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Design of Miniature Polymer Granule Extruder

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ABSTRACT
The purpose of this project is to design and produce a miniature polymer granule extruder which can 3D print just like a filament 3D printer with the same rate and quality. This project went through three different stages. The first stage involved researching similar projects and different design ideas for the extruder. The second stage consisted of designing a miniature polymer granule extruder using CAD software, in particular SolidWorks, and then testing the design on a SolidWorks simulation before producing the extruder. During the final stage, the practical stage, a prototype of the extruder was produced and then attached to the 3D desktop printer to run tests on two materials: sugar and high-density polyethene (HDPE). A successful miniature polymer granule should work as well as a filament 3D printer.

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I. INTRODUCTION

The aim of this project is to propose a design concept for a 3D printer miniature polymer pellet extruder that works as a desktop 3D printer. The extruder temperature and extrusion speed must be controlled through sensors and motors. Above all, the main control system is the 3D printer software that can control the maximum temperature, the required printing speed, and the printing layers. Therefore, a successful miniature polymer pellet extruder can operate just like the current desktop 3D printer. The process of 3D printing with a miniature polymer extruder is a new process in the 3D printing industry. Therefore, several variables should be considered. The first concerns whether the material family is thermoplastic, thermosetting, or elastomer. Secondly, adjusting the temperature depends on the material applied, and the temperature at which the material softens or melts must be maintained. Similarly, the dimension of the 3D object should be determined for the printing process. As a material produced by polymerisation, the plastic material used for this study has a rigid structure under an applied load and is usually found in most of the products in our daily lives. However, some plastics are very strong and brittle, whereas others are flexible and subject to both elastic and plastic deformation when stressed, as well as considerable deformation before fracture. The miniature polymer granule extruder can 3D print thermoplastic, thermosetting, and elastomers plastic because these materials can come in a form of plastic granules. Thus, having a miniature polymer granule extruder will result in the availability of new products in the market. [7]

II. LITERATURE REVIEW

The process of 3D printing begins with a plastic filament that pushes to pass through the extruder. Then, the plastic filament heats up in the extruder and melts into a viscous polymer. The molten plastic pushes out through the nozzle whilst the extruder operates. The solid filament acts like a plunger, pushing the molten plastic throughout the extruder nozzle. The molten plastic is laid down on the heated bed to produce the required object. Then, the nozzle is elevated, and a new layer is laid down.

Thus, with this process, the main issue still exists, namely the limited range of commercial polymer filaments. Hence, this can be considered as a key disadvantage of 3D printing with filaments. Consequently, this is the reason behind the desire to develop a 3D printer capable of 3D printing with plastic pellets. My project aims to design an extruder that can work with different types of plastic pellets to increase the range of the materials that can be used in 3D printing.

III. CURRENT PROJECTS

From my research and that of a previous student (student number 146740), it appears that few companies are working on the pellet extruder idea. In the previous research, the student claimed that none of the designs succeeded because of two reasons: the inaccuracy of the printer and the complexity and expense of the machine’s design.

In my research, I found that Sculptify have accomplished this project on 26 June 2014, and they called it the David 3D printer. At that time, I had the idea of buying the David, taking it apart, understanding the working mechanism of the machine, and developing the product further. Otherwise, I wanted to develop a universal hopper that could work on various machines, which was the impetus of this project, which aims to develop a new concept to fit with common 3D printers. [10]

A. Sculptify Project

The announcement of the David 3D printer was formalised with the release of a new video on YouTube featuring the David printer. Moreover, they added the new video on their website, which shows that the 3D printing process starts with the user feeding the printer with plastic rubber pellets and ends with a final product made from rubber. Nevertheless, they did not release any design drawings or concepts related to their printer; they only released the technical specifications of the machine, as shown in Table 1. [11]

Figure 1 The David 3D printer [11]

Specification	Values	Specification	Values
Printing Technology	FLEX (fused layer extrusion)	Positioning Precision	x- and y-axes: 8 micron z-axis: 3 microns
Build Volume	20w × 22d × 18.5 cm 8,140 cm^3	Stepper Motors	1.8° step angle with a minimum of 1/6 microstepping
Build Surface	Aluminium	Construction	Aircraft aluminium, polycarbonate windows
Hopper Volume	Continuously refillable	Weight	29kg
Nozzle Diameter	0.3 mm, 0.4 mm, 0.5 mm all included	Product Dimensions	53.8w × 50.2d × 62h cm
Extruder Max Temperature	330°C	Connectivity	USB
Layer Resolution	20 microns for PLA		

Table 1 The David 3D Printer Specifications

IV. DESIGN REQUIREMENTS

This project required the production of a miniature polymer granule extruder for a 3D printing machine that can 3D print plastic pellets, but such pellets would replace the plastic filament. Therefore, several requirements were considered for the extruder. Firstly, the extruder had to be able to hold plastic granules and pass them to the heating block.

Secondly, a rotating screw needed to shear and push the molten material, and a bearing had be placed on the hopper to simplify the rotation of the screw. In addition, a fan was required to cool down the heating block. Eventually, a PEEK insulator linked between the heating block and hopper was used to reduce the heat transfer.

A. Design specification

- An extruder able to hold plastic pellets
- A hopper with a fan to cool down the PEEK insulator and nozzle
- A rotating screw
- A redesigned bearing space for the screw
- A PEEK insulator to connect the hopper and the heating block cartridge

B. Theoretical Design phase

The flowchart below represents the process of selecting an appropriate design concept for the 3D printer hopper. Thus, the theoretical design stage consists of three main phases: concept generation, concept selection, and concept improvement. The concept selection phase was divided into two main sections: the first section, the concept selection, and the second section, the material selection. Both sections were linked to each other by applying an analytical hierarchy process (AHP), referred to in this part of the flowchart as concurrent design concept selection and the material selection model, where this model helps the designer to assess and decide the best design concepts and materials.

Once the design and the material are determined, then the designer can proceed to the next stage—implementing the selected concept and applying the material. For the hopper, this stage was achieved on computer-aided design (CAD) software before manufacturing the product, followed by the testing of the product on the software and, finally, the manufacture of the tested component. Therefore, the flow chart below displays the phases that the design went through in terms of design concept selection and material selection. This tool helps the designer to eliminate the concepts that cannot do the job and optimise those that can. [4]

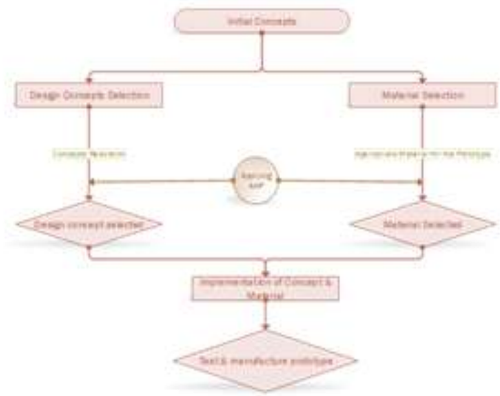


Figure 2 Analytical Hierarchy Process

C. Design Concept 1

The previous student developed the first concept, and I believe the idea came from the injection-moulding machine. Generally, concept 1 relies on several components, such as a screw to drive the plastic pellets through the PEEK insulator to the nozzle, as well as two gears connecting the motor and screw, in addition to thermal tape, a hotend, a nozzle, a heating block, a cartridge heater, and a thermistor. In my opinion, the design of the first concept serves as a good starting point despite the existence of some defects in the design of the extruder. It was noticed that the bearing slot was not correctly dimensioned; similarly, there was not much consideration for the tolerance. However, as the initial concept lacked of fan to cooldown the heating block, and the PEEK insulator took time to adjust it with the heating block. Overall, it was a successful design with minor design errors.

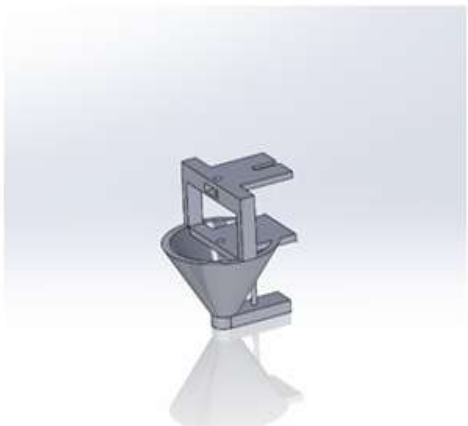


Figure 3 Modification of the Original Concept

D. Design Concept 2

In the second concept, suggested to refine the shape of the extruder, the shape completely changed from a conical shape to a pyramidal shape. The reason for that change was to reduce some of the unwanted features, such as the extruder stand, and to reduce material waste. In the new design, the extruder attached straight onto the 3D printer machine. It was also important to add a fan, as shown in the assembly image, to cool down the heating block and the nozzle. The top part of the hopper was kept as is, because the idea is effective. It is important to mention that the extruder was manufactured from plastic material, a tough PLA. In my point of view, it is fine to produce this part out of plastic material for testing, but it would be preferable to manufacture it from Aluminum alloy to enable it to handle the heat better and further reduce material waste.

Concept 2 underwent a few optimisation processes until it reached the pyramidal shape; in the beginning, the shape was not harmonic with the end bit. Figure 4 shows the original idea of concept 2, and the optimised idea is displayed in Figure 6. The inner area of the hopper is flat, which makes the granule stick during the printing process.

Many features of the felts [1] were involved in making the edges inclined, which may cause manufacturing defects. Thus, it was decided to optimise the design to provide better pellet flow and reduce some unwanted features. A brief look at Figure 7 reveals that there are no sharp edges inside. The developed concept illustrated in Figure 6

Concept 2	
Overall Length	105 mm
Overall Width	84 mm
Area	2026.43 mm^2
Thickness	5.83 mm
Nozzle Hole	9.50 mm
Drill Holes	6 mm
Screw Holes	3.20 mm

Table 2 Hopper Dimension

[1] Felts is a feature in SolidWorks, which replace sharp edges with curved corners.

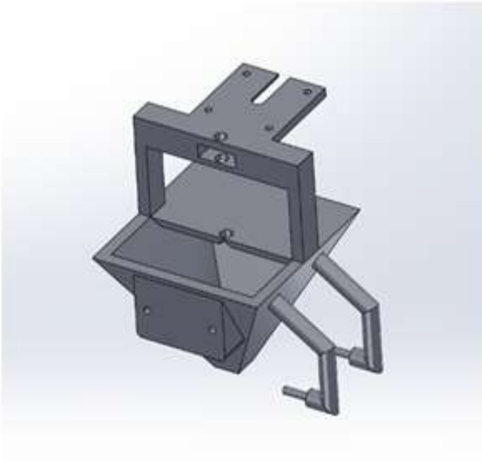


Figure 4 Concept 2 Development

E. Design Selection

The design selection of the extruder was based on a quantitative selection method called the Pugh matrix (PM).[2] The purpose of this tool is to indicate which concepts have met the design specification. Therefore, the criteria that the extruder must meet appear in the column on the left-hand side of the table. The next column contains the standard specifications of the extruder, obtained from the design specifications. The other three columns represent the suggested design concepts. These three concepts can be compared against the standard requirements. [5]

The selection process began as follows: 1 signifies that the design is better than the standard, 0 indicates that design meets the standard requirements, and -1 means that concept is worse than standard. Then, the numbers were added up to give positive and negative sums. Concepts that meet the project requirements have higher positive sums, and concepts that perform more poorly have either large negative sums or low positive sums. Consequently, concept 2 appeared to have a higher positive sum, making it good a concept for this project, along with the fact that concept 2 went through several modifications in term of shape, thickness, and the addition of missing components, such as the fan. The Pugh matrix tool, an effective and easy-to-apply selection method, just lists the requirements versus the concept and then compares them with the standard specifications. [5]

[2] Pugh matrix, part of Six Sigma, which is quality tool.

Criteria	Standard Specification	Concept 1	Concept 2
Hopper 3D Plastic Pellets	0	1	1
Hopper Must Have Fan	0	0	1
Rotating Screw	0	1	1
Bearing for the Screw	0	-1	1
PEEK Insulator	0	0	1
Sum of Positive	+0	+2	+4
Sum of Negative	-0	-1	-0
Total Score	0	1	5

Table 3 Pugh Matrix

F. Design Defect and Solution

During the design phase, two design defects became apparent after manufacturing the hopper. The first defect involved the positioning of the carrier holes: They should have been 33.5 mm but were actually 36 mm. This occurred because I was considering a tolerance of + or – 0.5 mm, but I added 3 mm extra. However, this issue could have solved by making one of the holes slightly larger than the other, so I used a drill to correct this defect. The second defect occurred on the fan holder. The end part where the fan should have been attached was broken because I was removing the supporting structure after the print was finished. I should have been very careful with it, but it broke because I applied too much force on it whilst removing the supporting structure. Still, I manged to fix the broken part by applying super glue and letting it dry for a few minutes.

Error!

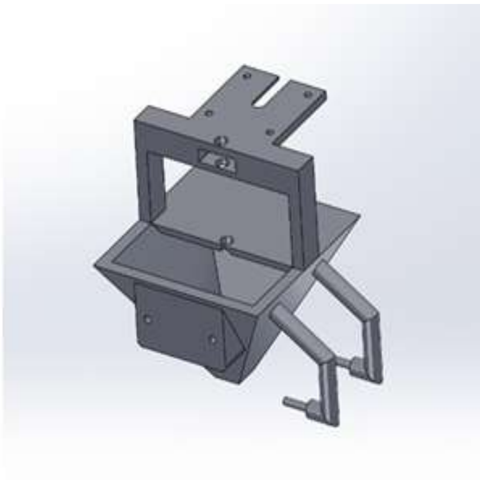


Figure 5 Concept 2 Defects

G. Hopper Assembly Process

The whole project consisted of a hopper, an auger, gears, a bearing, a stepper motor, a PEEK insulator, a fan, and heating block. The assembly process of the hopper includes the following steps.

1. Attach the hopper to the 3D printer frame with the 25 mm screws—no need to use the metal

connecting part provided with the machine because there are holes made to attach the hopper.

2. Mount the stepper motor in the top part of the hopper, and make sure that the motor cables are facing outside. Then, fix the motor to the hopper using screws.
3. Place the bearing in the slot designed for the top of the hopper, and then slide the auger through hopper, allowing the auger to pass down through the bearing.
4. Insert one of the gears in the motor shaft and the other one in the auger. Adjust the gears' teeth, and make sure they rotate together.
5. Mount the PEEK insulator at the end of the hopper and link to the heating block; both are fixed together by screws.
6. Place the fan in the two arms that come out from the hopper to cool the nozzle.
7. The motor, thermistor, cartridge heater, and fan are connected to the control board; Figure 10 displays the control circuit board connection.

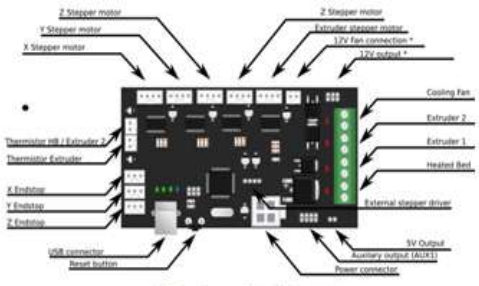


Figure 6 Printer Control Board

V. CURRENT 3D PRINITING

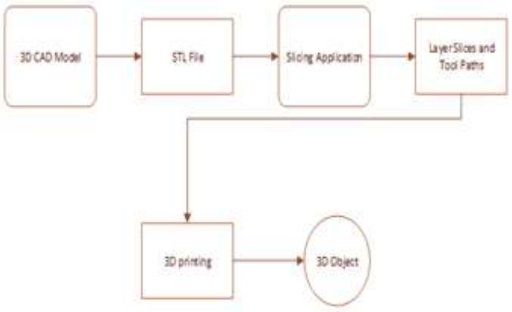


Figure 7 3D Printing Flowchart

As a process, 3D printing initiates with CAD, which is a 3D file of a design object created using CAD software, such as SolidWorks or AutoCAD. Once the design file is completed, it is transferred to a 3D printer machine. Then, a material must be selected for the component to be manufactured. A variety of materials can be used, such as plastic, metal, ceramic, resins, and food. However, this project focusses on 3D printing plastic materials, such as PLA and ABS, as well as other plastics. [1]

Moreover, 3D printing is automated process that builds modules layer by layer, and the thickness of a layer is about 0.1 mm. Nevertheless, it can be thicker or thinner depending on the size of the nozzle. Hence, the process of the printing can take hours or days, and it also depends on the size of the object. After printing, the object is removed from the machine, but for safety purposes, operators should wear gloves to protect themselves from toxic chemicals and hot surfaces. [1]

Eventually, most objects printed in 3D require post-processing for the printed component, which could entail brushing the remaining plastic or dipping the object to remove water-soluble supports. The object may be weak at this stage; therefore, it requires some time to cure, and this step is essential to make sure the object does not break. [2]

Figure 8 Filament 3D Printing Stages

The flowchart above represents filament 3D printing stages, with the traditional 3D printing process there are unnecessary steps, and duplicated steps are involved in the process. For example, filament research and development, including spooling and quality assurance, are duplicated steps in this process. Therefore, the traditional method increases the cost of the product due to the extra stages. [10]

A. Printing with Plastic Pellets

This project proposes a new idea—3D printing with plastic granules instead of a plastic filament. The plastic filament has some disadvantages, such as the fact that the plastic filament spool is large and complicated to work with. Moreover, the material options for the plastic filament spool are limited compared to those of plastic pellets. Therefore, it would be beneficial to replace the plastic filament with plastic pellets to introduce new materials. In addition, the plastic filament spools are expensive compared to plastic pellets. By looking at the flowchart of 3D printing with plastic pellets, it can be observed that many unnecessary steps are removed by using this approach. Thus, manufacturing with plastic granules affects the process and product cost, justifying the development of a new process like the one presented in this paper. [11]

Figure 2 Granule 3D Printing Stages

Therefore, for this project, I decided to develop a 3D printer machine able to print with plastic pellets, which has several implications for 3D printer technologies. Firstly, the plastic granules are available in various types of plastics and different colours.

This will revolutionise the 3D printing industry and open the door to a new range of materials since each material has it is unique properties. Some of them are brittle, others are rigid and durable, and others are soft and extremely flexible. Secondly, plastic granules are easy to use; the user simply pours the plastic pellets into the hopper, and the printing process starts. The final consideration is the cost. Effectively, the plastic pellets themselves are inexpensive and will eliminate multiple manufacturing steps, such as filament research and development, filament extruding, and spooling, leaving us with the following steps: raw material, pelletising, and quality assurance. Recently, Sculptify have developed a new generation of 3D printing that allows users to print directly with materials in pellet form. Figure 16 contains an image of a hopper design that I suggested for this project. The image only displays a view of the cross-section, so the reader can see what the hopper looks like from the inside. Table 4 provides more information on the hopper's dimensions. [10]

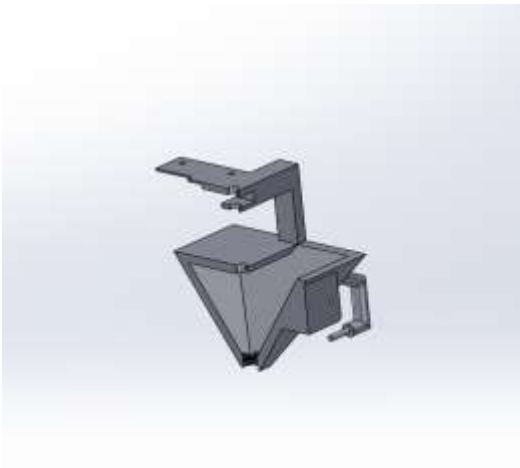


Figure 3 Extruder Section View

Concept 2	
Overall Length	105 mm
Overall Width	84 mm
Area	2026.43 mm^2
Thickness	5.83 mm
Nozzle Hole	9.50 mm
Drill Hole	6 mm
Screw Holes	3.20 mm

Table 4 Hopper Measurement

VI. DESIGN STUDY (RESULTS)

The design study for this paper was generated by a SolidWorks simulation to validate the design of the hopper, and it identified the maximum stress that could occur in the hopper carrier. Thus, small deformations may occur at the edges, but they do not lead to failure, as the motor weight is applied as a force on the top surface of the hopper. This force is distributed on a large area compared to the area that the motor occupies. The aim of this study to simulate the strength of the hopper to avoid any damages during the test.

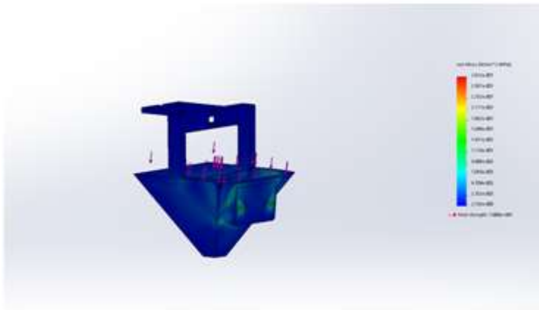


Figure 11 Stress Result

Furthermore, I applied the weights of all the components, including the motor, gears, screws, and the bearing. The reason for this is to determine if the hopper has the ability contain all those components. Therefore, the table below shows information about the applied forces. Force 1 was applied on the hopper surface. The second force was applied on the top slot where the motor shaft went through, and the last force was applied on the bearing slot.

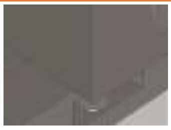
Load Name	Load Image	Load Details
Force 1		Entities: 1 face(s) Type: Apply Normal Force Value: 2.8 N
Force 2		Entities: 1 face(s) Type: Apply Normal Force Value: 0.0822 N
Force 3		Entities: 1 face(s) Type: Apply Normal Force Value: 0.074 N

Table 5 Applied Forces Result

A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

A. Temperature Control Process

During a manufacturing process of plastic materials, temperature control is an important area that must be regulated because different polymers have different softening and melting temperatures, which affects their physical properties. This effect occurs due to the heating block temperature control. When the temperature reaches desired value, it sends a signal to the system to shut it off. Then, when the temperature goes below the required value, it sends feedback to the control system to turn on the heater. This is a hysteresis control system that works by using dynamic response to change the temperature when it increases or decreases. [8] Therefore, with this control design, the system operates depending on the printed material. If PLA pellets are used to 3D print an item, then the temperature control system should be designed as follows. When the temperature goes below 180°, the heater cartridge turns on; when the temperature goes above 230°, it the cartridge shuts down. Because those are the printing values of PLA, this operation is accomplished with a thermistor. [9]

Principally, we need a temperature control device that can provide a balanced temperature during the process. The 3D printer used in this project, supported with a GT2560 controller, has the proportional–integral–derivative (PID) function, which measures convenient counter responses to variations in the process. [6] The PID algorithm involves three different specifications: proportional, integral, and derivative values. The PID works by calculating current errors, gathering past errors, and predicting the future errors based on the change of the current rate. Then, the sum of these three measurements is applied to modify the process and maintain the value of the temperature. [3, 8]

B. Hopper Testing and Analysis Result

Firstly, I had to check if the hopper could carry all the devices, such as the gears, the auger, the bearing, the motor, and the nozzle. This step can be accomplished in a SolidWorks simulation before producing the hopper. This section contains images and tables related to the materials, fixtures, loads, and forces applied. This step had to be done before manufacturing the hopper to prevent any critical failure that would lead to losses in terms of cost, time, and materials.

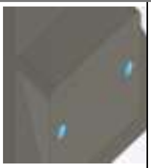
Nevertheless, during the test, I attached the hopper to the printer and inserted the auger through the hopper. Then, I connected the auger and stepper motor with two gears to deliver the plastic granules to the nozzle. The very first test I conducted was with sugar. The sugar was able to be processed, but it required a temperature of 210°C. After that, I tested HDPE granules, which did not yield a positive result even when I heated them to 240°C. These granules require a higher temperature, and the highest this machine can reach is 260°C. A small amount of plastic went out through the nozzle, but it was very hard to notice.

The table below provides an overview of the properties of the actual material used to produce the hopper. The first column contains an image of the model, and the second column shows the mechanical properties of the material used—PLA.

Model Reference	Properties
	Name: PLA Model Type: Linear Elastic Isotropic Default Failure Criterion: Unknown Yield Strength: 7e+007 N/m^2 Tensile Strength: 7e+007 N/m^2 Elastic Modulus: 3.5e+009 N/m^2 Poisson's Ratio: 0.36 Mass Density: 0.00125 kg/m^3 Shear Modulus: 1.287e+009 N/m^2

Table 6 Simulated PLA Mechanical Properties

The second table represents the fixed geometry of the design—the hopper carrier, the part directly attached to the 3D printer. I wanted to ensure that it could carry all the components without a failure in the fixed geometry.

Fixture Name	Fixture Image	Fixture Details
Fixed 1		Entities: 2 Face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction Force(N)	-2.39536e-005	-2.9563	1.02986e-005	2.9563
Reaction Moment (Nm.)	0	0	0	0

Table 7 Fixed Geometry Description

Overall, the test with sugar was successful despite the fact that it would burn; at least there was good amount of sugar flowing through the nozzle. With the plastic granules, on the other had, there was a little flow because the melting point of the material is above the machine strength. The size of the plastic granules does not matter; the main issue is the temperature. Although HDPE reached the softening point of 128℃, it could not reach the melting point, which is when the material becomes viscous. The material became stuck in the heating block, however; whenever I needed to repeat the test, I had to clean the nozzle. The cleaning process takes a long time and requires small tools to remove all the plastic. Images 12 and 13 were taken with an electronic magnifier to show the nozzle in both blocked and clean states. The blockage was caused by the HDPE. Image 12 illustrates how the plastic became stuck inside the nozzle, and image 13 was taken after the cleaning of the nozzle.

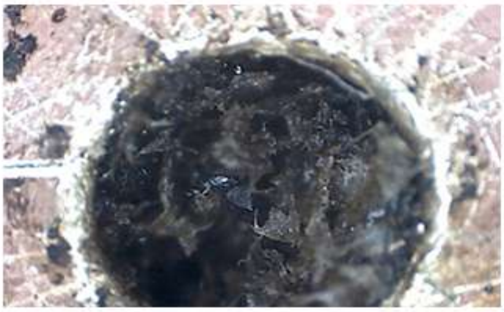


Figure 12 Microscopic Image of Blocked Printer Nozzle

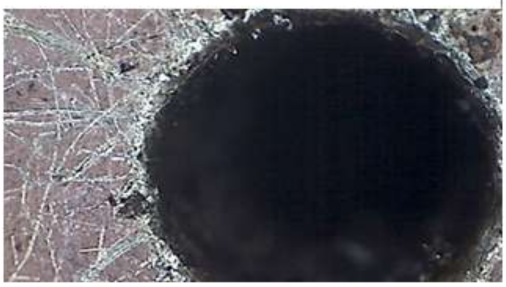


Figure 13 Microscopic Image of Clear Printer Nozzle

Some parts of the project were successes, and other parts were failures, even though I did not manage to produce a prototype with my machine. I succeed in producing a complete extruder with minor design defects that occurred in the hopper carrier and fan holder. However, the rest of the extruder was assembled properly. I was not able to achieve a full extrusion process, especially with HDPE granules. However, I manged to extrude with sugar, but at some point, the sugar became completely burnt. Therefore, since the sugar kept burning, I would not say that I also managed to fully extrude with sugar, but the sugar extruded until it started to burn. Further work is required on the speed of the external motor to figure out optimal extrusion speeds. Moreover, according to the findings of this research, the optimal temperature depends on the material; for sugar, the best temperature would be between 180℃ and 200℃, no more. In contrast, HDPE granules require temperatures 260℃ and above for better flow.

Additionally, from the flow test, I noticed that the material needed to be preheated before beginning to print. The preheating prepares the material for the print, which also improves the flow of the material through the nozzle. During the sugar test, it took about 8 minutes to preheat the suger to 180℃, and the HDPE reached 240℃ in approximately 14 minutes. A good range for the bed temperature when using sugar is somewhere between 60℃ and 100℃ so that the sugar will not stick on the machine bed. For other polymer granules, such as PLA or ABS, the bed temperature should be set at 40℃ and 60℃, respectively.

Furthermore, when using the external motor during the extrusion process, users should not reverse the direction of the motor. Otherwise, the material will come out and cool down, and then the auger will not be able to deliver the material to the nozzle. Eventually, the failure of this project is that I was not able to reach a full extrusion process.

VII. RECOMMENDATION

Several changes should be made to develop the 3D printing extrusion process. To begin with, both my design and that of the previous students worked, indicating that this project should be approached from different points of view. I would recommend changing the hopper material from plastic to Aluminum. Because I used PLA to manufacture the hopper, I realised that a great deal of heat transferred from the heating block to the hopper, and the hopper was slightly damaged from the inside.

Another challenge would be to find an ergonomic mechanism that can operate simultaneously with the hopper and the rest of the extruder components (i.e. the motor, auger, bearing, heating block, and nozzle). A multifunctional mechanism is one like the auger, which must also work as a plunger to push the material through the nozzle. In both designs, my design and the previous student design. The screw only delivers the material to the heating block and then to the nozzle. Researchers approaching this project as the previous student or I did will definitely need a screw that operates as a plunger. However, in my opinion, something that simply pushes the material down will suffice because, once the material is poured in the hopper, it is already being delivered to the nozzle, an injection force to push the material down is still required. The only advantage of having a screw is that it will shear and deliver the material.

In addition, different methods of connecting the PEEK insulator to the heating block should be found. I have used a nut to attach the heating block and PEEK insulator together, but this method was not effective. I would suggest having a nut of the same diameter size but with a different length to ensure that the PEEK insulator and the heating block are attached properly.

Furthermore, when attaching all the components to the printer, especially the hopper and the heating block, it is important to orient the z-axis correctly; otherwise, the heating block may collide with printer bed, which could damage the hopper. In my case, I increased the length of the screw, which hits the end stop—the z-axis switch. This is an important step.

Researchers who use the same machine do not need to program the printer because it is already programmed. All that is needed is to home the z-axis properly and adjust the motor speed to the recommended speed. Users should also download Pronterface Prusa to control the extruder temperature, bed temperature, motor speed, and the homing of the axes. These steps can also be achieved using the machine settings. Finally, the Prusa control allows users to modify the design to be printed in order to test the extruder.

VIII. CONCLUSION

To sum up, the aim of this project was to develop and design a miniature polymer granule extruder for a 3D printer. Nevertheless, the development and design were accomplished using SolidWorks software. The design that I proposed I was able to print sugar First, the heating block was preheated, and then the sugar was placed in the extruder. However, I was not able to print with HDPE even when I placed the material first and then preheated it since the material's melting point is higher than the heating block's maximum temperature. Therefore, printing with HDPE was not successful. The design that I proposed in the dissertation could be developed more with few modifications to the design

I observed minor defects on the hopper design could be easily overcome to enable the miniature extruder to function as intended. I strongly believe that the idea of this project will revolutionise the 3D printing industry in the future.

REFERENCES

[1]. 3D HUB (2018) Selecting the right 3D printing process,Availableat:https://www.3dhubs.com/knowledge-base/selecting-right-3d-printing-process (Accessed: 07 July 2018).
[2]. 3D printing (2018) 3D Printing Materials, Available at: https://3dprinting.com/materials/ (Accessed: 01 July 2018).
[3]. Alexander James Esbrook (2012) CONTROL OF SYSTEMS WITH HYSTERESIS USING SERVOCOMPENSATORS. [Online]. Available at:https://www.egr.msu.edu/~xbtan/Papers/Journal/Dissertations/Esbrook2012.pdf (Accessed: 25 July 2018).
[4]. Booker, J.D. and Swift, K.G. (2003) Process selection: From design to manufacture. 2nd edn. Oxford, England: Butterworth-Heinemann.
[5]. Bralla, J.G. (2007) Handbook of manufacturing processes - how products, components and materials are made. New York: Industrial Press Inc.,U.S.
[6]. BotBuilder (2016) Prusa i3 Printer Assembly Guide,Availableat:https://www.abella.net/dev/manual-r19.pdf
[7]. (Accessed: 02 August 2018).
[8]. John, V. (2003) Introduction to engineering materials. United Kingdom: Palgrave Macmillan. [
[9]. Panasonic (2011) Temperature Controllers Using Hysteresis,Availableat:https://na.industrial.panasonic.com/blog/temperature-controllersusinghysteresis
[10]. (Accessed: 02 August 2018).
[11]. schneider electric (2018) PID Control made easy, Available at: https://www.eurotherm.com/pid-control-made-easy(Accessed: 25 July 2018).

[12]. Sculptify (2014) Sculptify announces Kickstarter campaign in August. Features Video of David in Action.,Availableat:http://sculptify.com/blogs/news/14834025sculptifyannounceskickstartercampaign-in-august-features-video-of-david-in-action
[13]. (Accessed: 12 July 2018).
[14]. Sculptify (2014) Sculptify Introduces David, an innovative 3D Printer that works directly with a wide variety of materials., Available at: http://sculptify.com/blogs/news/14537597-sculptify-introduces-david-an-innovative-3d-printer-that-works-directly-with-a-wide-variety-of-materials (Accessed: 12 July 2018).

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