Master Thesis

Creating a new material for 3D printing out of recycled materials

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Division of Machine Design • Department of Design Sciences
Faculty of Engineering LTH • Lund University • 2016

LUND UNIVERSITY

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Preface

As an initiative from Brazil and commissioned by the Division of Machine Design this Master thesis in Mechanical Engineering, Product Development has been executed at Lund University, Faculty of Engineering.

I would like to thank my supervisor Olaf Diegel at the Division of Machine Design for giving me the opportunity to work with this project, that he has been available as my supervisor and giving me input whenever I needed throughout the project. Both guiding me through it and helping me overcome all the difficulties that I encountered along the way.

A special thank you to Johannes Ekdahl du Rietz for his time and patience and who helped me a lot with the understanding of the electrical components and processes of the project. Without him the project would have required a lot more time and patience from me.

Lund, January 2016

Charlotta Engstrand

Abstract

The aim of this thesis is to examine whether or not it is possible to create a material for 3D printing that is made out of recycled materials. There are a lot of material to choose from, but since this is a project that is initiated in the Favelas in Brazil, where they want to use recycled plastic as a material, that will be the starting point for this project. However, it is thought that using only recycled plastic will leave the 3D printed parts deformed due to the fact that different plastics shrink differently. This is why it is necessary to add a new material. Rubber from old tires is deemed as a good option since, at this moment, there are few possibilities of recycling tires. Consequently, they are easy to acquire and they are often possible to obtain for free at disposal plants. The goal is to find a combination of these two materials where the plastic encapsulates and act as glue for the rubber, and the 3D printed layers stick to each other without crumbling apart.

The first step of the process is to consider how to extract rubber powder from the old tires. An angle grinder is used, since this proved to be the best choice of the different techniques tried. It does not yield any larger volumes and it is time consuming, but for this project it was not considered of importance to optimize this process.

The next step is to design and assemble a printhead that can be used. The main functions of this printhead are to serve as a container for the added material, melting the plastic and extruding the material. The extrusion is solved by letting a DC-motor, placed on top of the container, power an auger that press the material down via an aluminum extruder to a nozzle. The aluminum extruder is heated by a heat cartridge allowing the plastic to melt.

When the printhead is ready to use it is attached to a 3D printer. It is then possible to start investigating what process temperature is optimal and what ratio of rubber and plastic powder that can be used.

The project was successful and the results obtained were as follow; the optimal process temperature for melting the plastic, in this case nylon, was approximately 200 °C and the ratio of rubber and plastic should be 50% rubber and 50% plastic in volume. For the rubber and nylon powder used in this project, that corresponded to 27% rubber and 73% plastic when weighted.

Keywords:

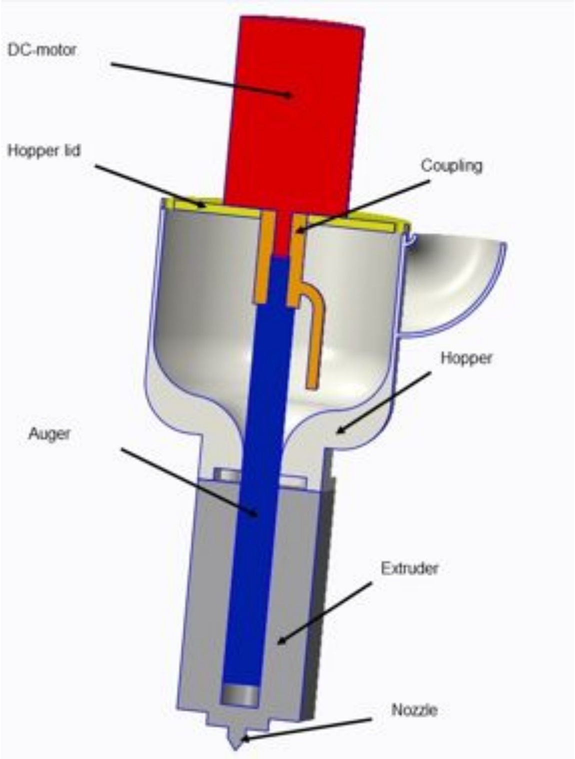
3D printing, recycled rubber, recycled plastic, new material, sustainability

Sammanfattning

Det här projektet kom till på grund av ett initiativ från Brasilien. Tanken är att plast som ligger och skräpar i de slumområden som finns i Brasilien ska samlas in och användas för att 3D-skriva med. Det finns dock ett problem med detta vilket är att den insamlade plasten troligtvis består av många olika sorter så som PET, LDPE, PP etcetera. Dessa plaster krymper olika mycket vid uppvärmning och kommer därför generera deformerade 3D utskrifter. Som ett sätt att försöka komma runt problemet tillsätts ett annat material som förblir oförändrat vid uppvärmning. Det finns många sådana material att välja från så som textil, sand, glas och gummi från gamla däck. Det sistnämnda anses vara bra ur två perspektiv, dels att det förblir opåverkat av värme upp till cirka 500 °C samt att det är ett bra sätt att återvinna gummit på, vilket annars är väldigt svårt i dagsläget. Det finns också oerhörda mängder gummi till följd av alla bildäck som slängs varje år. Det finns även mycket återvunnen plast att tillgå, men det finns bättre återvinningssystem för plast och därför anses det bättre desto mer gummi som kan användas i blandningen. På grund av den tidsram som råder för projektet så kommer huvudfokus ligga på att göra tester för att se om det går att kombinera de här två materialen med varandra och skriva ut med en 3D-skrivare. För att förenkla något kommer nylon att användas istället för en blandning av olika plastsorter.

Först och främst måste ett smidigt sätt att framställa gummipulver av däcken utarbetas. Lättast är att skära däcket i mindre bitar med hjälp av en mattkniv. Däremot används bara kanten på däcket eftersom det visar sig vara den delen som innehåller minst stål och textil som tillsätts för att stabilisera däcket. När kanterna är tillskurna görs ett försök att bearbeta dem med en rasp, något som visar sig vara oerhört tidskrävande samt att gummipulvret inte blir tillräckligt finkornigt. Istället används en vinkelslip. Den visar sig ha önskad effekt på gummipulvrets storlek, däremot är det fortfarande ganska tidskrävande och svårt att samla in gummipulvret som yr överallt när man använder vinkelslip. Det anses dock inte vara fokus på att optimera den här processen och pulvret som framställt duger väl till ändamålet.

Nästa steg är att designa och bygga ihop ett skrivarhuvud vars huvudfunktioner består i att smälta plasten, extrudera materialblandningen, samt agera behållare för densamma. Det färdiga skrivarhuvudet kan ses, något förenklad, i genomskärning i figur 1.



Figur 1 Tvärsnitt av skrivarhuvudet

Likströmsmotorn som sitter ovanpå materialbehållaren driver skruven som sitter i mitten vilken i sin tur pressar ner materialet genom aluminium-extrudern och till slut till munstycket som sitter längst ner. Vid munstycket sitter också en temperatursensor och ett värmeelement som smälter nylonen. En temperaturregulator reglerar värmen genom den återkoppling som den får från temperatursensorn. Regulatorn fungerar som ett av/på relä vars värmefunktion stängs av när den förinställda temperaturen har uppnåtts samt sätts på när för låg temperatur är registrerad. En fläkt på sidan av aluminium-extrudern ser till att värmen inte transporteras uppåt mot behållaren som är gjord av nylon och på så sätt smälter den.

Några första test görs sen med nylon och gummi för att testa att skrivarhuvudet fungerar som det ska. Det visar sig att munstycket är för litet i diameter för att extrudera gummipulvret. Från 0.3 mm borras det upp till 1 mm vilket fungerar mycket bättre. Skrivarhuvudet monteras sedan på en 3D skrivare för att kunna göra de sista och avgörande testerna. Dock måste några små justeringar till på 3D-skrivaren för att den ska fungera optimalt. Bland annat kopplas en resistor in i kontakten där det gamla skrivarhuvudet har suttit. Detta görs för att lura skrivaren att rätt temperatur på skrivarhuvudet är uppnådd. Temperaturåterkopplingen finns inbyggd i det gamla skrivarhuvudet, men när det tas bort saknas återkopplingen och programvaran för skrivaren kommer att tolka det som att processen inte är redo att köra. Resistorn lurar på så sätt programvaran att skrivarhuvudet är inkopplat och uppvärmt och redo att användas. En ny platta som materialet skrivs ut på sattes också in för att öka vidhäftningsförmågan, annars tenderade kanterna på utskrifterna att böja sig uppåt vilket försvårade utskriften och förstörde proverna.

För att få så bra förutsättningar som möjligt för att hitta rätt blandning av nylon och gummi gjordes först några temperaturtest med nylon för att se vilken precesstemperatur som var optimal. I ett spann från 190-215°C med 5°C temperaturökning för varje nytt test avgjordes vilken temperatur som var mest lämplig. Det visade sig att 200°C var den temperatur där utskrifterna såg ut som den datormodellerade versionen. Varmare än så och plasten smälte ihop och formen på utskriften förstördes. Om det var en kallare processtemperatur så var det svårt att få tillräckligt hög fart på extruderingen av materialet vilket gjorde att utskrifterna blev ofullständiga och saknade material på sina ställen.

Till sist tillsattes gummipulver för att undersöka hur stor andel gummi respektive nylon som var bäst. Tre tester gjordes, det första med 50% volymandelar gummipulver och 50% volymandelar nylon. I nästa test var proportionerna 60/40 gummi/nylon och till sist 70/30 gummi/nylon. Det visade sig att blandningen med 50% gummi och 50% nylon var den bästa. De andra test-volymerna uppvisade dåliga resultat där plasten misslyckades med att inkapsla och limma ihop gummit. Det som återstod var en utskrift som smulades sönder väldigt lätt. För att vara säker på att det verkligen gick att skriva ut med 50/50-blandningen och att det inte bara var en engångsföreteelse så gjordes fler tester, totalt fem, av den blandningen. Det visade sig att det var görbart flera gånger i rad och det önskade resultatet ansågs vara uppnått. Det slutliga resultatet kan ses i figur 2. Det bör understrykas att de angivna proportionerna är i volymandelar. 50% gummipulver och 50% nylon i volymandelar motsvaras av 27% gummipulver och 73% nylon i viktandelar eftersom gummipulvret har lägre densitet än nylonpulvret.

Figur 2 Slutliga resultatet

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1 Introduction

This chapter will briefly describe the background, aims and objectives of this project and what initiated it. Any limitations for the project will also be addressed in this chapter.

1.1 Background

Today there is a growing problem of litter and unrecyclable materials around the globe. Plastic is a main contributor to litter, and rubber tires are piled up due to problems with recycling the material.

The idea with this project is to create a unique material out of different plastic materials and rubber tires. In the favelas in Brazil people are collecting the plastic litter and want to be able to make an income from it. An idea is to create a new material for 3D printing using this collected plastic. However, it is very hard and extremely inefficient to determine what kind of plastic that has been collected and try to separate it. Not being able to separate the plastics creates a problem when the plastics have been melted and 3D printed and is going to harden. Because different plastics shrink differently, this will lead to deformed and unusable 3D models. However, if it is possible to combine the plastics with another material, the impact from the plastics might not be as influential. Using old tires made out of vulcanized rubber might be a solution.

1.2 Aims and purposes

The goal is not only to create a sustainable material for 3D printing, but also to gain socio-economic advantages in poor areas like the favelas in Brazil. The idea is that the people living in the favelas will be able to 3D print a lot of different products out of this recycled material. For example, they can print spare parts for houses, sewage pipes or products that they can sell to get an extra income just to mention a few possible applications of the material.

1.3 Problem formulation

The idea with this project is to somehow pulverize the rubber and use that as the main component in the new material. The rubber and plastic are to be mixed and added to a 3D printer where the plastic will be melted and will work as glue for the rubber. In conclusion, the main problem to solve with this project is if it is possible to combine these two materials and if so, how much of each material is needed.

1.4 Objectives

The overall objectives of the project can be divided into:

- Creating a rubber powder out of old tires.
- Designing a printhead that can extrude the material and attach the printhead to a 3D printer.
- Determine a process temperature for the material.
- Finding a material combination of plastics and rubber that can be 3D printed, trying to use as much rubber as possible.

1.5 Delimitations

A few delimitations have to be done due to the conditions of this project and are described below.

- It might be difficult to separate the rubber from the textile and steel in the tires with the tools provided at the institution. This might lead to a rubber powder of poor quality. However, the scope of the project does not comprehend optimizing the rubber powder and subsequently the powder possible to obtain will have to suffice.
- In this project plastic powder of nylon will be used instead of recycled plastics. Because at this stage it is more important to find the optimal ratio of rubber and plastic rather than focusing on the shrinkage impact of recycled plastic that will occur when different sorts of plastics are to be used.
- Due to time restrictions and not knowing how difficult it was to produce the desired material there was not enough time to 3D print any bigger models of use to display the possible applications of the material.
- This project only aims to clarify if it is possible to create this plastic and rubber material or not. If possible many improvements has to be done to make it possible to implement this project in the favelas. For example, it is necessary to find out what kind of 3D printer can be used, to optimize the process of extracting rubber and to improve the printhead. All of which there is not enough time for during this thesis.
- The final result will only be examined visually. No tests are done to verify the porosity or any other characteristics of the material, something that is necessary for further work.

2 Method

The method for this project is partly based on Ulrich and Eppinger's Product Design and Development Process [1]. However only one step in the process is taken into consideration, which is proof of concept. Furthermore, the specific methodology for this thesis will be described in detail.

2.1 Product Design and Development Process

As can be seen below in figure 2.1, Ulrich and Eppinger's Product Design Process is divided into a few steps. The first steps involve listing customer needs and creating and selecting a concept out of these specific needs. Due to the fact that this is a project initiated in Brazil and that a specific idea has already been created these steps has before been taken into consideration. For this project it is instead important to focus on the testing of the concept idea, which is a sub step to the concept development. This will be carried out as action based research where the process will be a progressive solving process.

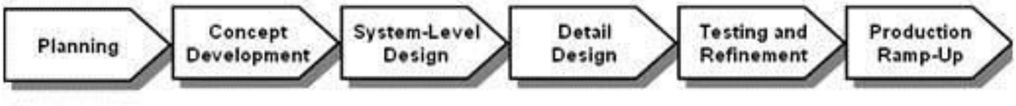

Figure 2.1 Ulrich and Eppinger's Product Design Process

2.1.1 Test product concept

The concept testing will be carried out as many iterative processes to obtain a combination of material that fulfills the requirement for this project. These tests will show if the goal is feasible, and if time allows, early prototypes will be 3D printed to show the possibilities with this new material.

2.2 Material processing

This project is focusing on using recycled materials and since plastic and rubber are to be used it is important to be able to process them in a way so that they are easy to use. Plastics are relatively easy to melt. The main problem occurs when old rubber tires are to be processed. Finding out a way to prepare the tires is therefore essential.

2.3 Designing a printhead

Existing printheads cannot be used for this project since they do not fulfill the requirements in terms of usability since they use a filament to print the material. By designing a new printhead it is possible to create one that can use the powder based mixture of rubber and nylon. For initial testing an UP printer from *3D Printing Systems* will be used, see figure 2.2. These printers extrude material from a filament. Since this project uses two materials it would be cumbersome and unnecessary to first create a filament and then extrude the material. Consequently, it is necessary to design a new printhead for this purpose that can mix the materials and extrude the mixture in one go. However, it should be noticed that not a lot of time is allotted to this part of the project. Designing a printhead that is optimal for extruding this material will take more time than is available for this project. Hence, the designing of the printhead will be to develop something that works for this project, but that will most likely has to be altered and improved for further studies.

Figure 2.2 UP 3D printer

2.4 Printhead and setup

Once a final printhead design has been made and 3D printed the next step would be to setup the different parts of the printhead. At first it is of importance to make sure that the extruder works and that it is able to mix and extrude the two materials. Once this is successfully done the printhead will be mounted to an UP printer.

2.5 Material combination

The main purpose with this project is to find a good combination of the chosen materials. With the help of the extruder it is possible to experiment with the proportions and determine whether the combination is sufficient or not. The desired result is a mixture of the two materials where the plastic encapsulates the rubber in order to make the 3D printed layers stick to each other. The final result will be examined visually and no further tests on the porosity are done since this project only aims to clarify if this material can be 3D printed or not. For further work the results will have to be examined in more detail to see what applications this material has.

3 Materials

It is possible to pick from a wide variety of materials to combine and test for 3D printing, all that have their pros and cons. The following section aims to clarify why the selected materials are chosen and why their characteristics are suitable for this project.

3.1 Recycled plastics

This project is initiated in the favelas in Brazil as an idea to solve the problem of littering in the areas as well as helping the habitants to create their own 3D printed parts at no cost since there is a widespread poverty in the areas. Using free and easy accessible material is a good solution to the problem. Based on this, using recycled plastics is an option since there is an abundance of the material due to littering and consequently the material is also for free. However, recycled plastics have different characteristics (see below, chapter 3.1.1) and to be able to use them one would need to separate the different varieties from each other. However possible, it is difficult and a costly process to do so and the advantages of using recycled material would be lost. Hence, separating them will not be an option for this project. It is instead of importance to find an alternative solution to be able to use the mixture of recycled plastics as it is.

3.1.1 Characteristics

Recycled plastics contain a large variety of different plastic materials that all have different applications, like containers, carrier bags, bottles etcetera. A few of the occurring varieties in recycled plastics are Low density polyethylene (LDPE) that can be found in carrier bags, Polyvinyl chloride (PVC) found in packaging and cling film, Polyethylene terephalate (PET) found in plastic bottles, Polypropylene (PP) found in food storage containers and Polystyrene (PS) found in disposable cutlery, cups and bowls just to name a few [2, p. 9-18].

These different types of plastics all have similar but different properties. According to Olaf Diegel [3] the shrinkage properties vary between different plastics. Although it does not vary a great deal it will still affect the outcome of the 3D printed parts and cause them to deform. For this project however, nylon powder (see figure 3.1) recycled from a 3D printer used at the Division of Machine Design will be used, because at this early stage it is more important to find a good material combination as described in chapter 2.5 rather than focusing on shrinkage. Though one should bear in mind that the outcome of this project will be altered if using different plastics.

Figure 3.1 Nylon powder

It is also relevant to have an idea of the melting temperatures of the different varieties. This is necessary in order to know what process temperature is needed when extruding the materials. This process temperature can be altered and it is valuable to know in what range changes can be made for different varieties of plastic, and in this case, what temperature is optimal for processing nylon.

3.2 Vulcanized rubber

To circumvent the problem of shrinkage a material needs to be added that shows no tendencies of these characteristics. Vulcanized rubber is a material of such kind, because of the cross-links of the rubber molecules that form during the vulcanization process. These cross-links are almost insoluble, making it hard to reform [4]. From a recycling point of view, it is good choice since there are few options today to recycle rubber [5]. A few areas where rubber granules are used are roads, athletic track surfaces and playgrounds [6], but the demand for rubber granules is far below the amount of produced vulcanized rubber [5]. Apart from this application, most of the rubber end up being burned as fuel, but also end up in landfills, contaminating the soil with toxic components [5] which is not in any way desirable from a recycling point of view.

3.2.1 Characteristics

As mentioned above, when vulcanized rubber has been formed once, the cross-links make it impossible to remold it in to a different shape without devulcanizing the rubber, a costly process [7]. This quality makes rubber a bad choice if you want to recycle it, but good for the purpose of this project. In other words, the physical properties of rubber stay unchanged until it burns and char. This is exactly what needs to be acquired and can then serve as a good material to mix with plastics. However, it is crucial to make sure that the temperature when rubber burns does not exceed the process temperature for 3D printing with the recycled plastics. According to U.S Fire Administration [8, p. 6] vulcanized rubber needs to be heated to 500 °C for an extended period of time before ignition. Again this leaves vulcanized rubber as a suitable component since the process temperature will most likely vary somewhere in between 190-230 °C when using nylon [3].

3.2.2 Processing of rubber tires

In order to be able to 3D print the vulcanized rubber it had to be pulverized somehow. The tire used was first cut into smaller pieces to make it easier to handle, see figure 3.2. Only the sidewall, see figure 3.3, of the tire was used due to the fact that there is not as much steel wires and textile in this section, hence it is easier to handle. The smaller pieces were then to be processed and pulverized starting with a rasp, see figure 3.4. It was quickly realized that this was far too time consuming, but also that the powder was too coarse for 3D printing. Instead an angle grinder was used, see figure 3.5. This created a fine rubber powder (see figure 3.6), suitable for the 3D printer.

Figure 3.2 Cutting of the tire

Figure 3.3 Structure of a car tire

Figure 3.4 Processing the tire with a rasp

Figure 3.5 Processing the tire with an angle grinder

Figure 3.6 Fine rubber powder

3.3 Toxins

It is crucial to make sure that the materials chosen does not release any toxins when processed. When vulcanized rubber is exposed to heat there is an increase of benzo(a)pyrene released in the air. However, according to researches done these values does not exceed the limits allowed and no precautionary measures needs to be done [9]. Although, it is worth mentioning that the release of benzo(a)pyrene is likely to decrease if rubber powder from tires produced after 2005 in the European Union are used [10]. This is due to the fact that the EU banned the use of softening oils in tires which are most likely responsible for the release of benzo(a)pyrene [9]. Worth noting is that when using an angle grinder to process the rubber a protective mask should be worn, because the rubber powder scatters everywhere and causes involuntary inhalation if a mask is not worn.

When it comes to nylon there is no need to be alarmed about particles escaping from the material according to Katarina Elner-Haglund [11]. Although nylon emits carbon dioxide, carbon monoxide and nitric oxide when heated, it is not classified as injurious to your health. Worth noting is that no researches has been done for this project on other plastic materials such as PET, LDPE etcetera and in order to use recycled plastics it is important to make sure the same goes for other plastic materials as for nylon.

4 Printhead design and setup

In order to be able to extrude the material it is necessary to design a printhead that will work as a blender and extruder for the two materials. This chapter focus on the different steps in making this new printhead.

4.1 Printhead functions

A hopper will work as a feeder and container for the plastic and rubber powder. Through a feeder the material will collect in a container. Mounted on top of the hopper is a lid which connects to a motor and an auger. The motor will power the auger which in turn will blend and press down the material via the extruder to the nozzle. There will be applied heat to the extruder via a thermocouple which in turn will be monitored by a temperature controller. It is crucial that the temperature is at a steady level in order to keep the plastics melted throughout the process. These are the main functions of the extruder. A more detailed description of the different parts can be seen in the sub chapters below.

4.2 Printhead assembly

The final assembly can be seen in figure 4.1 and a cross section of a simplified version of the printhead can be seen in figure 4.2. Furthermore, the different parts are explained more thoroughly in chapter 4.3.

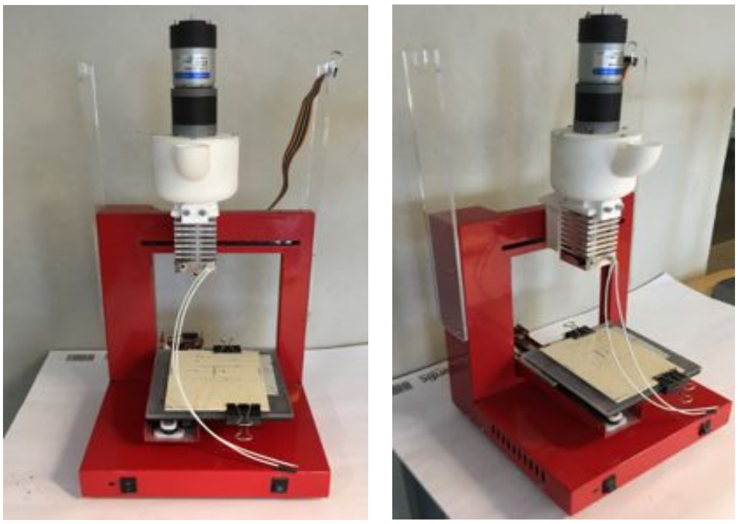

Figure 4.1 Printhead assembly

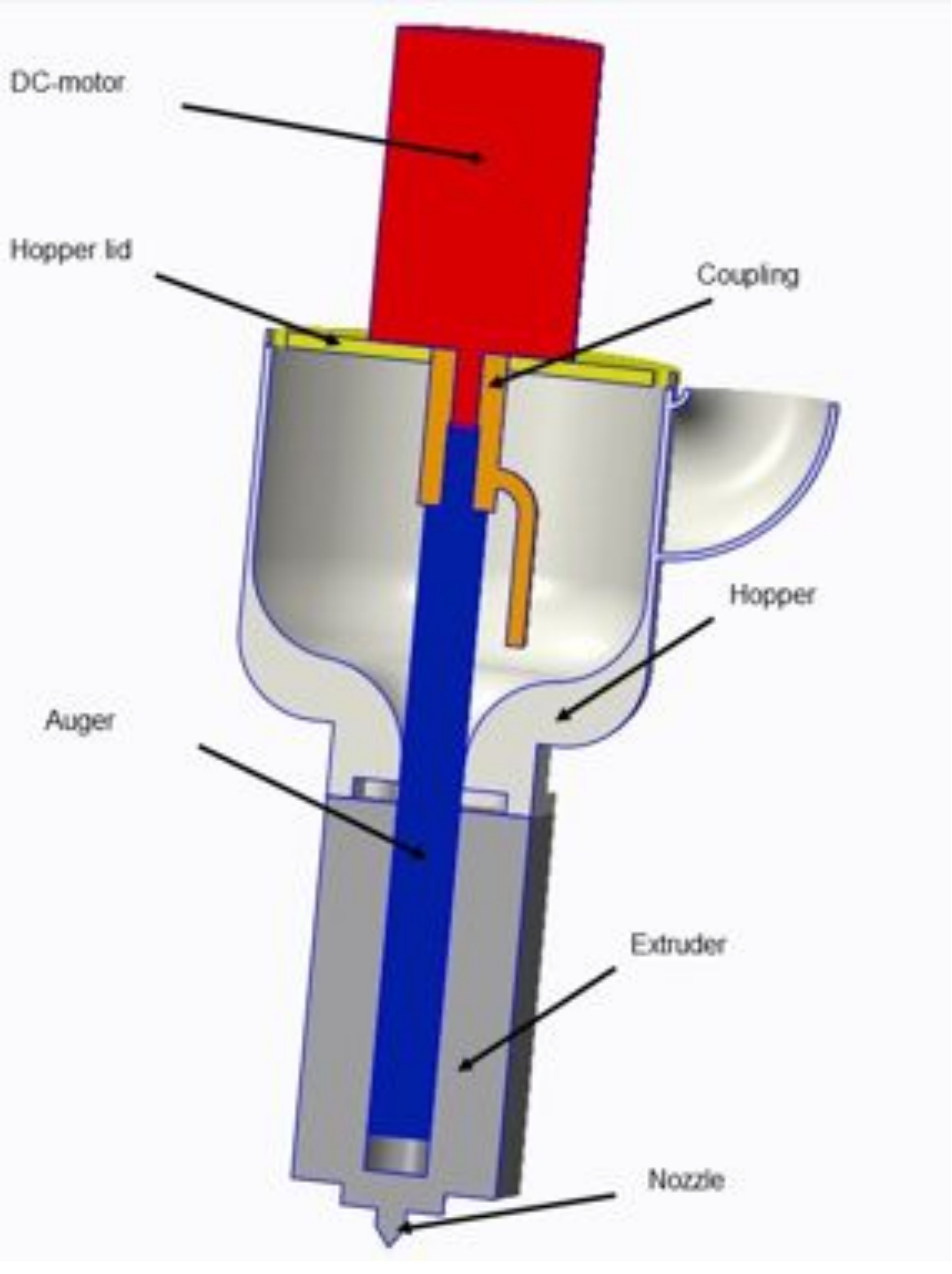

Figure 4.2 Cross section of printhead

4.3 Printhead design

4.3.1 Hopper

The hopper needs to be big enough to house the materials and the auger, but also to roughly blend the pellets and granules. When designing the part, it was necessary to make sure these criteria were fulfilled, but also to make sure that there were no sharp edges on the inside where the material could stick. A smooth passing is desirable. The hopper is 3D printed in nylon, and to be certain that the hopper will not melt during the extruding process a fan is added, see below in chapter 4.2.9. The end result of the designed hopper can be seen in figure 4.3 and a cross-section of the same hopper in figure 4.4.

Figure 4.3 3D model of hopper

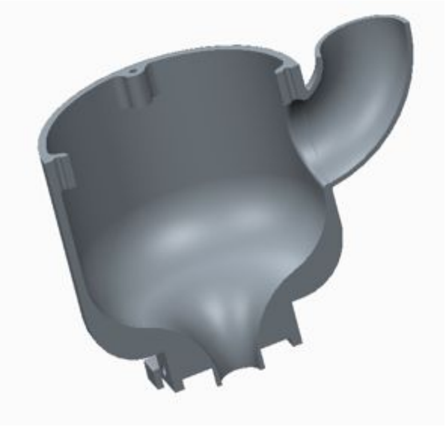

Figure 4.4 Cross-section of hopper

4.3.2 Hopper lid

The lid, see figure 4.5, will prevent any material from escaping the hopper, but the main functions are to mount the motor and auger. Connecting the two is a coupling that transfers the torque from the motor to the auger, see below 4.3.3. The lid is also to be 3D printed and the material is consequently the same as for the hopper.

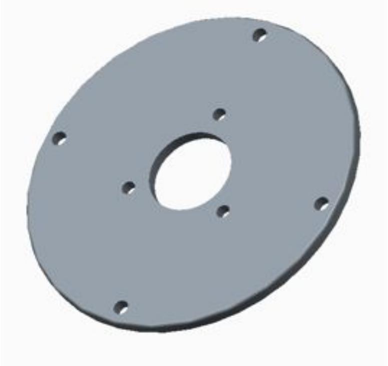

Figure 4.5 Hopper lid

4.3.3 Coupling

The coupling has a fairly simple design with a cylinder with two holes placed on each end. One cylindrical to fit the motor and one square to fit the auger. Two screw holes were added in case the fitting of the holes were not tight enough, to fasten the motor and auger. A bonus feature is the blender attached to the side that is added to mix the materials added to the hopper. The coupling can be seen in figure 4.6.

Figure 4.6 Coupling, bottom and top view

4.3.4 Extruder

The extruder is made out of aluminum to prevent the applied heat to melt the extruder. Two holes are placed at the lower part of the extruder to be able to attach the temperature sensor and a heat block, see figure 4.7. The fins make it easier to attach the hopper to the extruder but also make the total weight of the construction lighter and the heat transport and cooling off of the extruder easier.

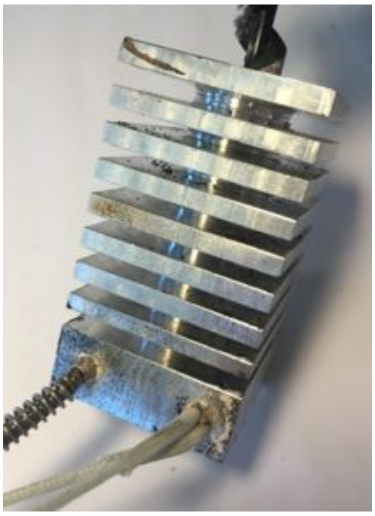

Figure 4.7 Aluminum extruder

4.3.5 Nozzle

A brass nozzle is attached to the bottom of the extruder that initially have an extruding diameter of 0.3 millimeters, see figure 4.8. If required after some initial testing it is possible to change the nozzle to a bigger diameter.

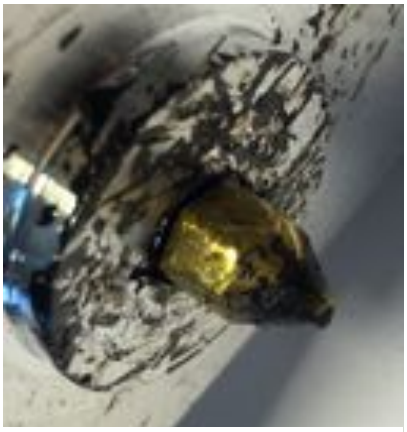

Figure 4.8 Brass nozzle

4.3.6 Auger

The auger is a 12 mm drill that is rotating to press the material down through the extruder. Note, in order for the screw to press the material down it has to rotate counterclockwise.

4.3.7 DC-motor

A motor that can power the auger needs to have a torque strong enough to be able to extrude the viscous material. A DC-motor with a voltage of 24 V is used and can be seen in figure 4.9.

Figure 4.9 DC-motor

4.3.8 Temperature controller

The temperature controller used is a *Watlow EZ-zone PM express,* see figure 4.10, that has a built in thermocouple that receives feedback from the temperature sensor and communicate the information to the heating element. The controller will monitor the process temperature and use an on off relay to control the applied heat. Once the temperature reaches the preset value the relay will switch off and stop heating and on the contrary it will start heating again when the temperature is below the preset value. When using an on off relay, it is unavoidable to have a variation in temperature of a few degrees. Using a PID controller instead will eliminate this variation, however for this process a few degrees will most likely not make a greater impact on the result. As long as the overshoot is not too big and causes the nylon to melt too much or on the other hand the temperature is too low, leaving the nylon too viscous, the on/off function will suffice. Furthermore, to avoid the relay to switch on and off due to small variations of the temperature the hysteresis is set to 2 °C to eliminate these rapid changes. In figure 4.11 it is possible to see how the wires from the heat cartridge, temperature sensor and power chord are connected to the controller. The temperature sensor is connected to S1 and R1, the power chord to 98 and 99 and the heat cartridge to K1 and 98 with a wire linking J1 and 99. For further explanation on settings see user's guide in Appendix C.

Figure 4.10 Watlow EZ-zone

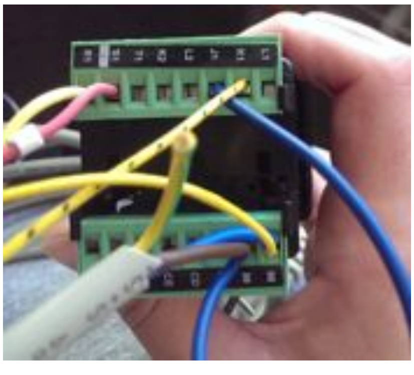

Figure 4.11 Wire connection

4.3.9 Cooling fan

To make sure that the extruder does not get too hot and consequently melt the plastic hopper, a 12 V fan, see figure 4.12, is installed on the extruder to cool it off. Initially only one fan is placed on the extruder, but depending on how much heat needs to be applied a second one might be added.

Figure 4.12 12 V fan

4.3.10 Heat cartridge

In order to be able to melt the plastics a heating element is required. For this purpose, a heat cartridge is used with a power output of 200W, see figure 4.13. To improve the heat transportation from the cartridge to the aluminum extruder, a small amount of heat compound was added on the surface of the cartridge. It is also possible to use a heat band instead. However, the extruder would then require a slightly different design in order to be able to attach the heat band.

Figure 4.13 Heat cartridge

4.3.11 Temperature sensor

The temperature sensor is a thermocouple placed close to the heat cartridge to give an accurate reading of the temperature. To improve the reading of temperature, some heat compound was added at the surface of the sensor. The thermocouple can be seen in figure 4.14.

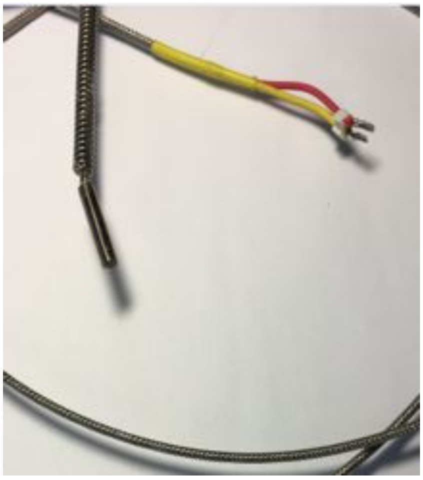

Figure 4.14 Temperature sensor

4.3.12 Mounting bracket

A mounting bracket will be attached to the hopper and extruder in order to mount the printhead to a desk or similar. This is required to be able to do initial testing to verify that the extruder works as intended. The mount, figure 4.15, screws to a wooden block that in turn is mounted to a desk with a clamp. Later on in the project another mounting bracket is required in order to mount the printhead to a 3D printer, see chapter 6.2 for further explanation.

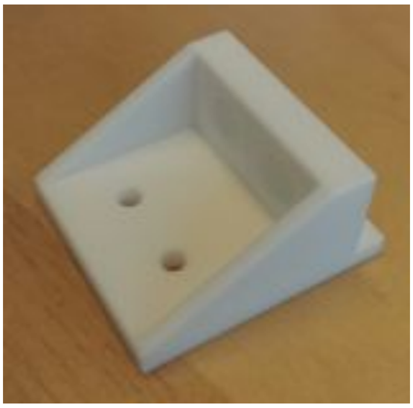

Figure 4.15 Mount

4.3.13 Power supply

A power supply is needed for the DC-motor, the cooling fan and the temperature controller. They all run on a 230 V power supply. The DC-motor and cooling fan are connected to a mutual power supply where the voltage can be monitored and altered. The motor has a maximum voltage of 24 V whereas the cooling fan has a maximum voltage of 12 V. The power supply used, see figure 4.16, can control the two components separately in order to change the voltage for each component without affecting the other. However, connecting them in such a way makes it impossible to alter the voltage for the DC-motor to more than 20 V. If more torque is needed another power supply, with higher voltage, is required. Initially 20 V will suffice for testing. The temperature controller is separately connected to a wall outlet of 230 V.

Figure 4.16 Power supply

5 Initial testing and refinment

To be able to improve the printhead and make it function as intended initial testing and refinement of the printhead is necessary. This chapter aims to clarify how this was carried out and why.

5.1 Testing with nylon

To verify that the printhead functions as intended a few initial tests were carried out with nylon. The first tests gave the desired results and a nylon string, of 0.3 millimeters in diameter, was extruded from the printhead. The temperature required was approximately 195 °C, which is below the expected temperature that needed to be applied in order for the nylon to melt. The results can be seen in figure 5.1.

Figure 5.1 Nylon string

5.2 Testing with nylon and vulcanized rubber

The first test carried out with a mixture of nylon and rubber was not as successful. The rubber powder had a tendency to plug the nozzle, subsequently nothing was extruded. To avoid plugging of the nozzle the diameter was increased to 1.0 mm. However, the rubber powder might still contain parts bigger than 1.0 mm. To remove these parts, the powder was sifted with a common sieve for kitchen use, see figure 5.2.

Figure 5.2 Sieve

With the new nozzle and a finer rubber powder, new tests were carried out with rubber and nylon resulting in a successful extruding process. The desired results of a rubber-nylon string can be seen in figure 5.3.

Figure 5.3 Rubber-nylon string

5.3 Final setup of printhead

An incident with the heat cartridge lead to the need of investing in a new one. The new heat cartridge had slightly different measurements than the original. Consequently, the hole in the extruder had to be made bigger in diameter to fit the new heat cartridge. Other than this no changes had to be made to the printhead setup.

6 3D printer setup

This chapter describes in detail the printer setup and the small adjustments and changes that had to be made in order to be able to print the rubber and nylon mixture with the accuracy needed to get the desired result.

6.1 3D printer

The 3D printer chosen for this project is an UP 3D printer, see figure 2.2, that already has an existing printhead attached. This is removed in order to be able to attach the printhead designed for this project. Some slight adjustments need to be done when the old printhead is removed due to the fact that the UP printer software needs temperature feedback from the printhead to be able to print. In order to trick the software that the right printing temperature is reached a resistor is connected to the printhead plug in, see figure 6.1. The size of the resistor depends on what fabricated temperature is required. In this case it is a 200 Ω resistor that will create an infinite resistance that causes the software to believe that the maximum possible temperature is reached. The same thing is done to the platform, because of a malfunctioning heat cartridge to keep the platform heated. Once again a resistor is connected to the platform plug in, in order to create the illusion that it has reached the desired temperature. Furthermore, it is chosen to print a square to do the tests throughout the project. Because it is necessary to print a lot of tests, printing a small square is time efficient because of its simple form. However, it will still be enough in order to examine the outcome of the printed parts.

Figure 6.1 Resistance plugged in to 3D printer

6.2 Mount

The printhead was initially mounted to the printer in a way that the software did not agree with. The software only allows the nozzle to start at a height in between 125-145 millimeters above default level of the platform. A new mount was created to heighten the printhead from 80 millimeters to 130 millimeters above default level. The mount is a five-centimeter long aluminum piece with holes in both ends, see figure 6.2. It is a simple construction that was only used for the first tests when the speed of the auger and temperature were determined. It quickly proved after the first tests that the torque caused by the heavy printhead was too much and the construction was too unstable, causing the mount to rotate around its own axis. A new mount had to be designed in order to improve the accuracy of the tests. It is made out of nylon and has two holes on the top to avoid any rotation, and a cavity near the bottom where the 3D printer is to be attached. The new redesigned mount can be seen in figure 6.3.

Figure 6.2 First mount

Figure 6.3 Second mount

6.3 Calibration of platform

After installing the new mount, it was necessary to calibrate the platform, which has to be leveled in order for the extruded material to stick to the surface. The first tests showed that nylon does not stick very well to the existing plastic platform and double sided tape was added, see figure 6.4.

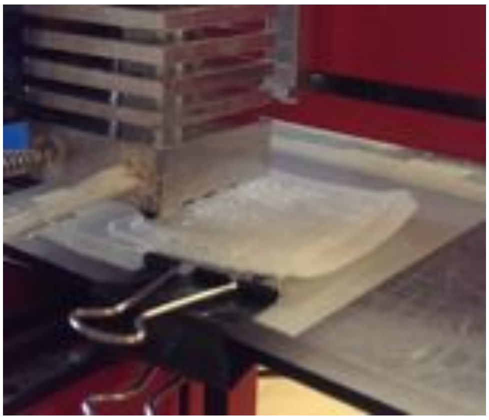

Figure 6.4 Platform with double sided tape

This increased the adhesiveness substantially. However, there were still some problems with curled up edges that was probably due to an unleveled platform. Fine adjustments were made to get the platform as leveled as possible. Unfortunately, there were still some remaining problems with the edges and it could also be noticed that the warmer the process the more curling of the edges would appear. The double sided tape was instead replaced by veroboard to notice if it would make any changes of the adhesiveness. It proved to be a success due to the fact that the extruded material is pierced in to the holes of the veroboard with a result of no curled edges as can be seen in figure 6.5.

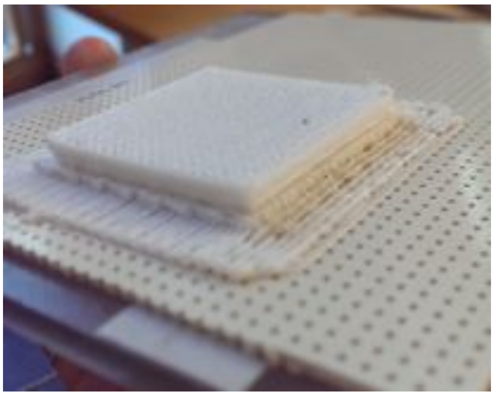

Figure 6.5 Platform with veroboard

6.4 Settings of auger speed, temperature and fan

There are three components that can be altered to get the right settings and have a great impact of the extruding process. The auger speed is controlled by the DC motor that has a power of 24 V. However, with the power supply used it is only possible to obtain 20 V for the DC motor which shows to be enough for the extrusion rate when combining with increased temperatures. The temperature should be approximately 200 °C to obtain an optimal extrusion rate. The temperature setting is explained further in 6.5. In order to reach these temperatures, the fan has to be set to around 7-8 V out of its 12 V maximum.

6.5 Temperature setting

A few tests had to be carried out to decide in what temperature range nylon could be printed. Some extrusion was possible at low process temperatures, approximately 170-180 °C, however the extrusion rate was too slow to be able to 3D print anything of use. To make sure what the optimal temperature setting is six different samples were printed in a range that was believed to be feasible. Starting at 190 °C with a five-degree increase for every sample up to 215 °C. The test results can be seen in figure 6.6-6.11.

Figure 6.6 Sample 1

Figure 6.7 Sample 2

Figure 6.8 Sample 3

Figure 6.9 Sample 4

Figure 6.10 Sample 5

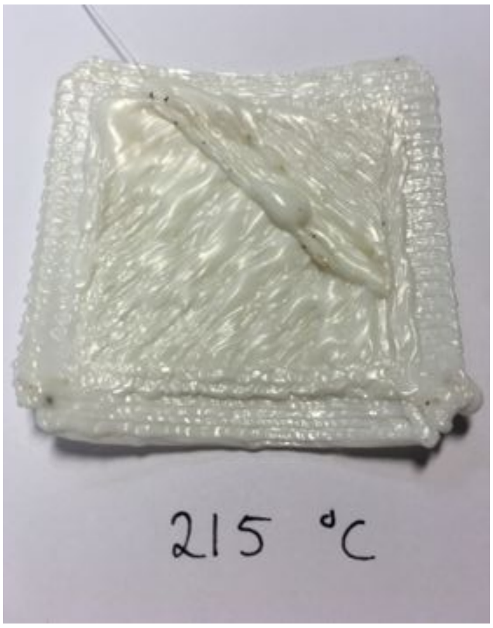

Figure 6.11 Sample 6

Sample 1 and 2 shows tendancies of an extrusion rate that is too slow. When this happen the printhead will move too quickly compared to how much material is extruded and will lead to a sparse and unfinished structure of the 3D printed samples, as can be seen in figure 6.6 and 6.7. On the other hand, if the temperature is too high the nylon will melt too much, ruining the structure of the sample as can be seen in figure 6.9-6.11. From what these samples show, the optimal temperature appears to be around 200°C, that can be seen in figure 6.8. The structure of this sample is resembling the 3D modeled part. Furthermore, as 200°C appears to be the best temperature for printing nylon, it is assumed that the same goes for rubber and nylon, since the rubber is unaffected by the heat applied. If this appears to be wrong, new temperature tests have to be carried out with a rubber and nylon mixture.

7 Material combination

The goal of the project and the tests made to reach that goal is described further in this chapter.

7.1 Ratio of rubber and nylon

The goal of this project is to create a material combination of rubber and nylon that can be 3D printed, preferably using as much rubber as possible, since this will help to decrease the shrinkage impact of the plastic added. To determine whether this is plausible and how much rubber is possible to add it is decided to do a few samples of different mixtures. The ratios are chosen based on that it is desirable to add as much rubber as possible, and if less than 50% rubber is used it is believed that the impact from plastic will be too big. Hence it is decided to start with 50% rubber and 50% nylon in volume and for every sample increasing the rubber 10% in volume. Since rubber powder has lower density than nylon powder the weight ratio, when equal volume parts, can be estimated to 27% rubber powder and 73% nylon powder.

The different samples can be seen in figure 7.1-7.3

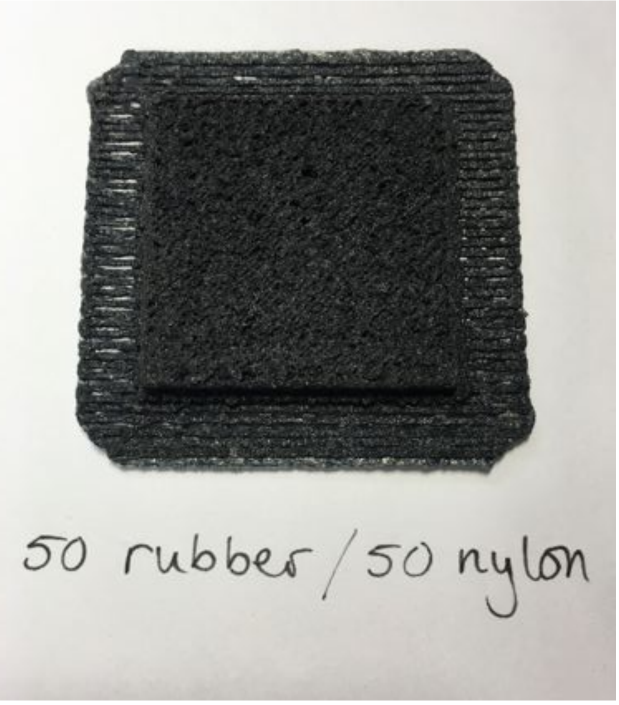

Figure 7.1 Sample A

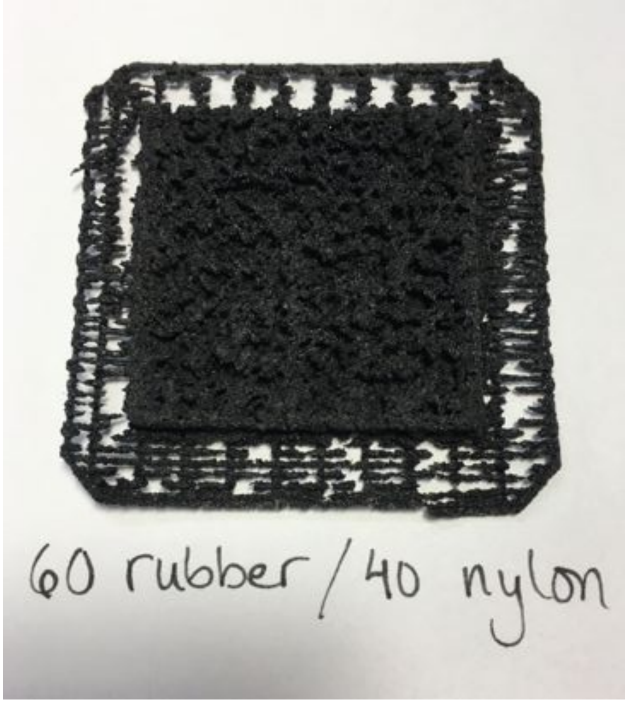

Figure 7.2 Sample B

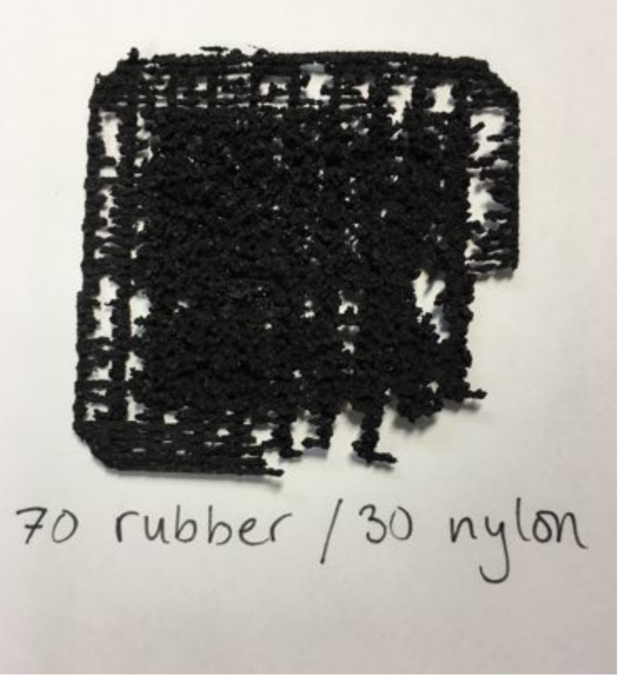

Figure 7.3 Sample C

As is evident, the only adequate sample is the first one, sample A. The two others fail to encapsulate the rubber powder causing the samples to crumble. It was also verified that the printing temperature was sufficient based on a visual examination of the structure of the 3D printed parts. With this result, no other tests were carried out with different ratios of rubber and nylon. However, it is important to verify that it is possible to use 50% rubber and 50% nylon, consequently, more samples had to be printed with these proportions. The results can be seen in figure 7.4-7.8.

Figure 7.4 Test 1

Figure 7.5 Test 2

Figure 7.6 Test 3

Figure 7.7 Test 4

Figure 7.8 Test 5

The tests show no sign of vary a lot from sample to sample and it is possible to make the assumption that using 50% rubber and 50% nylon and printing it at 200 °C will give the desired result. A cross section view of test 5 can be seen in figure 7.9. This cross section displays that the different layers stick to each other as wanted.

Figure 7.9 Cross section of test 5

8 Final results

In this chapter the final results of the thesis will be displayed, starting with the 3D printer setup, chosen temperature and lastly, what ratio of material that is optimal.

8.1 Creating a rubber powder

Creating a rubber powder proved to be fairly inefficient and time consuming, but enough powder was extracted when using an angle grinder to pulverize the tire that had been cut up into smaller pieces.

8.2 3D printer and printhead setup

The 3D printer itself only needed some slight adjustments. First of all, the existing printhead plug-in and the platform had to be tricked by a resistance that let it believe that the optimal temperature was reached, see figure 8.1.

Figure 8.1 Resistance plugged in to 3D printer

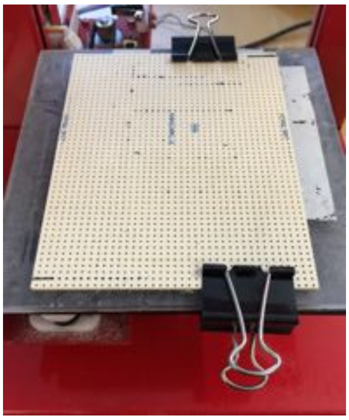

Figure 8.2 Veroboard

Secondly the existing plastic platform had to be changed to a veroboard in order for the extruded material to stick, see figure 8.2.

The challenging part was to create a printhead that was suitable for powder material. To avoid any material from getting stuck in the hopper, the inner walls were slanted towards the middle and a feeder was attached to the side to be able to feed the material, see figure 8.3. A fan was added to avoid the hopper to melt. A mount for the printhead was designed in order for the printhead to be raised five centimeters. The aluminum extruder has two holes at the lower part for insertion of temperature sensor and heat cartridge, see figure 8.4. The assembled printhead can be seen attached to the 3D printer in figure 8.5.

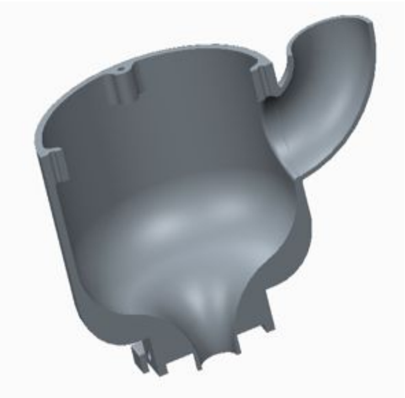

Figure 8.3 Cross-section of hopper

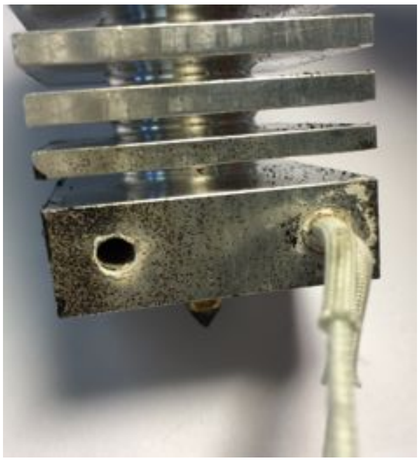

Figure 8.4 Holes for heat cartridge and temperature sensor

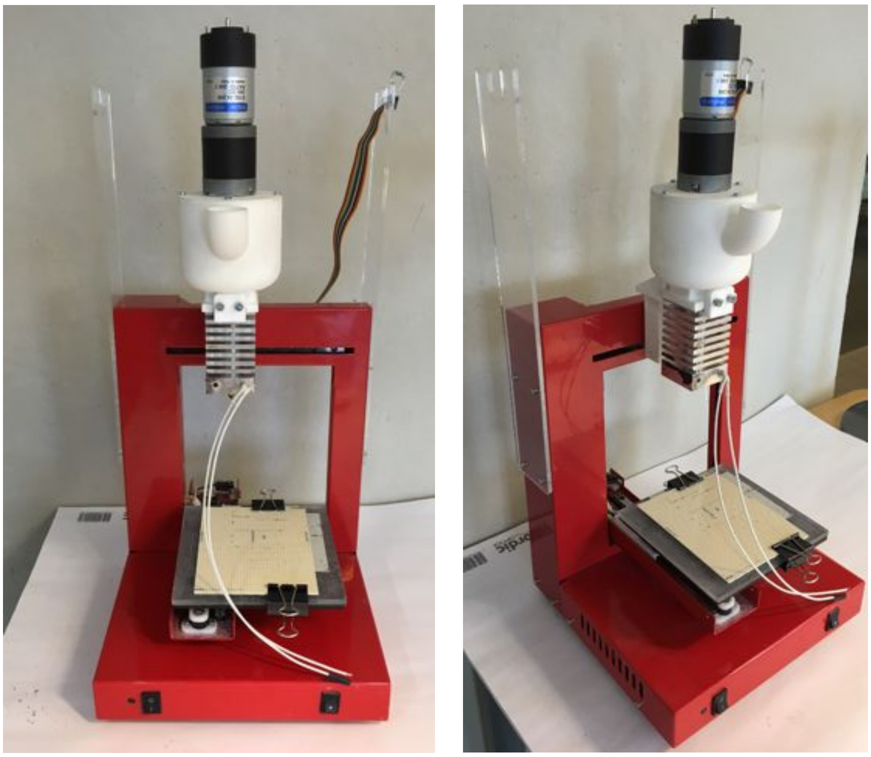

Figure 8.5 Printhead attached to 3D printer

8.3 Temperature

The optimal temperature to print at was estimated to approximately 200 °C, the result of printed nylon at this temperature can be seen in figure 8.6.

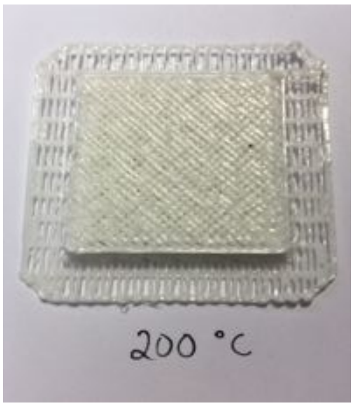

Figure 8.6 Sample 3

8.4 Material combination

Finally, the ratio of rubber and nylon powder was investigated and it was proven that the best results were obtained when the volume parts of nylon and rubber were equal. This corresponds to 27% rubber powder and 73% nylon powder when weighted. The result can be observed in figure 8.7. Consequently, the results of the project proved to be successful and it is possible to say that printing with nylon and rubber can be done. Hence, the goal of this project has been reached, and it has been shown that the bigger project, of implementing this in the favelas, is feasible and therefore it is possible to continue with this project. However there is a lot more that needs to be done and it is necessary to improve the different steps of the process to be able to implement it in the favelas. The goal of this thesis was only to show if the material could be printed or not, which was successful.

Figure 8.7 Final result

9 Discussion and future work

The discussion aims to clarify any uncertainties and changes that have been made along the way. It is also the section where it is possible to read more about why certain decisions were made and what kind of outcomes these decisions created. Furthermore, examples of future work are also presented in this chapter.

9.1 Scope of thesis

The scope of the thesis was slightly changed during the process. Initially the focus was to observe how the shrinkage of the plastics would affect the 3D printed parts and if the rubber was to prevent any impact of shrinkage tendencies. However, as designing the printhead proved to be more time consuming than expected the scope was altered, and instead it was decided to focus on finding a sufficient material combination of rubber and nylon.

9.2 Method

The method for the project was initially quite straightforward. However, a few changes occurred along the way that was not accounted for in the beginning. A few more steps were added to the process later on such as setting up the actual printer. This did not interfere with the work process more than it extended the time schedule for the project.

9.3 Choice of materials

It is not necessary to limit the filling material to rubber that was chosen due to its economic and ecological advantages. Any other material that has the same characteristics regarding the absence of shrinking and expanding when exposed to heat should be possible to use. Sand, glass, ceramics and even textile are materials with those characteristics and therefore might be an alternative to rubber. Due to the time limit of the project there was not enough time to test with these materials, but it is interesting to have in mind that there are other materials that can be used if rubber is not available or if different characteristics with the final material is wanted.

The process of extracting rubber powder from tires was not focused on in this project, but it might be a good idea to develop an easier and better way to do this. To do so would hopefully save a lot of time and eliminate the problem of clogging the nozzle. It is also necessary to find a way to process the recycled plastic just like the rubber, so it can be easy to use.

Something that is also outside the scope, is considering the health issues associated with rubber tires. However, it is interesting just to mention a few words about it, since this thesis is focused on sustainability. When using or processing tires they emit benzo(a)pyrene which is highly carcinogenic. Studies also show that chemicals are released in rubber mats in playgrounds that are made out of recycled rubber tires. These chemicals can cause irritation of the lungs, skin and eyes, etcetera. The chemicals are emitted when humans or objects scratch the surface of the flooring. In other words, rubber tires are not only sensitive to heating but also to wear and tear [12]. This information might question the use of tires for products that are exposed to human contact. Even though the emissions are not higher than emissions from tires when driving a car, it might still be of interest to find an alternative for rubber tires to use as a filling material.

On the up side though, is that the softening oils that contain these polycyclic aromatic hydrocarbons have been banned in the European Union [8]. If rubber tires are to be used it is possible to use tires manufactured in the EU after. Again, this might interfere with the purpose of the project. It is safe to say that using tires manufacture in Europe will be far more expensive and less eco-friendly than using local discarded tires, due to the need of transport.

9.4 Printhead design and setup

The design and creation of the printhead required more time than expected. First of all, the hopper, hopper lid and coupling had to be designed to fit the motor used. In order to do so I had to upgrade my CAD skills, something that I had not accounted for when planning the process. When done with the new design there was also some waiting time to 3D print my parts. Unfortunately, the hopper lid and coupling had to be redesigned and 3D printed again due to the fact that a different, more powerful motor was to be used instead.

After some first tests with extruding nylon it was possible to see that it was difficult to reach any higher temperatures than 195 °C. This was probably due to the fact that the hole for the heat cartridge was not snug enough. Hence, some changes were made to the aluminum extruder, that however, created a little mishap and a new extruder had to be made. The heat cartridge was also damaged along the way and a new similar cartridge had to be ordered. All these setbacks of course delayed the project a bit, but nothing too troublesome.

Some problems regarding the temperature accuracy were discovered. One was the actual reading of the temperature. It is not certain that the placement of the temperature sensor is optimal and it is not certain that the read temperature is representing the process temperature closer to the auger. So if design changes of the extruder are to be made it is important to bear in mind that the optimal process temperature presented in this thesis might be altered. A second problem was discovered with the temperature when using the on/off relay in the temperature controller. When the preset temperature was reached and the relay switched off, the temperature immediately dropped approximately 11°C leading to a decrease in the extrusion rate. I could not see any immediate changes to the parts that were 3D printed, but I was only printing squares and if greater accuracy is required this might well be a problem. It is possible to instead use the PID setting on the temperature controller to obtain a smoother temperature curve, something that is worth investigating further.

Some design flaws were discovered during the project. Even though the hopper was designed with slanted inner walls, it proved to be too much friction between the added material and the hopper. The feeding hole could have also been made bigger, there were some difficulties with adding the material without spilling, and the blender attached to the coupling could have been made longer since there was plenty of room inside the hopper. It would definitely be an idea to improve the hopper for future work as it is quite easily done and will make the execution of the tests easier.

Lastly, there was a problem with the auger getting stuck in the extruder due to the nylon that solidified when no more heat was applied, see figure 9.1.

Figure 9.1 Auger stuck in extruder

Consequently, this complicated the cleaning process. Cleaning the extruder was necessary whenever the process temperature needed to be lower than the latest temperature. For example, if a test was carried out with a process temperature of 205 °C, this would cause the nylon to melt to a certain level in the hole where the auger was placed, reaching higher levels in the hole, when more heat was applied. When the heat was removed the nylon would solidify, see figure 9.2.

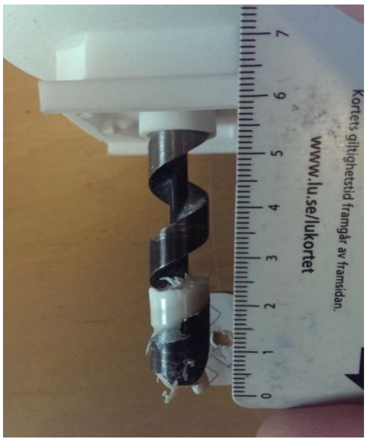

Figure 9.2 Solidified nylon

If a test with lower process temperature than 205°C was required after that, the applied heat would not be able to melt all of the stiffened nylon, thus the auger would get stuck and the extrusion rate would be drastically impeded. Hence, cleaning of the auger was required quite often and it would be worth the while to figure out how to make that process easier. A similar problem was that the auger got stuck even though it had been cleaned and the process temperature was constant. This especially occurred when rubber powder was added. The more rubber that was added the more frequent the interruptions. One theory might be that the friction from the rubber was too much for the motor to handle, but also that there were occasionally larger grains of rubber added that wedged the auger. However, this problem was not very prominent when using 50/50 of rubber and nylon, hence, no solution to the problem was deemed needed.

9.5 Initial testing

During the first tests with nylon the process temperature was increased to almost 220°C. This proved to be too warm for the hopper and consequently caused the mount and minor parts of the hopper to melt. The same happened if the fan was set too low or period wise was switched off. The heat would then transfer too quickly in the extruder without any chances of cooling it off.

As has been mentioned before a kitchen sieve was used to filter the rubber powder. A better sieve with exact measurements could have been used in order to get rid of all grains bigger than one millimeter. If better accuracy is required I would definitely recommend investing in a new one.

9.6 3D printer setup

The printhead that was attached to the UP 3D printer proved to be slightly too heavy for the printer. The weight from the printhead caused disturbances during printing and it was hard for the printhead to keep up with the printing rate and the rapid changes of direction. This caused the printhead to wobble and momentarily dislocate the nozzle. However, the printed results were deemed accurate enough for this thesis, but it might be a good idea to look into other 3D printer models to find one that can handle the weight of the printhead or on the other hand, find a way to decrease the weight of the printhead.

Furthermore, it is mentioned earlier that a resistor is used to trick the printer software that the correct temperature of the platform has been reached. This was done due to the fact that the heat cartridge for the platform was out of order. It would have been preferred to heat the platform, since this would have stopped the edges of the printed material from curling up. This is why an alternative, the veroboard, had to be used. Note that this only concerns the platform. The resistor used to trick the printhead is still needed.

9.7 Material combination

Initially it was believed that more rubber than nylon could be used in the mixture. This proved to be wrong as the ratio ended up being 50/50. However, tests with 51-59% rubber in the mixture were never done, and it might be worth the while to investigate, since it is better from a recycling point of view if more rubber is used. It might also be possible to use more rubber powder if a finer powder can be obtained or if a stronger motor is used.

9.8 Final results

Due to time restrictions there was not enough time to test with different sorts of plastics, but since they have different characteristics it is worth noting that the process of finding a material combination might be altered. For example, it is most likely that the process temperature will be different since different plastics have different melting temperatures.

No tests have been done on the actual material. For example, it is necessary to make sure if the material is suitable for printing sewage pipes or parts for houses. To do so there are a lot of requirements that need to be fulfilled, for example if the material is water permeable or firm enough to build spare parts for houses, just to mention a few.

9.9 Time schedule

The time frame for the project ended up being a bit longer than expected, the original and the revised version can be seen in appendix B. This has mainly to do with the fact that the printhead design process was prolonged. Also a few more steps had to be added to the time schedule that was not initially accounted for, such as installing the temperature controller, redesigning the printhead and performing temperature tests on nylon. Unfortunately, there was no time to print prototypes to show for the applications of the material. This shows how difficult it is to plan a project in advance, and that it is important to plan ahead for any unexpected events so you do not fall behind.

9.10 Future work

The suggestions for future work have been mentioned above and it is obvious that this project is only the start of a bigger one. A short summary of the detected areas where improvements can be done are:

- Improving the process of extracting rubber powder.
- Improving the design of the printhead.
- Finding a suitable 3D printer that can be used further on.
- Finding a way to extract plastic powder out of recycled plastics.
- Investigate other materials that can be a supplement to rubber.
- See what shrinkage impact recycled plastic will have when heated.
- Investigate what health impacts rubber has on human health.
- Printing prototypes to see what the material can be used for.

As is evident there are a lot of improvements can be done and there is a lot of research to do before this project can be implemented in the favelas. I also think it is important to follow up, because if this project proves to be successful, I believe that this material can be used in other similar places to the favelas, but also as a way of recycling rubber in the western world where there currently are few options to do so.

9.11 Self-evaluation

Generally, I would say that I am satisfied with the results of the thesis and the work that I have done throughout the process. However, there have been a few minor bumps in the road along the way. I have been dependent on others to help me with parts of my project that I might have been able to do myself. For example, when a new aluminum extruder had to be made I could probably have done it myself, but instead I had help from another person, hence a lot of time was wasted waiting for spare parts to be finished.

Something I would have done differently is the planning of the project. This is due to the fact that the design and making of the printhead was far more time consuming than I anticipated. If I would have known in the beginning of the project, I would have reserved more time for the actual planning and designing of the printhead. It would hopefully have saved me some time in the end and not forcing me to redesign and make useless parts in vain. However, this also taught me that it is a lot harder to plan a big project ahead and that you will always encounter something unexpected.

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Image references

Figure 2.1 Design Thinking Metodology, January 12, 2016.
http://designthinkingmethodology.weebly.com/methodologies.html

Figure 2.2 Resins online, January 12, 2016.
http://www.resins-online.com/learning-zone/3d-printing/

Figure 3.2 Hankook Driving Emotion, Structure of Tires, January 12, 2016.
http://www.hankooktire.ca/Tech/Structure.php?pageNum=5&subNum=3&ChildNum=4

Appendix A: E-mail references

A.1 E-mail from Tommy Edeskär [8]

Hej Charlotta!

Jag kan inte ge ett uttömmande svar på din fråga för just upphettning till 200 grader men kan kanske ge lite ledning ändå. Vid tillverkning av gummimodifierad beläggning hettar man upp gummigranulat från däck till åtminstone 165-175 grader. Och för det finns det undersökningar gjorda. Det rekommenderas inte att hetta upp gummit över 175 grader för att det påverkar egenskaperna negativt för användning i beläggningar. Det finns inga undersökningar på upphettning av enbart granulat utan bara på blandningarna av gummigranulat och bitumen:

- Den totala mängden kolväten som avgår vid upphettning med däckgranulatinblandning minskar

- Det har påvisats en ökning av avgång från benso(a)pyren (PAH)

Den uppmätta halten av bensoa)pyren ligger nära det hygieniska gränsvärdet. Vid normal utspädning i luft minskar den. Inga speciella försiktighetsåtgärder vidtas idag för att arbeta med gummimodifierad bitumen eftersom de hygieniska gränsvärdena inte överstigs. Avgången av benso(a)pyren beror troligen på kvaliteten av gummigranulaten. Ett sätt att hantera det är att köpa in däckgranulat som tillverkas av däck insamlade inom EU (helst norden) eftersom vi fasat ut HA-oljor i EU.

Hälsningar

Tommy

Ursprunglig fråga:

Hej!

Mitt namn är Charlotta och jag håller just nu på att skriva mitt examensarbete på Lunds Tekniska Högskola. Mitt projekt går ut på att återanvända gamla däck för att kunna göra ett nytt material att använda för 3D skrivare. De återanvända däcken kommer att värmas upp till temperaturer kring 200 grader och det kanske är något långsökt, men jag undrar helt enkelt om ni har någon kunskap om vad som händer när man värmer upp däcken till dessa temperaturer. Jag tänker främst på om det på något sätt är skadligt och om det frigörs gifter vid uppvärmningen.

Tack för er tid.

Med vänliga hälsningar,
Charlotta Engstrand

A.2 E-mail from Katarina Elner-Haglund [10]

Hej Charlotta!

Polyamidprodukter har en max kontinuerlig användningstemperatur på 120 grader C och en kortvarig topptemperatur på 180 grader C. All uppvärmning innebär nedbrytning.

Vid exvis formsprutning värms granulaten till smälta och cylindertemperaturen ligger då runt 280 grader, men smältan har givetvis betydligt lägre temperatur under förloppet. Det gäller att tillföra precis exakt så mycket energi att plasten smälter så den kan formas, men inte mer för då bryts materialet ner onödigt mycket...

Nedbrytningsprodukter är exvis kväveoxider, koloxid, koldioxid. Dessa är inte nyttiga, men klassas inte heller som hälsofarliga.

Häls
/Katarina

Ursprunglig fråga:

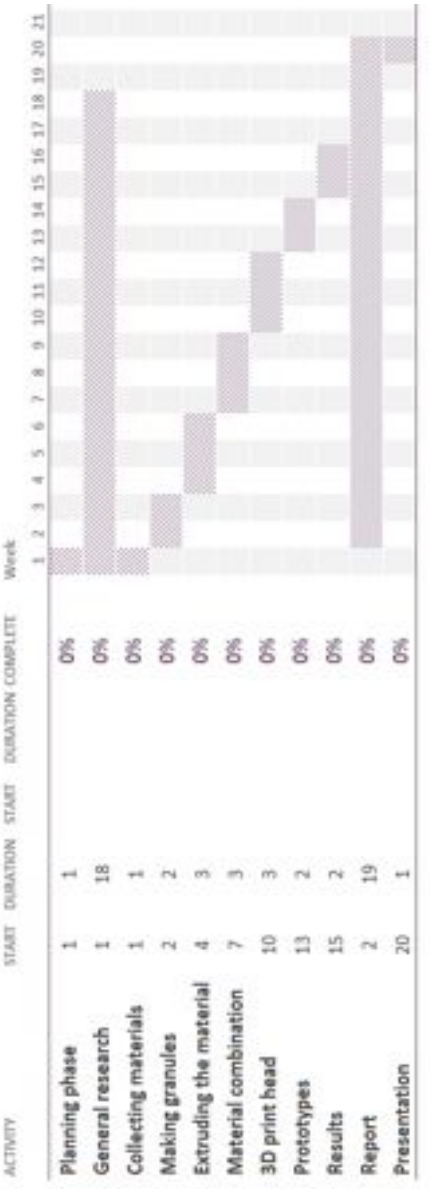
Hej Katarina!

Jag håller på att skriva mitt examensarbete här på institutionen där jag bland annat 3D skriver med nylon. Jag undrar helt enkelt om du vet vad som händer med nylon när man smälter det? Jag tänker främst på om det avger farliga ämnen när man värmer det till runt 200-250 grader celsius.

Med vänliga hälsningar Charlotta Engstrand

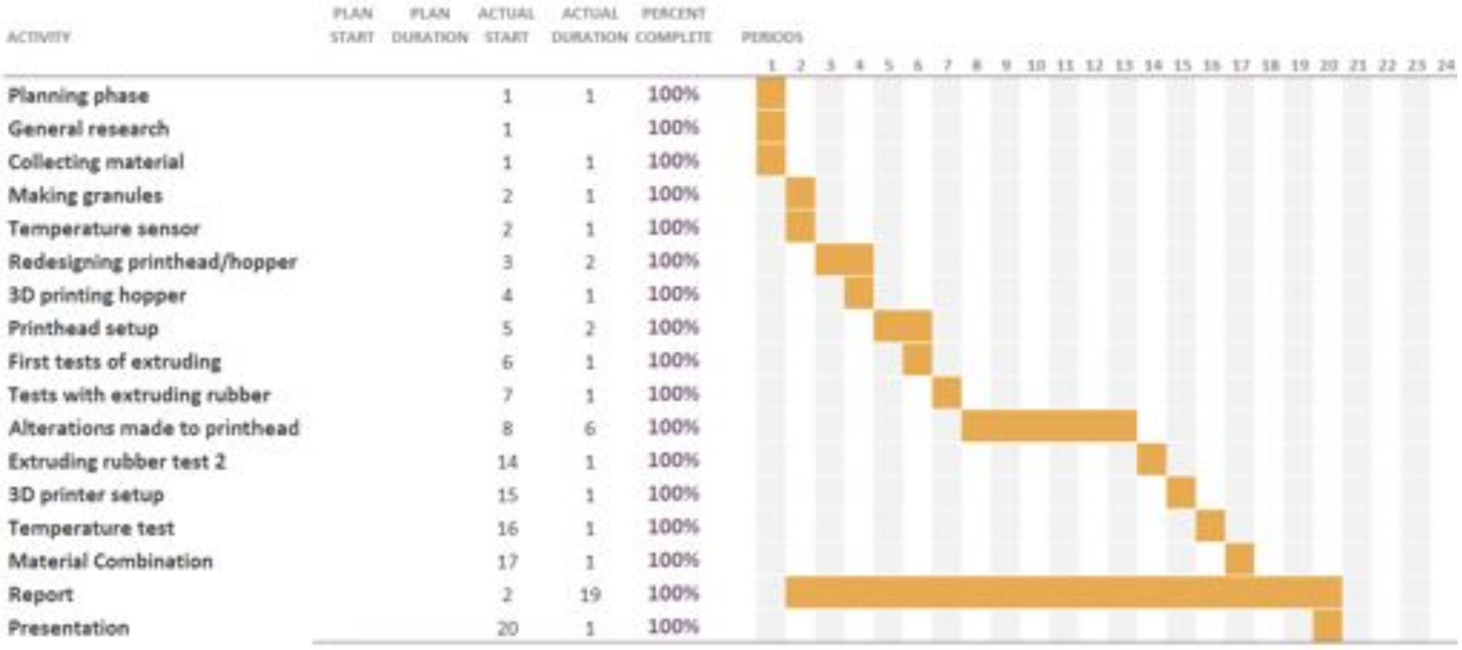
Appendix B: Time schedule

B.1 Intended time schedule



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Planning phase	1	1			0%	▨																				
General research	1	18			0%	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
Collecting materials	1	1			0%	▨																				
Making granules	2	2			0%		▨	▨																		
Extruding the material	4	3			0%				▨	▨	▨															
Material combination	7	3			0%							▨	▨	▨												
3D print head	10	3			0%										▨	▨	▨									
Prototypes	13	2			0%													▨	▨							
Results	15	2			0%															▨	▨					
Report	2	19			0%		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Presentation	20	1			0%																				▨	

B.2 Revised time schedule



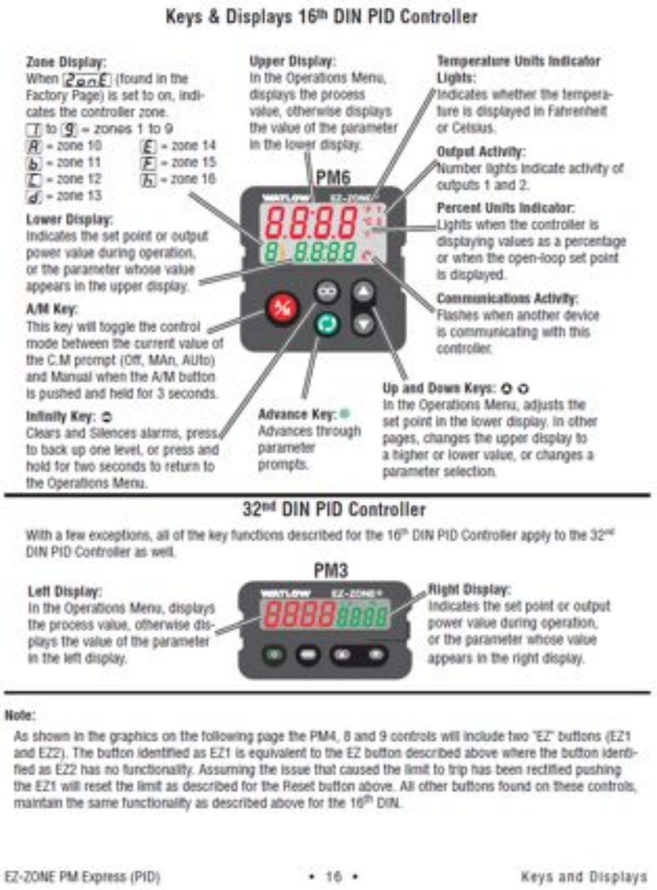
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	PERIODS																							
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Planning phase			1	1	100%	🟧																							
General research			1		100%	🟧																							
Collecting material			1	1	100%	🟧																							
Making granules			2	1	100%		🟧																						
Temperature sensor			2	1	100%		🟧																						
Redesigning printhead/hopper			3	2	100%			🟧	🟧																				
3D printing hopper			4	1	100%				🟧																				
Printhead setup			5	2	100%					🟧	🟧																		
First tests of extruding			6	1	100%						🟧																		
Tests with extruding rubber			7	1	100%							🟧																	
Alterations made to printhead			8	6	100%								🟧	🟧	🟧	🟧	🟧	🟧											
Extruding rubber test 2			14	1	100%														🟧										
3D printer setup			15	1	100%															🟧									
Temperature test			16	1	100%																🟧								
Material Combination			17	1	100%																	🟧							
Report			2	19	100%		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧				
Presentation			20	1	100%																				🟧				

Appendix C: User’s guide

C.1 User’s guide for temperature controller

Note that this is not the complete user’s guide. Only pages that seem necessary for understanding the functions used in this project are attached. The settings used are:

- Sensor type, set to tC
- Linearization set to J
- Display units, set to °C
- Heat algorithm, set to on/off
- Hysteresis, set to 2 °C



Keys & Displays 16th DIN PID Controller

Zone Display:
When ZonE (found in the Factory Page) is set to on, indicates the controller zone.
1 to 9 = zones 1 to 9
A = zone 10
b = zone 11
C = zone 12
d = zone 13
E = zone 14
F = zone 15
h = zone 16

Lower Display:
Indicates the set point or output power value during operation, or the parameter whose value appears in the upper display.

A/M Key:
This key will toggle the control mode between the current value of the C.M prompt (Off, MAn, AUto) and Manual when the A/M button is pushed and held for 3 seconds.

Infinity Key: ⊖
Clears and Silences alarms, press to back up one level, or press and hold for two seconds to return to the Operations Menu.

Upper Display:
In the Operations Menu, displays the process value, otherwise displays the value of the parameter in the lower display.

PM6

Advance Key: ●
Advances through parameter prompts.

Temperature Units Indicator Lights:
Indicates whether the temperature is displayed in Fahrenheit or Celsius.

Output Activity:
Number lights indicate activity of outputs 1 and 2.

Percent Units Indicator:
Lights when the controller is displaying values as a percentage or when the open-loop set point is displayed.

Communications Activity:
Flashes when another device is communicating with this controller.

Up and Down Keys: ○ ○
In the Operations Menu, adjusts the set point in the lower display. In other pages, changes the upper display to a higher or lower value, or changes a parameter selection.

32nd DIN PID Controller

With a few exceptions, all of the key functions described for the 16th DIN PID Controller apply to the 32nd DIN PID Controller as well.

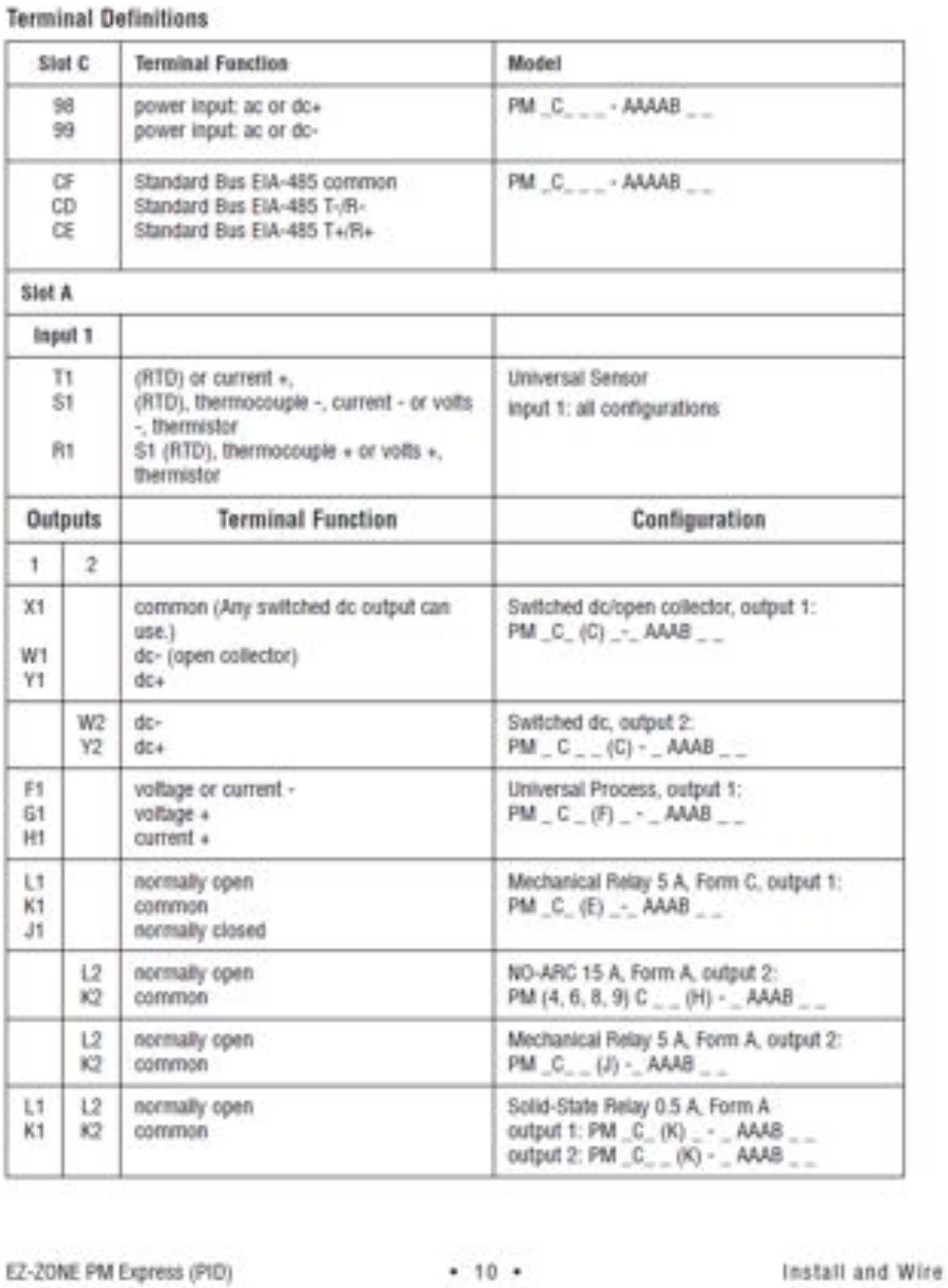
PM3

Left Display:
In the Operations Menu, displays the process value, otherwise displays the value of the parameter in the left display.

Right Display:
Indicates the set point or output power value during operation, or the parameter whose value appears in the right display.

Note:
As shown in the graphics on the following page the PM4, 8 and 9 controls will include two "EZ" buttons (EZ1 and EZ2). The button identified as EZ1 is equivalent to the EZ button described above where the button identified as EZ2 has no functionality. Assuming the issue that caused the limit to trip has been rectified pushing the EZ1 will reset the limit as described for the Reset button above. All other buttons found on these controls, maintain the same functionality as described above for the 16th DIN.

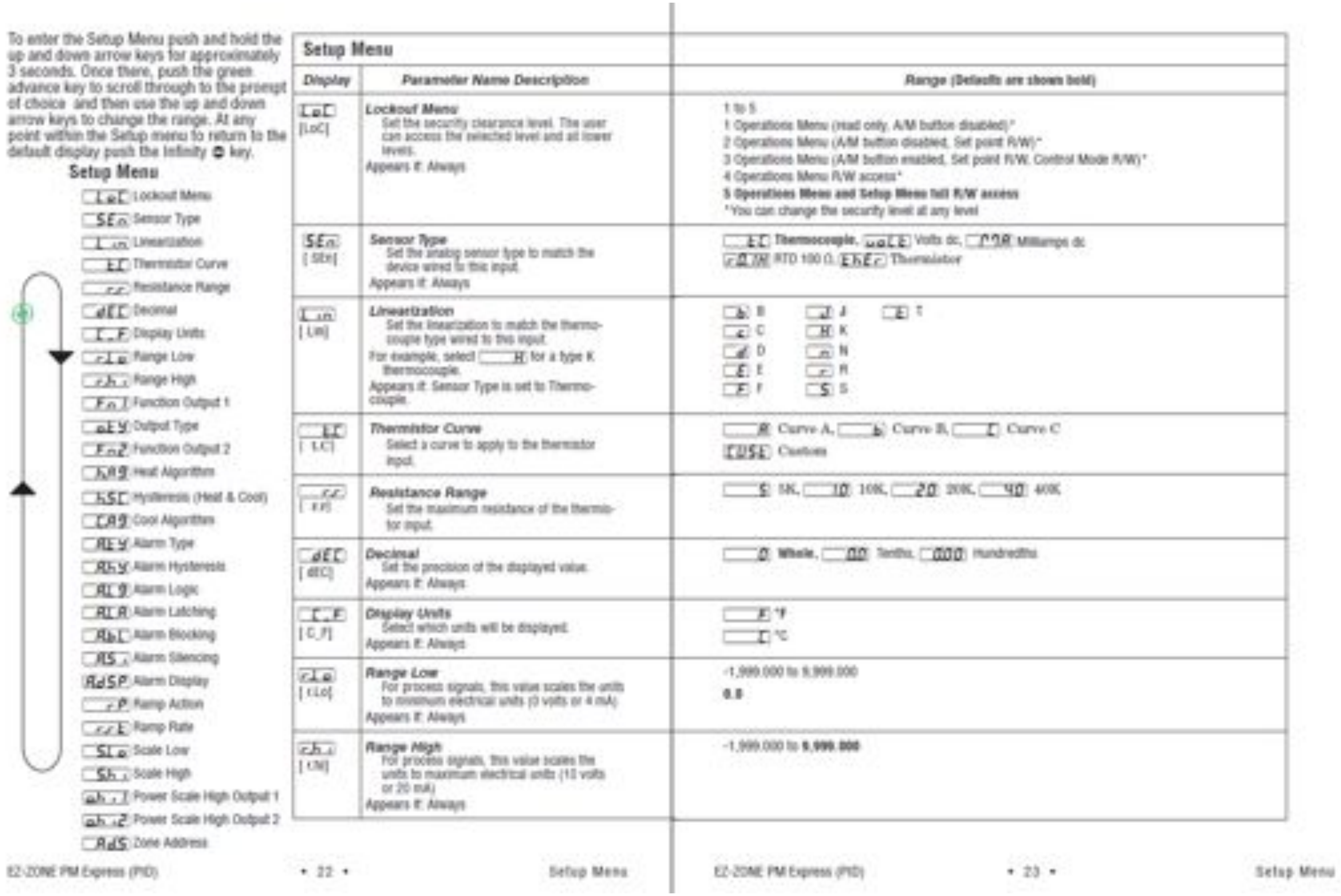
EZ-ZONE PM Express (PID) • 16 • Keys and Displays



Terminal Definitions

Slot C		Terminal Function	Model
98 99		power input: ac or dc+ power input: ac or dc-	PM _C_ _ _ - AAAAB _ _
CF CD CE		Standard Bus EIA-485 common Standard Bus EIA-485 T-/R- Standard Bus EIA-485 T+/R+	PM _C_ _ _ - AAAAB _ _
Slot A			
Input 1			
T1 S1 R1		(RTD) or current +, (RTD), thermocouple -, current - or volts -, thermistor S1 (RTD), thermocouple + or volts +, thermistor	Universal Sensor input 1: all configurations
Outputs		**Terminal Function**	**Configuration**
1	2		
X1 W1 Y1		common (Any switched dc output can use.) dc- (open collector) dc+	Switched dc/open collector, output 1: PM _C_ (C) _-_ AAAB _ _
	W2 Y2	dc- dc+	Switched dc, output 2: PM _ C _ _ (C) - _ AAAB _ _
F1 G1 H1		voltage or current - voltage + current +	Universal Process, output 1: PM _ C _ (F) _ - _ AAAB _ _
L1 K1 J1		normally open common normally closed	Mechanical Relay 5 A, Form C, output 1: PM _C_ (E) _-_ AAAB _ _
	L2 K2	normally open common	NO-ARC 15 A, Form A, output 2: PM (4, 6, 8, 9) C _ _ (H) - _ AAAB _ _
	L2 K2	normally open common	Mechanical Relay 5 A, Form A, output 2: PM _C_ _ (J) -_ AAAB _ _
L1 K1	L2 K2	normally open common	Solid-State Relay 0.5 A, Form A output 1: PM _C_ (K) _ - _ AAAB _ _ output 2: PM _C_ _ (K) - _ AAAB _ _

EZ-ZONE PM Express (PID) • 10 • Install and Wire



To enter the Setup Menu push and hold the up and down arrow keys for approximately 3 seconds. Once there, push the green advance key to scroll through to the prompt of choice and then use the up and down arrow keys to change the range. At any point within the Setup menu to return to the default display push the Infinity ⊜ key.

Setup Menu

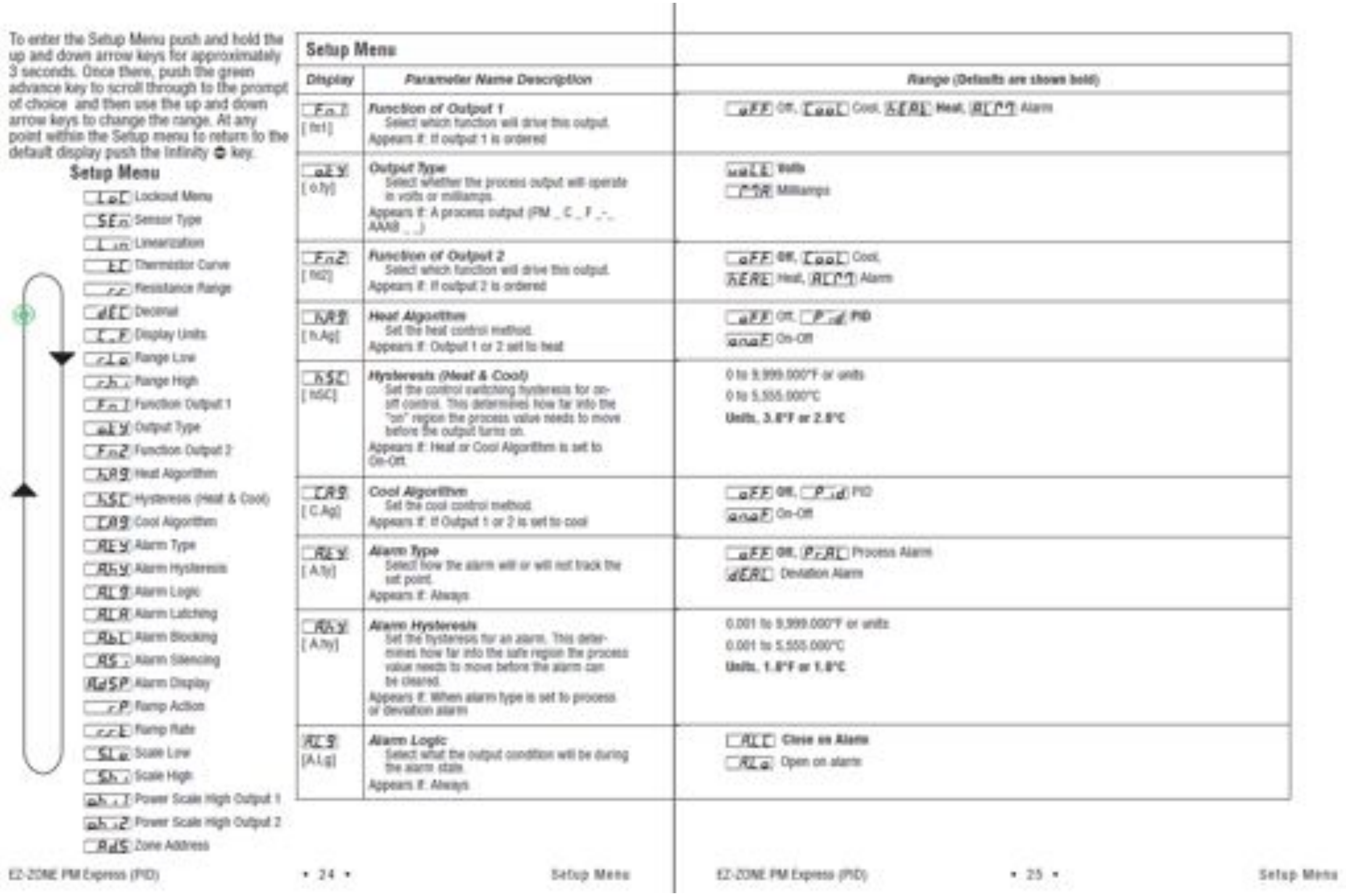
LoC Lockout Menu
SEn Sensor Type
Lin Linearization
t.C Thermistor Curve
r.r Resistance Range
dEC Decimal
C_F Display Units
rLo Range Low
rhi Range High
Fn1 Function Output 1
otY Output Type
Fn2 Function Output 2
hAg Heat Algorithm
hSC Hysteresis (Heat & Cool)
CAg Cool Algorithm
AtY Alarm Type
AhY Alarm Hysteresis
ALg Alarm Logic
ALA Alarm Latching
AbL Alarm Blocking
ASi Alarm Silencing
AdSP Alarm Display
rP Ramp Action
rrt Ramp Rate
SLo Scale Low
Shi Scale High
ohi1 Power Scale High Output 1
ohi2 Power Scale High Output 2
AdS Zone Address

EZ-ZONE PM Express (PID) • 22 • Setup Menu

Setup Menu

Display	Parameter Name Description	Range (Defaults are shown bold)
LoC [LoC]	*Lockout Menu* Set the security clearance level. The user can access the selected level and all lower levels. Appears if: Always	1 to 5 1 Operations Menu (read only, A/M button disabled)* 2 Operations Menu (A/M button disabled, Set point R/W)* 3 Operations Menu (A/M button enabled, Set point R/W, Control Mode R/W)* 4 Operations Menu R/W access* **5 Operations Menu and Setup Menu full R/W access** *You can change the security level at any level
SEn [SEn]	*Sensor Type* Set the analog sensor type to match the device wired to this input. Appears if: Always	tC **Thermocouple,** VoLt Volts dc, mA Milliamps dc r0.1H RTD 100 Ω, thEr Thermistor
Lin [Lin]	*Linearization* Set the linearization to match the thermocouple type wired to this input. For example, select H for a type K thermocouple. Appears if: Sensor Type is set to Thermocouple.	b B J J t T c C H K d D n N E E r R F F S S
tC [t.C]	*Thermistor Curve* Select a curve to apply to the thermistor input.	A Curve A, b Curve B, C Curve C CUSt Custom
rr [r.r]	*Resistance Range* Set the maximum resistance of the thermistor input.	5 5K, 10 10K, 20 20K, 40 40K
dEC [dEC]	*Decimal* Set the precision of the displayed value. Appears if: Always	0 **Whole,** 0.0 Tenths, 0.00 Hundredths
C_F [C_F]	*Display Units* Select which units will be displayed. Appears if: Always	F °F C °C
rLo [r.Lo]	*Range Low* For process signals, this value scales the units to minimum electrical units (0 volts or 4 mA) Appears if: Always	-1,999.000 to 9,999.000 **0.0**
rhi [r.hi]	*Range High* For process signals, this value scales the units to maximum electrical units (10 volts or 20 mA) Appears if: Always	-1,999.000 to **9,999.000**

EZ-ZONE PM Express (PID) • 23 • Setup Menu



To enter the Setup Menu push and hold the up and down arrow keys for approximately 3 seconds. Once there, push the green advance key to scroll through to the prompt of choice and then use the up and down arrow keys to change the range. At any point within the Setup menu to return to the default display push the Infinity ⊖ key.

Setup Menu

- LoC Lockout Menu
- SEn Sensor Type
- Lin Linearization
- tC Thermistor Curve
- rr Resistance Range
- dEC Decimal
- C_F Display Units
- rLo Range Low
- rhi Range High
- Fn1 Function Output 1
- oty Output Type
- Fn2 Function Output 2
- hAg Heat Algorithm
- hSC Hysteresis (Heat & Cool)
- CAg Cool Algorithm
- Aty Alarm Type
- Ahy Alarm Hysteresis
- ALg Alarm Logic
- ALA Alarm Latching
- AbL Alarm Blocking
- ASi Alarm Silencing
- AdSP Alarm Display
- rP Ramp Action
- rrt Ramp Rate
- SLo Scale Low
- Shi Scale High
- phi1 Power Scale High Output 1
- phi2 Power Scale High Output 2
- AdS Zone Address

Setup Menu

Display	Parameter Name Description	Range (Defaults are shown bold)
Fn1 [fn1]	***Function of Output 1*** Select which function will drive this output. Appears if: If output 1 is ordered	oFF Off, CooL Cool, hEAt **Heat**, ALM Alarm
oty [o.ty]	***Output Type*** Select whether the process output will operate in volts or milliamps. Appears if: A process output (PM _ C _ F _-_ AAA8 _ _)	volt **Volts** mA Milliamps
Fn2 [fn2]	***Function of Output 2*** Select which function will drive this output. Appears if: If output 2 is ordered	oFF **Off**, CooL Cool, hEAt Heat, ALM Alarm
hAg [h.Ag]	***Heat Algorithm*** Set the heat control method. Appears if: Output 1 or 2 set to heat	oFF Off, PId **PID** onoF On-Off
hSC [hSC]	***Hysteresis (Heat & Cool)*** Set the control switching hysteresis for on-off control. This determines how far into the "on" region the process value needs to move before the output turns on. Appears if: Heat or Cool Algorithm is set to On-Off.	0 to 9,999.000°F or units 0 to 5,555.000°C **Units, 3.6°F or 2.0°C**
CAg [C.Ag]	***Cool Algorithm*** Set the cool control method. Appears if: If Output 1 or 2 is set to cool	oFF **Off**, PId PID onoF On-Off
Aty [A.ty]	***Alarm Type*** Select how the alarm will or will not track the set point. Appears if: Always	oFF **Off**, PrAL Process Alarm dEAL Deviation Alarm
Ahy [A.hy]	***Alarm Hysteresis*** Set the hysteresis for an alarm. This determines how far into the safe region the process value needs to move before the alarm can be cleared. Appears if: When alarm type is set to process or deviation alarm	0.001 to 9,999.000°F or units 0.001 to 5,555.000°C **Units, 1.8°F or 1.0°C**
ALg [A.Lg]	***Alarm Logic*** Select what the output condition will be during the alarm state. Appears if: Always	ALC **Close on Alarm** ALo Open on alarm

EZ-ZONE PM Express (PID) • 24 • Setup Menu

EZ-ZONE PM Express (PID) • 25 • Setup Menu