FEED RATE EFFECTS ON FILAMENT EXTRUSION FOR FREEFORM FILAMENT FABRICATION

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ABSTRACT

Extrusion methods is one of the most commonly used in Fused Deposition Modeling (FDM), and remains one of the most versatile. This study focus on the feed rate effects on filament extrusion by experimental process that was conducted. For the first step, testing jig was built to ease the extrusion process is carried out. Testing jig was designed using the FDM extruder which have made a major component in this study. From the results of the filament extrusion was conducted, feed rate plays an important role for the smooth in extrusion process. The results obtained, the feed rate applied to drive the filament into the extruder head should be between 5 mm/s until 15 mm/s only. In addition, the temperature also plays an important role in ensuring that the extruded filament can exits with ease and smooth, while the size of the nozzle also affects the filament diameter based on the material used. From the entire results obtained, the validation has been carried to all the filaments being studied by determining the suitable temperature and feed rate speed for extrusion processes especially for use in Freeform Fabrication machine.

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ABSTRAK

Kaedah penyemperitan adalah salah satu kaedah yang biasa digunakan dalam *Fused Deposition Modeling* (FDM), dan menjadi salah satu kaedah yang pelbagai guna. Kajian ini memfokuskan kepada kesan yang berlaku terhadap kadar suapan *(feed rate)* pada proses penyemperitan filamen melalui proses eksperimen yang telah dijalankan. Pada permulaan kajian, peralatan ujikaji (*testing jig)* telah dibina untuk memudahkan proses penyemperitan dilakukan. *Testing jig* telah dibina dengan menggunakan penyemperit FDM *(FDM extruder)* dimana ia adalah komponen utama dalam kajian ini. Daripada keputusan yang telah diperolehi, kadar suapan memainkan peranan yang penting dalam melancarkan proses penyemperitan filament. Keputusan yang diperolehi, kadar suapan yang sesuai digunakan untuk memandu filamen ke dalam *extruder head* adalah 5 mm/s sehingga 15 mm/s sahaja. Di samping itu, suhu juga memainkan peranan yang penting dalam memastikan filament yang telah disemperit dapat keluar dengan mudah dan lancar, manakala saiz muncung *(nozzle diameter)* pula telah memberi kesan terhadap diameter filamen berdasarkan filament yang digunakan. Daripada keseluruhan keputusan yang diperolehi, pengesahan telah dijalankan kepada semua filamen yang dikaji iaitu ABS, HIPS, dan ABS + Copper dengan menentukan suhu dan kadar kelajuan suapan yang sesuai bagi proses penyemperitan terutama untuk digunakan dalam mesin fabrikasi bentuk bebas (Prusa i3 printer).

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Extrusion methods are one of the most usually used in Fused Deposition Modeling (FDM), and remains one of the most multipurpose. Extrusion Freeforming (EF) is the term that will be used to describe extrusion technologies that differ from FDM, which is trademarked by Stratasys. EF parts are built by depositing a small bead of softened polymer through an extrusion head onto a work platform. The nozzle (or platform) moves via computer control to put down a pattern on the platform. Complete parts are built by laying down successive patterns one layer at a time. Since the release of the original patent for FDM, sales of low cost extrusion based machines has increased dramatically. This has also lead to a corresponding growth in the number of vendors providing filament materials and a consequent drop in material prices. Due to the fact many different materials can be extruded through a nozzle, extrusion based Additive Manufacturing (AM) provides greater flexibility in producing multi-material parts and assemblies than powder based methods. However, FDM has a number of short comings when compared with other AM technologies. In particular, the build speed, strength and surface quality of FDM parts is lesser to Laser Sintering parts (Brajlih et al. 2011).

In the freeform filament extrusion process, softened polymer flows through a nozzle that is translated along a prescribed path over a build platform. The deposited material solidifies very quickly. Once the layer is formed, the build platform lowers by an amount equal to the layer thickness so that the next layer can be printed. With the help of numerically controlled stages, the movement of the nozzle (deposition head) and the building platform is controlled in the horizontal and vertical directions respectively. Extrudable thermoplastics are available in a type of colors. Additionally, thermoplastics are cheap and safe to use. The build volume of most freeform filament fabrication machines is relatively small, hence they are most commonly used as desktop prototyping machines.

1.2 Problem Statement

Freeform Filament Fabrication (FFF) has been traditionally used only to rapidly prototype designs, thus there has been an insistence to use the fused deposition modeling process to manufacture final products. Recent improvements in the area of FFF has brought to the creation of inexpensive desktop based rapid prototypes such as the Replicating Rapid-Prototyper (RepRap), Fab@Home desktop, Makerbot Replicator and so on (Malone and Lipson 2007). Currently, many researchers aim to develop and produce new material through FFF process. To that end, they also need to examine the flow behaviour of the filament at thermoplastic extruder, such as level of suitable temperature to melt of filament, feed rate speed of the extruder motor, the diameter size of the nozzle and so forth. If this parameters is changed, it also affects the extruded melt flow behaviour. However, FDM extruder playing an important role in order to improve the quality of 3D printing objects especially on freeform filament extrusion. Therefore, in this study the experimental work will be conducted to ensure the filament extrusion can be studied in more detail before the new material or existing materials will be used in the actual machine. This is because, when the flow behaviour at the material is unknown for example temperature imposed inappropriate to melt the filament, it can also cause damage to the machine, especially the thermoplastic extruder. Hence there exists a need to study the printing process where extruded filament fails to meet expected results. This study focuses on some of these issues and aims to establish a process to be followed in order to predict the output of a filament extrusion head. Therefore, such specified parameters will be investigated in present study.

1.3 Objectives

The objectives of this study are:

i. To design and fabricate (hardware and firmware) apparatus and testing jig for experimental work
ii. To evaluate the effect of filament feed rates over changes in parameters.
iii. To achieve consistency and precise control of the molten thermoplastic flow in the FDM process through experimental work.

1.4 Scope of Study

The study is focused on following scopes:

i. Three FDM extruder parameters will be studied namely:
    a. effect of temperature
    b. the feed rate speed in filament extruding
    c. size of diameter nozzle.

ii. Arduino MEGA 2560 will be used for the controller of Pronterface software
iii. The material use as benchmark are:
    a. ABS (Acrylonitrile butadiene styrene)
    b. High Impact Polystyrene (HIPS)
    c. ABS + Copper
iv. The filament extrusion process in FDM extruder is regarding following specification:
    a. Extruded filament consistency (by using two different size nozzle with 0.4 mm and 0.6 mm.)
    b. Steady state flow rate offsets

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will review some literatures that has been done previous researchers from various sources including book, journal, technical report, proceeding paper and article. This information is significant to this study because it can be a guideline in achieving final goal. This chapter will focus on FDM process through studies that have been done by previous researchers especially on flow characteristic in FDM extruder where it is major issue to be discussed in this study. Nevertheless, every relating aspects in this study such as methods, parameters, and results will be account as references parameter before undergoing the experiment process.

Later on, it also discuss about original material that used in FDM process. Therefore, materials also play an important role and have an impression of the flow characteristics in the FDM extruder based on several factors such as the size, strength, temperature imposed and so on. Present study also concern on the feedstock filament requirement such as flexibility, stiffness and hardness in order to gain success in FDM processing (Novakova and Kuric 2012).

2.2 Rapid Prototyping Methods

2.2.1 Fused Deposition Modeling

Fused deposition modeling (FDM) is an extrusion based Additive Manufacturing technology which is the main area of research of this project. The process was developed by Scot Crump of Stratasys in the late 80s and was commercialised in 1990, and produces prototype parts out of Acrylonitrile Butadiene Styrene (ABS) plastic. Another types of material, FDM technology can also be used with Polycarbonates (PC), Polycaprolactone (PCL), Polyphenylsulfones (PPSF) and waxes (Patel et al. 2014).

Fused deposition modeling process starts with the creation of a part on a computer aided design (CAD) system as a solid model using CAD software. Then the part file is converted into Stereolithography (STL) file using a specific translator on the CAD system. The STL file is then converted into SLC file by slicing them into thin cross sections at a desired resolution. The sliced model is then changed into Stratasys modelling language (SML) file, which contains actual instructions code for the FDM machine tip to follow the specified tool path (Wang et al. 2001). Figure 2.1 shows basic of FDM process as below.

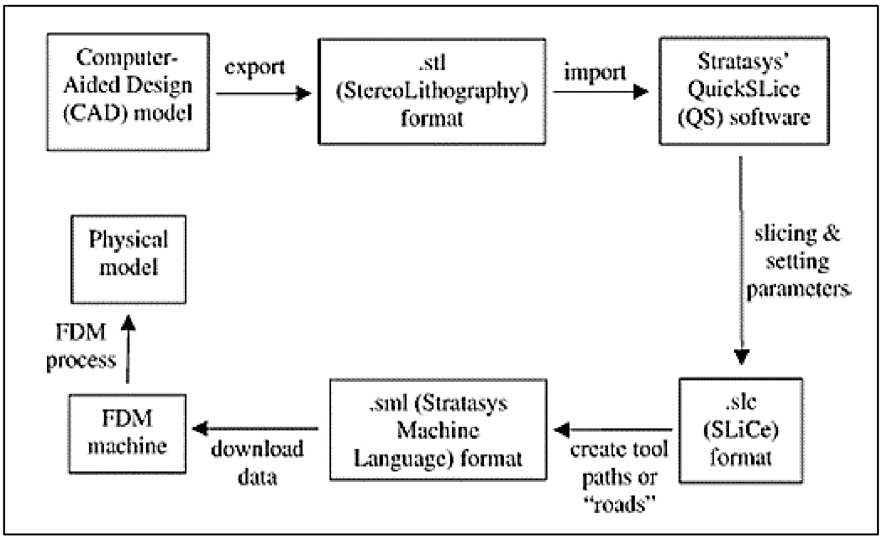

Figure 2.1: Basic of Fused Deposition Modeling process (Zein et al. 2002)

In FDM, the prototyping process begins with unwinding the feedstock filament from a reel and feeding it through the liquefier located inside the system working envelop, where it gets gradually heated by temperature gradient provided by a number of coils wrapped helically about the axis of the liquefier. The implementation of FDM process is shown in Figure 2.2.

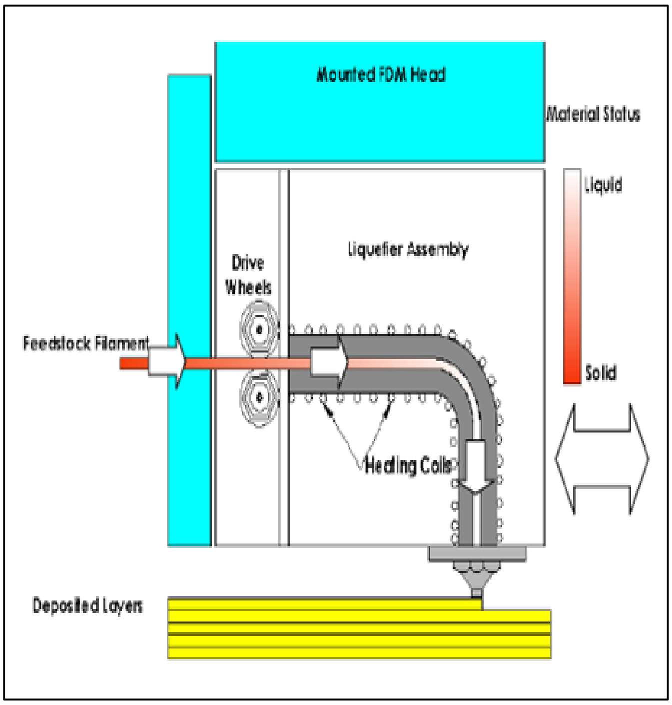

Figure 2.2: Fused Deposition Modelling process (Mostafa et al. 2009)

The heated liquefier melts the plastic filament and deposits the melt through a nozzle attached at the exit controlling the diameter of final extruded. Two step motors at the entrance of liquefier make sure a continuous supply of material during the model build-up. The nozzle is controlled by a computer aided manufacturing package which can be used to move the nozzle in horizontal and vertical directions. Upon receipt of precise tool paths prepared by the Insight software, the nozzle moves over the foam substrate depositing a thin bead of thermoplastic model material along with any necessary support structure. Deposition of fine extruded filaments onto the substrate produces a layer corresponding to a slice of the CAD model of the object. Once a layer is built the substrate moves down in Z direction in order to prepare the stage for the deposition of next layer. The deposited filaments cool down immediately below the glass transition temperature of the polymer and get hardened. The entire build system is contained within a temperature- controlled environment with temperatures just below the glass-transition temperature of the polymer to provide an efficient intra-layer bonding (Cooper 2001), (Novakova-marcincinova 2012).

There are two designs used for the liquefier assembly on the commercially produced FDM machines, first with straight tube and another design with angle 90^{o} bent tube. The earlier design provides less dimensional inaccuracy on the extruded strands due to the improved die-swell phenomenon whereas the former design as shown in Figure 2.2 meanwhile Figure 2.3 shows a more continuous design and smooth flow of the filament extrusion.

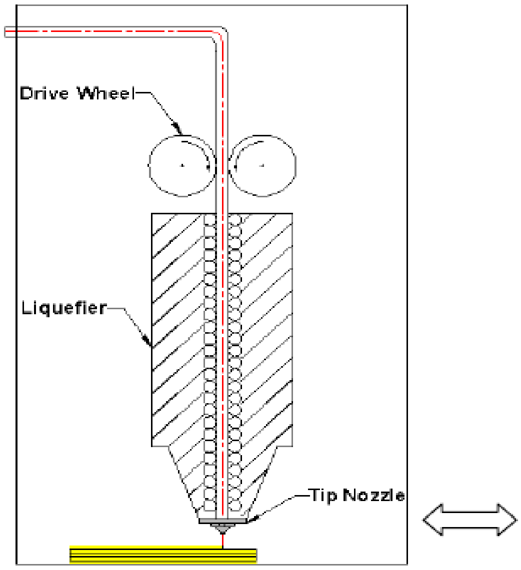

Figure 2.3: Straight Nozzle of FDM Liquefier

In addition, different types of machines are available in the market today and each machine has its own capability to build parts due to a variety of factors. These would be dependent upon the company manufactured by, the size of the machine, the type of extrusion head used, the range of materials the machine can use etc. The range of materials over which the FDM machines can operate are mainly like ABS, PC, elastomer, and wax. These materials have properties like high strength, performance and also made of high dimensional accuracy. Owing to these properties they can be easily used in making models, prototypes, and concept or design components. They are also used in investment casting and increasingly being used in medical applications, like filling for damaged section of brain. Recent research and development in this field has lead to more companies starting to replace conventional methods of machining and using for making parts which may be used as a smaller part of an assembly or even used as end user parts.

2.2.2 Stereolithography (SLA)

Stereolithography was introduced in 1987 by 3D Systems Corporation. It was one of the first Additive Manufacturing processes to reach the market. In this type of system a low power laser beam is used to cure the models made by photosensitive resins. An STL (Stereolithography) file is required to be used as an input to the machine which builds the parts. This is done by converting the CAD Model of part into an STL file through the modeling software. Figure 2.4 shows the basic stereolithography setup.

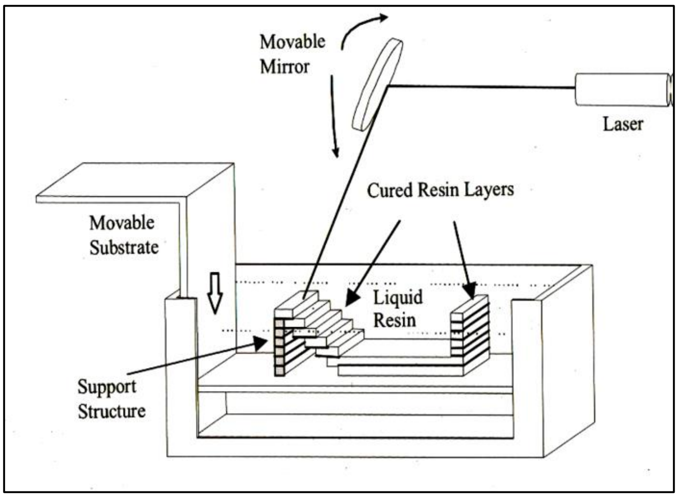

Figure 2.4: Stereolithography

A movable table is placed near the end of the container which is filled with a liquid photopolymer resin. The property of the resin is such that when light of a particular colour strikes it, the liquid turns into solid. The most common form of light used with this type of process is the ultra violet rays but other resins that work with visible light can also be used (Chua et al. 2010).

A laser beam is used for tracing the cross section of the object to mould which causes the liquid to harden in the areas where the laser strikes. After a layer has been done, the table lowers to a height equal to the thickness of a layer. To speed the process of recoating, many stereolithography systems drew a knife edge to smoothen the surface. Upon completion of the process the object is elevated from the vat and allowed to drain. Excess resin from is removed manually from the surface of the object. The object is then given a final cure by bathing it in intense light in a closed box similar to oven. After the final cure, supports are cut off and the surfaces are sanded or otherwise finished.

2.2.3 Selective Laser Sintering (SLS)

Selective laser sintering was first commercialized in the 1987 by DTM Corporation. SLS was developed and patented by Dr Carl Deckard. Unlike other manufacturing processes such as Stereolithography and Fused deposition modeling, SLS does not require support structures due to the fact that part being constructed is surrounded by unsintered powder at all times. In this type of process a high power laser is used to fuse small particles of plastic, metal into a desired three dimensional object.

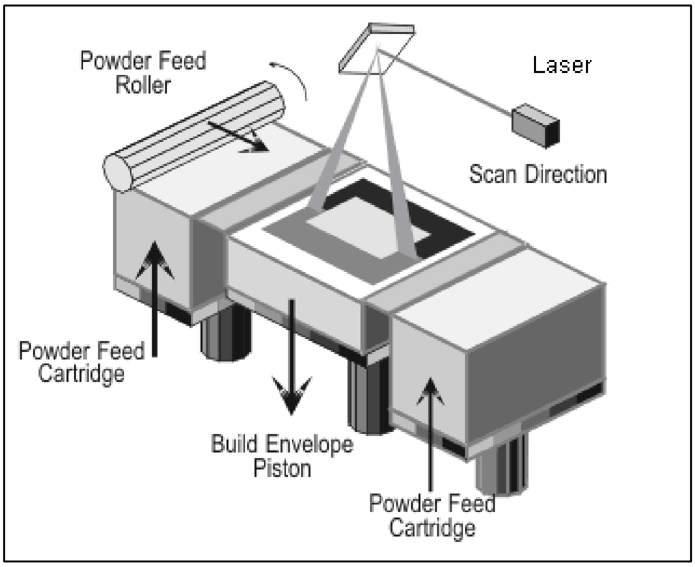

Figure 2.5: Selective Laser Sintering System

An SLS setup is depicted in Figure 2.5 has the capability to be used with a wide variety of materials like green sand, metals and polymers for different applications. The object to be made is first modeled in CAD software, which is then converted into a STL file. The STL file is a format which contains the whole model in a slice by slice data readable by the corresponding machinery. This file is fed to the machine after which the processing starts. A roller filled with material is used spread the material over a platform which is built up one on top of another. A laser is then used to follow a pattern over a set of points with the information provided in the STL file. The path were the laser is traced is sintered. The platform is then lowered to a height equal to one slice of the model and another layer of powder is deposited over the previous layer (Cooper 2001).

2.2.4 Laminated Object Manufacturing (LOM)

Laminated Object Manufacturing is a process in which layers of adhesive coated paper, plastic or metal are glued together to make three dimensional models. The principal United States (U.S) commercial provider of Laminated Object manufacturing was Helisys, which ceased operation in 2000. However, the company's products are still sold and serviced by a successor organization, Cubic technologies. Typical system of Laminated Object Manufacturing (LOM) has been shown in Figure 2.6.

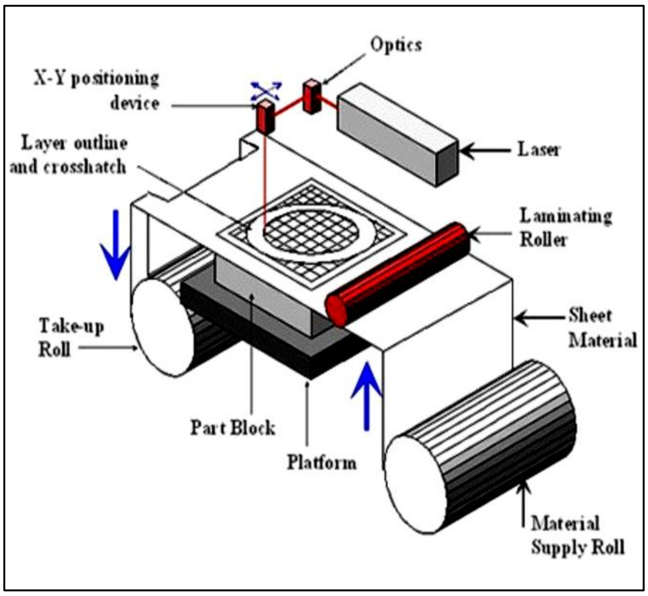

Figure 2.6: Laminated Object Manufacturing Process

The mixture of an additive and a subtractive gave birth to this form of prototyping. The figure shown above gives an illustrative example of a laminated object manufacturing model. Layers of materials are added one by one and a laser is used to trace the shape of the model at that cross section. As the layer is cut, unnecessary parts on the side are removed. A cylindrical feeder bound with all the material is used as a material supply role. A special type of tape is applied onto the platform so that the material can get attached. The sheet is then fed in, the other side of which is given into a take up role after being processed by the laser. The laminating roller is rolled across the surface which helps in activating the adhesive and also to apply simultaneous downward pressure. A carbon dioxide laser is used to cut an outline of the cross sectional shape of the model. A border is then cut around the desired part which enables the part to stay intact as each new layer is created. The laser then proceeds to create hatch marks or cubes surrounding the pattern within the border. This is done so that the cubes can act as supporting structure to the parts and there is no movement during the building process (Cooper 2001). This process is repeated till the part is built. When the build is completed the part is then removed from the platform.

2.2.5 Laser Engineered Net Shaping (LENS)

Laser Engineered Net shaping is one of the first type of Additive Manufacturing systems to use metals in the deposition system. Figure 2.7 below is shown the process of LENS. The parts made from this type of system are full strength metals ranging from steel, titanium, aluminum, vanadium and so on. This process was developed by Sandia national laboratories and cooperation from various other industry members. Similar to most of the Additive Manufacturing process, LENS also used a layer by layer approach to build a part. The CAD model of the part is used to obtain a STL file which is used as an input to the machine which builds the parts from the bottom layer onwards. A high powered laser is used to fuse the metal powder when it is fed from feeder tubes into its focal point. This powder is then turned into a layer when deposited in the required shape. The deposition device then moves up the distance equal to the height of one layer to proceed to deposit the next layer. This process is repeated till the complete part is built.

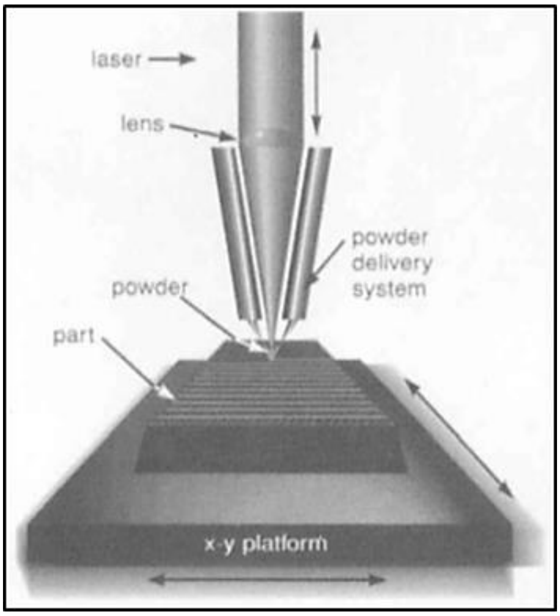

Figure 2.7: A Sample LENS process

2.3 FDM Materials

Fused Deposition Modeling is one of the typical RP processes that provide functional prototypes of ABS plastic. FDM produces the highest quality parts in Acrylonitrile Butadiene Styrene (ABS) which the material is combined the strength and rigidity of the acrilonotrile and strene polymers with the toughness of the Polybutadiene rubber.

The most important mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of Polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in another properties. The properties of FDM materials is shown in Table 2.1.

Table 2.1: Properties of FDM materials

No.	Material	Characteristic	Color	Application
1	ABS	- Up to 80% of the strength of injection moulded ABS	White, blue, yellow, red, steel gray, green, , gray	- Prototypes, patterns, tools and end-use parts
2	ABS-ESD7 (Acrylonitrile butadiene styrene-electrostatic dissipative)	- Prevents a buildup of static electricity, so it will not produce a static shock or cause other materials like powders, dust and fine particles to stick to it.	Black	- End-use components, Electronic products, Industrial equipment and Jigs and fixtures for assembly of electronic components.
3	ABS-M30	- Greater tensile, impact, and flexural strength - 25-75% stronger than the standard ABS material	White, natural, black, dark gray, blue, red	- For conceptual modeling, functional prototyping, manufacturing tools, and end-use -parts.
4	ABS-M30I	- High strength material	Ivory (a creamy-white color)	- For the medical, pharmaceutical and food packaging industries

5	ABSI	- ABS type with high impact strength and the translucent nature of ABSi is beneficial for monitoring material flow and light transmission	White, black, gray, translucent natural, translucent red	- For conceptual modeling, functional prototyping and direct digital manufacturing
6	PC (polycarbonate)	- Accuracy, durability and stability	White	- Automotive, aerospace, medical
7	PC-ABS	- Strength and heat resistance of PC and the flexibility of ABS	Black	- Automotive, electronics and telecommunications applications
8	PC-ISO (ISO 10993 USP Class VI)	- Strength and medical compatibility	White, translucent natural	- Used in food and drug packaging and medical device manufacturing
9	PPSF/PPSU (polyphenylsulfone)	- Highest heat and chemical resistant of all FDM materials - mechanically superior material, greatest strength	Tan (yellowish)	- For aerospace, automotive and medical applications
10	ULTEM 1010	- Chemical resistance and tensile strength of any FDM thermoplastic	Tan (yellowish)	- Food production tools and custom medical devices - For an out-of-cabin aerospace applications and under-the-hood automotive applications
11	ULTEM 9085	- Strength, durability, and resistance to heat and chemicals FDM thermoplastic - Highest tensile and flexural strength	Tan and black	- For the commercial transportation industry especially aerospace, marine and ground vehicles

Type of materials used in FDM play a very important part as they are the ones who decide the final use-ability of the part. There have been quite a lot of experiments with different materials in FDM to explore which material suits best and for which purpose. Based on Nikzad et al. (2009) the new metal polymer composite is developed from Iron powder and ABS powder is used. The main reason for selection of iron powder as short fiber as short fiber fillet was it reasonably good mechanical and thermal properties as well as it capability of mixing and surface bonding with polymers. A new composite material with 10% iron particles filled in ABS polymer matrix has been effectively developed for through application in FDM Additive Manufacturing process. Experiments contain been conducted to characterize the thermal, mechanical, and rheological properties. The metal powder was purchased from Sigma-Aldrich in Australia. From the study, the purity of metal powder was 99.7% with average particle size 45 µm was used for this investigation.

Masood and Song (2004) have been developed a new metal/polymer composite material for use in FDM process. The reason for using iron in the composite mixture was for its reasonably good mechanical and thermal properties and its capabilities of mixing and surface binding with polymers. They used two main types of constituent materials are used to develop the new composite material. The first material, used as the matrix, is the P301 polyamide thermoplastic. Three samples of composite materials consisting of iron particles of given volume and a specific particle size were mixed in the matrix of nylon P301 material. The first sample consisted of 70% nylon and 30% iron by volume with particle size 50-80 µm. The second sample consists of 60% nylon and 40% iron with particle size of 50-80 µm. The third sample consists of 60% nylon and 40% iron with particle size less than 30 µm. The filaments were made and each type of filament made was tested for its tensile properties. It was found that the variation of modulus of elasticity and tensile strength and tensile elongation of composites were strongly dependent upon the varying size of metal particles.

2.4 FDM Extruder

The extruder in the fused deposition modeling process is responsible for taking raw plastic filament, heating it up, and extruding it through a tiny nozzle to deposit thermoplastic material on the build-surface. In many ways FDM extruders are the least understood and most complicated parts of a 3D printer. While gantry systems, (that position the extruder and move it around to draw each layer) are very well established and have existed since the 1800's, thermoplastic extruders for use in 3D printers are relatively novel, having been first developed by Stratasys Inc. in the late 1980's. Figure 2.8 shows one type of extruder Makerbot MK6 StepStruder.

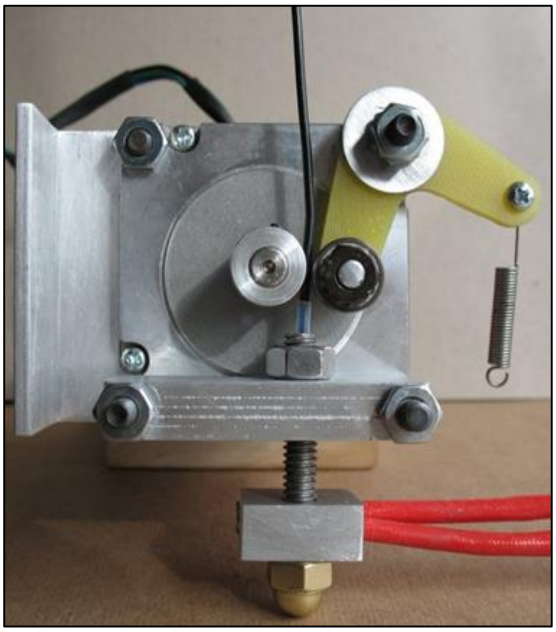

Figure 2.8: Makerbot MK6 StepStruder

To extrude molten plastic filament, the "Cold End" forces the raw material usually a 1.75mm or 3mm diameter filament into the hot end. Figure 2.9 is shown of molten plastic flow in the extrusion process by using Polycaprolactone (PCL) feedstock. The filament should then go through the "Hot End" of the extruder with the heater and out of the nozzle at a reasonable speed. The extruded material falls onto the build platform (sometimes heated) and then layer by layer onto the part as it is built up. Despite the extruder's complication though, every extruder is comprised of a few standard primary components.

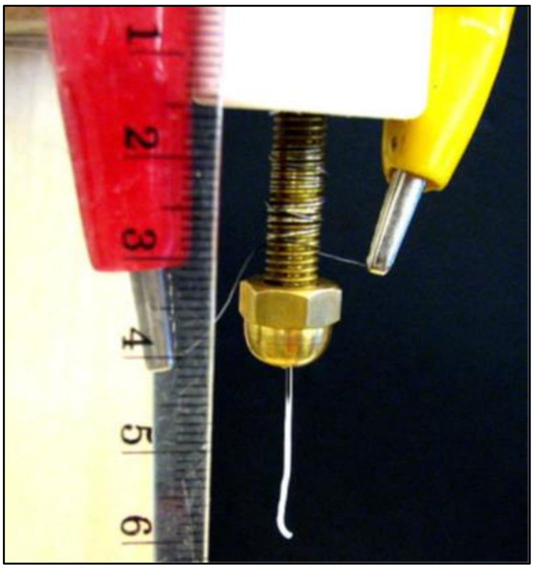

Figure 2.9: The PCL deposition flow of a RepRap extruder (Roxas and Ju 2008)

Simple cross-section schematic of the extrusion process is presented on the Figure 2.10. Plastic material in the hard state is positioned on the intake of the extruder. The guiding mechanism then conducts material, also called filament, down the extruder pipe via rollers or similar principle. The extruder pipe diameter dimension must be as close as possible to the filament diameter size. Temperature ranges in the extrusion of the plastics range from 100°C to about 250°C. It also must be related to the type of used material because if the temperature level is unsuitable, it can lead to molecular deficiencies and material destruction. For instance a Polypropylene (PP) is extruded at about 160°C and the ABS at about 240°C to fulfill the self-bonding conditions.

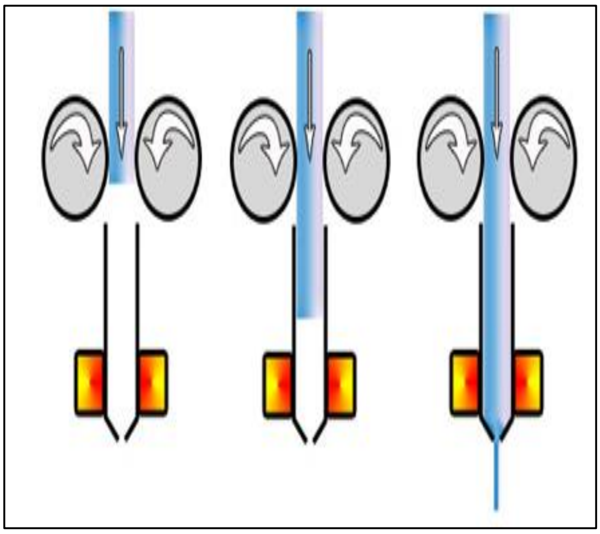

Figure 2.10: Cross sketch of the extruder

2.5 Components of FDM Extruder

There are two primary components of an FDM thermoplastic extruder, first the filament drive mechanism and the heated nozzle, or hot-end.

The filament drive mechanism is what drives the raw plastic filament into the heated nozzle. It is usually comprised of an actuator like an electric motor and a drive gear to grip the filament and translate the rotational motion of the actuator into linear motion of the filament. The drive mechanism needs to be powerful enough to force the plastic filament through the heated nozzle, or hot-end.

The hot-end is what the raw filament finally passes through before being deposited in the fused deposition modeling process. It is comprised of a heater, a temperature sensor, and a fine tipped nozzle. Figure 2.11 below is shown the components in FDM extruder. The molten plastic exits the heating chamber through the other hole at the tip. The hole in the tip or nozzle has a diameter of between 0.3mm and 1.0mm with typical size of 0.5mm with present generation extruders. Outside the tip of the barrel is a heating means, either a wire element or a standard wire wound resistor. The temperature sensor is used to provide feedback to the controller such that the temperature can be regulated to a certain temperature (Langford and Paper 2012).

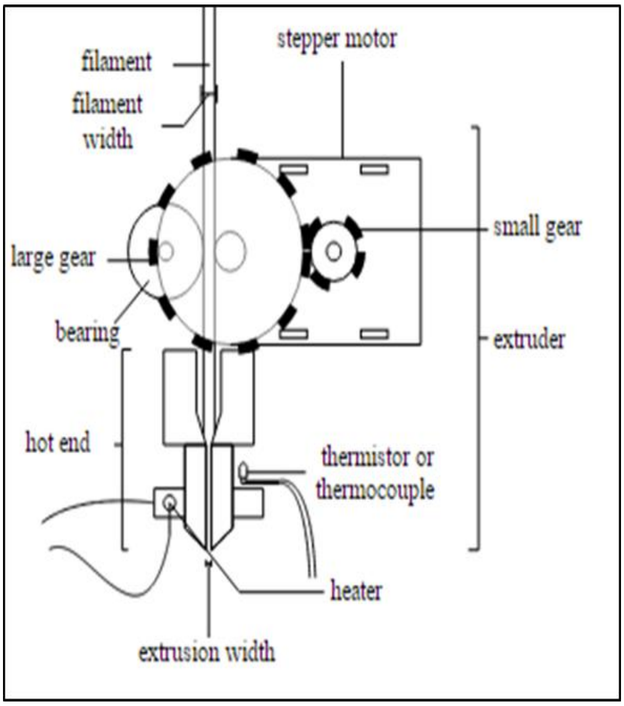

Figure 2.11: The components in FDM extruder

2.6 Research Review

2.6.1 Fused Deposition Modeling (FDM)

Recently, FDM technique gain popularity among manufacturing process especially in Additive Manufacturing. A large number of study has been progressively produced by previous researchers in order to gain better understanding and improve this technique. The main focus of this study is about flow characteristics which plays important role in controlling flow quality at FDM extruder.

Mostafa et al. (2009) conducted 2D and 3D numerical analysis of melt flow behaviour of a representative ABS-iron composite through the 90-degree bent tube of the liquefier head of the fused deposition modelling process using ANSYS finite element package. Main flow parameters including temperature, velocity, and pressure drop have been investigate. In this study, the new ABS-metal composite is developed, a mixture of 10% iron powder and 90% ABS powder by volume were selected with the aim of producing appropriate feedstock filament for FDM processing. In this research, the FDM3000 machine is used, in which the feedstock material is fed in the form of a flexible plastic filament. The results of the analysis were found the flow behaviour of the melt flow channel is affected by the pressure drop, velocity, and the geometrical dimension at the exit.

Masood and Arivazhagan (2012) have studied about dynamic mechanical properties of Fused Deposition Modelling (FDM) Additive Manufacturing processed material Acrylonitrile butadiene styrene (ABS). This research focussed on the frequency scan of the FDM made ABS material in order to find out both modulus and viscosity values and the effect of FDM parameters over these properties. They found the solid normal built style gives more strength when compared to double dense and sparse built styles. It is also found that the loss modulus increases with increase in temperature, but viscosity values decrease with the increase in the temperature.

According to Galantucci et al. (2009) have reported the influence of FDM machining parameters on acrylonitrile butadiene styrene (ABS) prototype's surface finish. The surface finish of products after the modification of extrusion parameters has been measured and processed through designed experiments. The roughness of FDM prototypes is analyzed. Process parameters have been shown to affect the Ra.

In particular the slice height and the raster width are important parameters while the tip diameter has little importance for surfaces running either parallel or perpendicular to the build direction. A chemical post processing treatment was analyzed which yields a significant improvement of the Ra of the treated specimens. The proposed chemical treatment is economic, fast and easy to use.

Nancharaiah et al. (2010) have conducted the experiment to determining the optimum surface finish and dimensional accuracy of a part built by the Fused Deposition Modeling (FDM) process. They have found that effect of the process parameters layer thickness, road width, raster angle and air gap on the surface finish and dimensional accuracy. Experiments were conducted using Taguchi’s design of experiments with three levels for each factor. From the ANOVA analysis, it was found that the layer thickness and road width affect the surface quality and part accuracy greatly. Raster angle has little effect. But air gap has more effect on dimensional accuracy and little effect on surface quality.

Anitha et al. (2001) they have study of effect of various process parameters of fused deposition modeling on the quality of FDM made part .Taguchi method is used for optimization of both process design and product design they have selected three important FDM factor such as layer thickness , road width and speed deposition each of at three level. Taguchi’s L18 orthogonal array was selected in order to design the experiments and signal to noise ratio is applied to find out most significant factor on the response characteristics, at last regression analysis was used in order to predict the experimental data. After the experimental work they have found that layer thickness is affected 49.37% without pooling and with pooling it is affected 51.57% at 99% level of significant road width and speed contribute 15.57% and 15.83% at 99% level of significance according to s/n ratio they have contribute that the layer thickness is the most effective FDM parameter among three, which affect the output response.

Alhubail (2012) have conducted the experiments to find out the effect of main FDM process variable parameters. Five important FDM parameters like layer thickness, air gap, raster width, contour width and raster orientation are on their effect quality of surface roughness, dimensional accuracy and tensile strength. They have selected the new ABS M30, bio medical material in order to fabricate the parts, full factorial method was used for design of experiments a number of analytical methods such as regression analysis, analysis of variance were used to determine the influence of the variable FDM process parameter settings. After the experimental work they have found that not all FDM parameter have impact on the proposed response characteristics, they have also conclude that air gap parameters has been proved statistically to influence the surface finish of FDM built parts with thinner layer may reduce the surface roughness they have also find that negative air gap increase the tensile strength, layer thickness and raster width may prove better dimensional accuracy.

Hoon et al. (2002) have characterized the properties of ABS parts fabricated by the FDM 1650. They were examined the process parameters of FDM such as raster orientation, air gap, bead width, color and model temperature by using design of experiments (DOE). Tensile strength and compressive strength of directionally fabricated specimens were measured and compare with injection molded ABS P400 material. The result showed the air gap and raster orientation affect the tensile strength of an FDM parts greatly. Bead width, model temperature and color have little effect. The measure tensile strength of the ABS material with optimum FDM parameter were between 65 to 72 % of the measured of injection molded ABS and the compressive strength ranged from 80 to 90 percent of the injection molded ABS.

In another study, Sa'ude et al. (2013) investigated of dynamic mechanical properties of a copper-ABS composite material for possible fused deposition modeling (FDM) feedstock. The material consists of copper powder filled in an acrylonitrile butadiene styrene (ABS). The DMA testing has been successfully used to produce results for the storage modulus (E'), loss modulus (E") and Tan Delta (δ). After the experimental work they have found that the dynamic mechanical properties of copper filled in ABS are greatly affected by the volume percentage of the copper content. The suitable material and binder selection, mixing method and parameter setting on melting temperature, pressure and cooling time may offer a great potential area for the metal feedstock fabrication in the wire filament extrusion through the extruder machine. In addition, Table 2.2 below presents a summary of previous studies for the FDM process.

Table 2.2: Summaries of Literature Review

No.	Title	Authors/ Year	Methodology	Findings / Result / Discussion
1	Critical Parameters Influencing The Quality Of Prototype In Fused Deposition Modeling	R. Anitha, S. Arunachalam, P. Radhakrishnan. (2001)	- By using Taguchi method - Taguchi's L18 orthogonal array for design of experiments (DOE)	Three important FDM factor such as layer thickness, road width and speed deposition each of at three level. Layer thickness is affected 49.37% without pooling and with pooling it is affected 51.57% at 99% level of significant road width and speed contribute 15.57% and 15.83% at 99% level of significance and it is the most effective FDM parameter
2	Anisotropic Material Properties Of Fused Deposition Modeling ABS Additive Manufacturing	Ahn Sung Hoon, Montero Michael, Odell Dan, Roundy Shad, Wright Paul K. (2002)	- By using design of experiments (DOE)	Parameters of FDM such as raster orientation, air gap, bead width, color and model temperature. The result showed the air gap and raster orientation affect the tensile strength of an FDM parts greatly while bead width, model temperature and color have little effect.
3	Thermal Characteristic of a New Metal/Polymer Matrial for FDM Additive Manufacturing Process	S.H. Masood and W.Q.Song. (2005)	Two method : Mathematical modelling and finite element analysis (FEA)	The paper present about melts flow behaviour (MFB) using accurate channel geometry by varying filament velocity at the entry and by varying nozzle diameters and angles at the exit. The comparative results of both methods suggest that the pressure drop and the velocities of the melt flow depend on the flow channel parameters.

Table 2.2: (continue)

4	A study of melt flow analysis of an ABS-Iron Composite in FDM process	Mostafa Nikzad, Syed Hasan Masood, Igor Sbarski, Andrew Groth. (2009)	- By using Ansys Flotran and CFX finite element	Main flow parameters including temperature, velocity, and pressure drop have been investigate. The result obtained by both of analysis has been compared and show a very good correlation in predicting the flow behaviour
5	An Experimental Investigation on Surface Quality and Dimensional Accuracy of FDM Components	T. Nancharaiah, D. Ranga Raju and V. Ramachandra Raju. (2010)	- Using Taguchi's design of experiments - ANOVA software for analysis	Effect of the process parameters layer thickness, road width, raster angle and air gap on the surface finish and dimensional accuracy. Result showed the layer thickness and road width affect the surface quality and part accuracy greatly. Raster angle has little effect, air gap has more effect on dimensional accuracy and little effect on surface quality.
6	Dynamic Mechanical Properties of ABS Material Processed by Fused Deposition Modelling	Adhiyamaan Arivazhagan, S.H. Masood. (2012)	- Focus on the frequency scan of the FDM made ABS material in order to find out both modulus and viscosity values and the effect of FDM parameters over these properties	Results show that solid normal built style gives more strength when compared to double dense and sparse built styles. It is also found that the loss modulus increases with increase in temperature, but viscosity values decrease with the increase in the temperature.
7	Statistical-Based Optimization Of Process Parameters Of Fused Deposition Modeling For Improved Quality	Alhubail Mohammad. (2012)	- Full factorial method is used for design of experiments	Parameters is used like layer thickness, air gap, raster width, contour width and raster orientation are on their effect quality of surface roughness, dimensional accuracy and tensile strength. They have found that not all FDM parameter have impact on the proposed response characteristics

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is principally to give explanation on the subject of procedure and work step that will used in this project. This study will be undergone experimental process which consisting fabrication including cutting and joining, and assembly process. The related component in this study can be divided into two categories hardware and firmware. The hardware component is only extruder while the firmware are Arduino MEGA 2560 and RepRap Arduino Mega Pololu Shield (RAMP 1.4). A computer compiler namely Sprinter need to be installed into RAMPS prior to assembly process in order to provide a good information display to Pronterface software. Furthermore, this chapter will be discussed the methodology of the study that describes the materials and equipment used on the filament extrusion process that have been conducted. Figure 3.1 and Figure 3.2 shown the K-Chart for the study and experimental process flowchart.

3.2 K-Chart

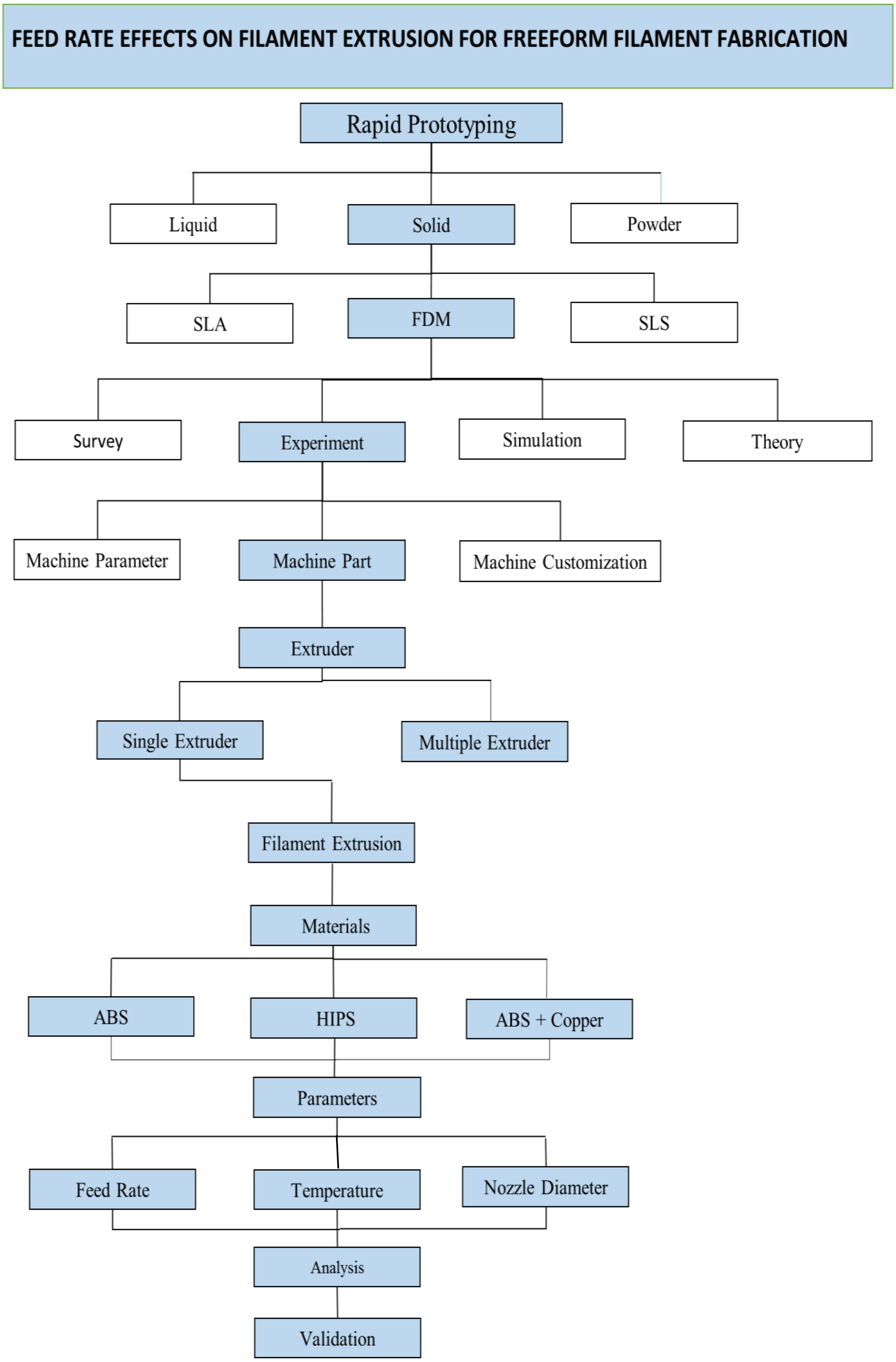

Figure 3.1: Chart of the study

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