

ABSTRACT
This paper presents a prototyping system based on the deposition of material at room temperature. First, it describes the extruder device and its operation coupled to a CNC machine. After, is described the system parameters that are: extrusion speed and the displacement table speed. At least, it describes the functional parameters that are: the uniformity of the filaments, their spacing and cohesion. The practical results obtained suggest that the built system is viable for building rapid prototypes and products. The novelty in this article is the fact that we use an inexpensive material that can be produced and applied at room temperature to without additional care.

INTRODUCTION

In Rapid Prototyping Processes, materials are transformed from one physical state to another to define an object with a desired shape called prototype, or nowadays, a quick product as it is described in references [1-3]. These state changes, for example, from solid to liquid or liquid to solid may be accomplished by different techniques. For example, by melting it with laser rays or heat generated by electrical resistance and still accomplish the solidification of liquid. Finally, with the material in a workable condition, the prototypes are produced combining multi-layers in x, y and z directions.

The prototyping processes are complex and expensive because many variables are needed to be controlled, such as those that affect the transformation of the built material from one state to another, as it can be seen in references [4,5]. This paper describes the use of a material that changes its physical state at room temperature and then is used to manufacture basic geometric shapes. The use of this material was initially proposed by the first author and his collaborators as indicated by the authors in references [6,7]. To extrude this material, the following parameters were studied: extrusion speed of the filaments and its spreading on a flat surface.

OVERVIEW AND RELATED WORKS

To change a material from one state to another is necessary to control various parameters in the prototyping process. For example, in the process of Stereolithography it is necessary to control the focus adjustment, the scanning diameter and the depth of resin solidification. A comprehensive reading of this subject can be seen in references [8–12]. In the process of laser sinter it is necessary to control the focus of the laser and the time of incidence of the rays on the portion of the material to occur at polymerization [13]. Additionally, it is necessary to treat toxic gases generated by burning the material as shown at the approaches described in references [14–17].

In addition, there are other processes that can be grouped under the name of Fused Modeling Layer. They are: Fused Deposition Modeling, Multiphase Jet Solidification and Extruder Machine. All these processes have a characteristic in common: the fact that they use electrical resistance for melting the material. In these processes it is necessary to control the temperature for the exact melting point of the material. For more details see the published works by [18]; [19] and [20]. In these techniques objects are constructed additively, layer by layer. In Figure 1 is shown a summary of these techniques, thermal processes and used materials.

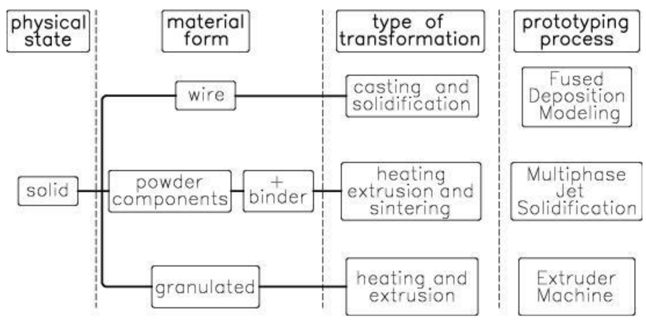

Figure 1. Raw material conditions for some Fused Layer Modeling processes.
Source: The authors

In the Fused Layer Modeling process (FLM) it is not necessary the treatment of toxic gases. Also, this technique does not use lasers to melt the material. That's why this technique has a low cost of acquisition and maintenance. Also, the FLM technique is well diffused because it can simplify the prototyping process from the point of view of the variables that need to be controlled as indicated by references. In this context is proposed, in this work, a prototyping technique which uses a material that does not require resistance to melting, which reduces the number of variables to be controlled. Considering, as the context, the set of techniques mentioned and organized in the flowchart shown in Figure 1, the Deposition at Room Temperature technique can be included in it according to the modified flowchart shown in Figure 2.

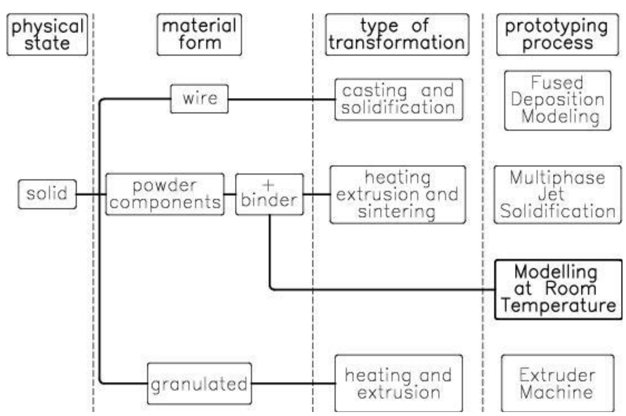

Figure 2. Raw material conditions for some RP processes with branch proposals.
Source: The authors

MATERIAL EXTRUDED AT ROOM TEMPERATURE

In this study we used a carbohydrate-based composite which can be produced, used and cured at room temperature. This composite is a homogeneous paste which does not require heating to be extruded. In this compound there are elements which, besides facilitating the flow, decrease the friction resistance on the inner walls of the cylinder and give greater flexibility and malleability during the extrusion process. The components and amounts that make up this composite are:

- **Carbohydrate:** 80 mL, powder used to structural binder;
- **Glue:** 50mL, liquid used to fix paper;
- **Vinegar**: 2.5 mL, liquid with antioxidant function;
- **Benzoate:** 5.0 mL, conservative liquid;
- **Stearin:** 2.5 mL, liquid for demolding and maintain the composite malleability;
- **Cream hands:** 2.5 mL, liquid paste for use in the hands;
- **Glycerin:** 2.5 mL, liquid with solvent and softener function.

In preparing the paste, hand cream is the last component added into the mix. The other components may be added in any order. The mixing of these materials and amounts result in approximately 145 mL. Once prepared, the formed past has a uniform consistency and its extruded filaments exhibit good adhesion between them. Figure 3 showed the uniformity of the extruded filaments. The layer thickness is the same as the extruder nozzle and its cure time was 24 hours in a 25oC room temperature.

Figure 3. Uniformity of the extruded composite filaments.
Source: The authors

The authors [22] have used starch-based materials to produce three-dimensional (3D) porous scaffolds, but our carbohydrate-based composite produced a non porous filament and this is an advantage in producing more resistant forms. For an overview of the composite materials applied in rapid prototyping processes see, for example, the reference [20].

EXTRUDER DEVICE

To perform the material extrusion as filaments it was designed as an extruder device. This device consists of a DC motor, a gearbox, and the material storage cylinder. A DC motor has been chosen to drive the screw, because the gearbox has a very great reduction of the engine and requires a high speed input, between 1744 rpm (6 volts) and 8574 rpm (24 volts). These conditions provide the proper torque to move the mass inside the cylinder. The use of DC motors in this type of device has been applied by Lira and his collaborators according to [6] and [7] since 2007. Inside the cylinder there is a piston whose body is a trapezoidal screw.

A complete view of this extruder device and CNC table machine is shown in Figure 4.

Figure 4. Complete view of extruder device and CNC machine plate.
Source: The authors

The motor transmits motion to the gearbox at low rpm and the screw compresses the material against the nozzle, through which the filaments are extruded. The realistic external view and section view of cylinder, trapezoidal screw and nozzle are shown in Figure 5. The deposited material is spread in X and Y directions according to a tool path, such that this process builds the prototype with efficiency and geometrical accuracy, similarly to what is described in the works of [23] and [24].

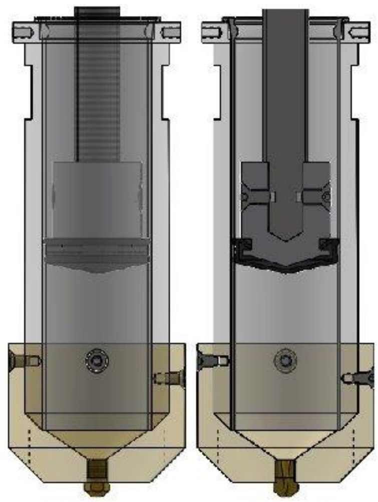

Figure 5. External view and section view of the cylinder, trapezoidal screw and nozzle.
Source: The authors

In Figure 6 it is shown the real complete device. Its maximum dimensions are (300x80x60) mm. It can store 155.30 mL of material and extrude it in about 5 hours.

Figure 6. Constructed complete extruder device.
Source: The authors

EXTRUSION PARAMETERS

In this system the extrusion process occurs according to the number of rotations of the DC motor. The rotations pass by the gearbox and are transmitted to the trapezoidal screw. By the time, it determines the piston displacement speed. At last, the speed of the piston determines the speed of the extrusion material.

For maximum voltage of 18V, the maximum practical extrusion speed obtained was 1382.22 mm/min. For the minimum voltage of 6V, the minimum practical extrusion speed obtained was 350.45 mm/min. These speeds are determined for each voltage value 6V, 8V, 10V, 12V, 14V, 16V and 18V, considering the extruded volume for 2 minutes.

This volume is then placed in a test tube with a known volume of liquid. The extruded volume is obtained by reading the displaced liquid volume. To minimize variability in reading, the tests were repeated 10 times for each voltage, resulting in better accuracy. This experimental procedure is illustrated in Figure 7.

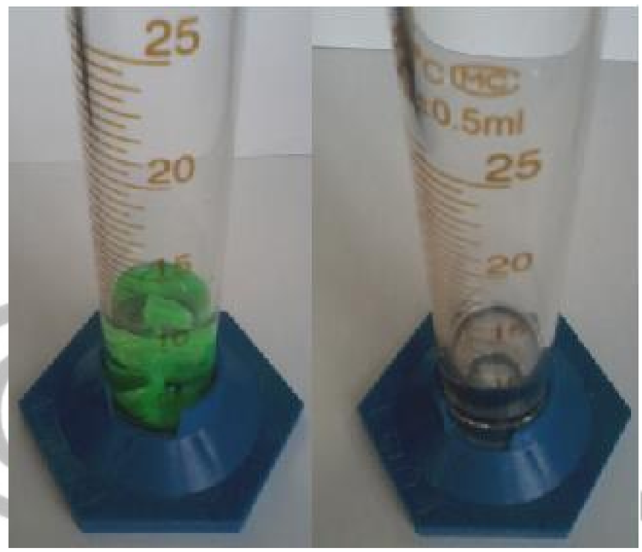

Figure 7. Determination of the volume extruded based on the displaced volume.
Source: The authors

For maximum voltage of 18V, the maximum theoretical extrusion speed obtained was 1382.22 mm/min. For minimum voltage of 6V, the minimum practical extrusion speed obtained was 350.45 mm/min. These speeds are determined for each voltage value 6V, 8V, 10V, 12V, 14V, 16V and 18V. The theoretical velocity of extruded material, considering that it is an incompressible fluid, is given by the

$$Ve = \frac{2}{\pi}\left(\frac{C_d}{N_d}\right)^2 \frac{R_i}{l} P \qquad (1)$$

where, Cd is the Cylinder diameter, Nd is the Nozzle diameter, Ri is the input rotation in the gearbox, the transmission ratio and P is the thread Pitch of the trapezoidal screw. For the subject Fluid Mechanics it is indicated the reference [25]. The complete summary of the practical and theoretical results are shown in Figure 8. This graph shows that the experimental and practical extrusion speeds are very close. On average, the experimental is 8.42% lower.

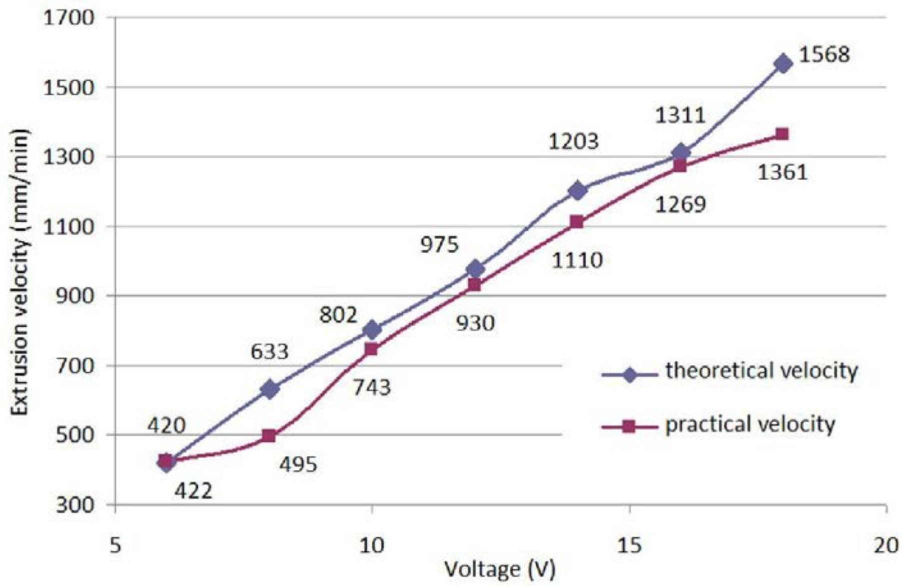

Figure 8. Theoretical and practical velocities of filament extrusion.
Source: The authors

CONSTRUCTED SHAPES

In the final adjustment of the extruder device we construct a set of circular and rectangular shapes. The evolution process of the device to produce circular shapes can be seen in Figure 9. These circular shapes have a good level of finish and the size shown in this Figure reflects the real size of the shapes.

Figure 9. Rectangular and others types of shapes.
Source: The authors

The obtained rectangular shapes reflect also a good finish level according to the union of the filaments. In Figure 10 is shown a series of circular shapes in a rectangular base constructed with the device.

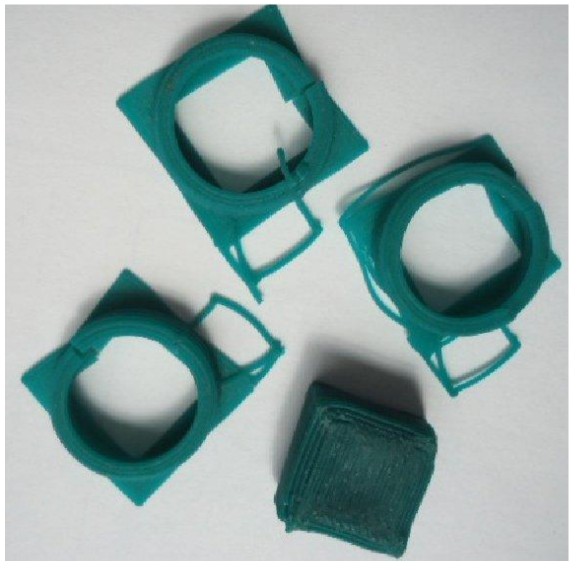

Figure 10. Rectangular and others types of shapes.
Source: The authors

Conclusion

The prototyped parts using material at room temperature in the extruder device system had adequate quality both in geometric terms and in physical consistency [26]. During the process of building the forms it has been observed that the extruded filaments had visually good constancy of thickness and adhesion between layers.

To achieve the adjustment level in the extruder system that allowed the construction of the parts shown, it was made a theoretical study and practical experiments to determine the optimal speeds for both, extrusion of the filaments and spreading layers. Based on these results, it can be assumed that the practical extrusion speeds and theoretical extrusion are approximately the same. The main results achieved in this study is that the velocity of displacement of the CNC table and the extrusion speed of the filaments are the same. Thus, the extruded filaments kept uniform thickness.

Acknowledgment

The authors express their deepest thanks to the technical machining laboratory of the Federal University of ABC for the manufacture and assembly of the extruder device.

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