DESIGN AND FABRICATION OF POLYVINYL CHLORIDE PIPE LABORATORY EXTRUSION MACHINE

Mechanical engineering laboratory of Federal University of Minna, Nigeria requires extrusion machine that can be used for teaching and learning of PVC extrusion process. The teaching and learning of PVC extrusion are rarely thought using extrusion machines that help to bridge the gap between engineering graduate in industry and student learning in the university. Against this background, a need emerges for the design, and fabrication of laboratory PVC extrusion machine. The laboratory PVC extrusion machine is a machine that could be used to produce thermoplastics pipes. The PVC pipe is done by forcing the resin (PVC melt) to flow through an opening annular die. It is necessary to produce the pipe with indigenous technology to meet increasing demands of pipe usage in our homes such as, portable water sewage and electrical conduit pipes. The design of extrusion machine involves selection of specified drives, feeding and control systems. The drives used were spur gears, screw shaft, thrust bearing and electric motor. The required power for the machine was 6.93 kW with power scale up factor of 0.122 and gearing ratio of 2:1. The feeding system is cylindrical barrel of diameter 770mm and hopper with electrical control switch for control purpose. The machine is designed analytically and modelled using Pro-Engineer software before being fabricated. The compression ratio used for the design of the machine was 8:1 with extruder length being 1120 mm. The maximum shear stress for the extruder design was 17.1 $\mathrm{k}N/\mathrm{m}^2$ with extrusion pressure of 7.7 $M\ N/\mathrm{m}^2$. The design extruder circumference speed was 1.2 m/s with plastic flow rate of 1m/s. The velocity drop at die inlet was $0.1\frac{m}{s}$. Drag or volumetric flow rate of the PVC melt from the extruder was 0.0009 m^3/s. The mass flow rate of the PVC melt was 7.9kg/s. The pipe produced by the machine is 40mm diameter. The pipe was bent in structure due to lack of automated temperature controller system in the machine and a plate to slide on to avoid deformation due to its weight. The machine efficiency is 51% and it was fabricated with locally sourced materials. The use of this machine for practising PVC extrusion process will boost student’s knowledge of extruding process.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Historical Background of the Study

According to Crawford (2000), manufacturing methods basically involve operations such as cutting, forging and casting. As time progressed, less readily available natural materials, such as ores, are converted into metals and also pass through a secondary mechanical working stage to be turned into something good and useful for mankind. The method chosen for a particular application will depend on many factors on the material being formed, the shape of the end-product, the market size, etc. And the methods available are continually increasing in number as new types of market demands mean that new manufacturing methods have to be developed to meet special needs (Crawford, 2000). Many of these new methods are hybrids of existing methods and they enable new shapes to be created with unique functionality or more attractive economics, therefore extrusion is one of the manufacturing methods called forming that does base on this fact.

Natural polymers have been with human beings since the beginning of time and began to be chemically modified during the 1800s to produce a number of materials. The manufacture of synthetic polymers has started since the early twentieth century. During World War II, the polymer industry has continued to grow increasingly and since then it has evolved into one of the fastest growing industries in the world. For the year 2000, nearly 200 million tons of synthetic polymeric materials, or plastics, were produced throughout the world to satisfy the ever increasing market demands (Griskey, 1995 and Carraher, 2003). Compared to other materials, polymers have plenty of advantages such as light weight, corrosion-resistance, and ease of manufacture. Plastic materials can be classified into two general classes, thermosets and thermoplastics. Unlike thermosets which cannot be reprocessed once the product is formed, thermoplastics can be reprocessed many times through certain approaches. Thermoplastics occupy more than 80% of the commercial polymer products in the world due to its advantage of being re-processable (Throne, 2004). Likewise, polyvinyl chloride (PVC) pipes a thermoplastic type of plastic have been considered as the ideal candidates for fulfilling the increasing market needs.

1.2 Statement of the Study

Presently in mechanical engineering laboratory of Federal University of Minna, Nigeria there is no extrusion machine that can be used for practicing extrusion process. Therefore, there is a need to understand the theoretical aspect of manufacturing process of PVC pipe forming by practical procedure. Teaching and learning of manufacturing process such as PVC extrusion will be effective if they are well supported with practical. The teaching and learning of PVC extrusion are rarely thought using machines that bridge the gap between working in industry and learning in the university. Against this background a need emerges for the design, and fabrication of laboratory PVC extrusion machine using locally sourced material.

1.3 Justification and Significance of the Study

Extrusion is a metal forming process that is employed in thermoplastic forming of pipes, tubes, wires etc. This process forces metal or plastic to flow through a shaped opening die under pressure (Dhar, 2005). The material is plastically deformed under compression in the die cavity. The process can be carried out hot or cold depending on ductility of the material. The tooling cost and setup is expensive for the extrusion process, but the actual manufactured part cost is inexpensive when producing significant quantities of extrusion products. Various materials can be extruded by this process and they are aluminium, copper, steel, magnesium, and plastics but aluminium, copper and plastics are most suitable for extrusion. This study is based on plastic extrusion of pipes.

Plastics are so widely used today, because it is almost inevitable due to its relatively low cost or their lightness or their ready availability in many colours. These are important factors; there are few applications where they would be sufficient justification for using plastics. For instance, in the automotive industry, where weight saving is a commendable objective to save energy. Plastics can be mechanically formed into complex shapes at very high speed at relatively low temperatures. This means that manufacturing costs are low, which is key requirement in any successful business. Thus the contributions to energy savings are more likely to come from the lower fuel bill at the manufacturing stage than at the end-user stage. The additional attributes of lightness, colour fastness, flexibility, chemical resistance, electrical insulation and so on, are bonus factors that are to be welcomed and can be put to good use in specific applications of plastics.

The driving force in any production environment is the tight control of the manufacturing process. To gain such control, the design, industrial, production and material engineering departments must generate effective process plans to manufacture products like thermoplastics and also to have worked on the formal design of the product. Production engineering need to be involved in product design cycle of polyvinyl chloride (PVC) pipe which could be available for home and industrial use. Extrusion is useful to produce PVC pipe in mass production in industry for instance the use of automated extrusion machine in Imurat International Ltd, Minna has helped producing thousands of quality PVC pipes per week. Therefore carrying out a research on production of PVC pipe would help in linking classroom understanding nature of extruding/forming process of thermoplastic to the industrial design application of the thermoplastics extrusion. The study undergoes process planning and design of PVC pipe within our environment. The pipe produced could be used to pass sewage and also to collect rain water in our homes.

1.4 Aim and Objectives of the Study

The study aims to design and develop a laboratory model of thermoplastic extrusion machine that can be used to demonstrate extrusion process to the student. The machine can also be used by practising technologist in the school of engineering workshop.

The objectives of this thesis are to:

i. design of polyvinyl chloride pipe laboratory extrusion machine
ii. fabricating of polyvinyl chloride pipe laboratory extrusion machine

1.5 Scope of the Study

This study covers the process planning and design of mono-extrusion die for thermoplastic or PVC pipe production. The study uses basic design specification for gear and shaft for power transmission. In the study, the die is designed based on annular cross section approach which serves as outlet for producing the PVC pipe. The study uses forward extrusion approach; hence Pro-Engineer is used for 3-Dimessional modelling of the laboratory extrusion machine. Failure analysis of the shaft is also carried out. Therefore, the laboratory extrusion machine is designed and fabricated for mechanical engineering student as a means of carrying-out workshop practise.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Polymeric Materials

The polymers materials consists of different atoms that are arrange in a long chain format. The polymeric materials are atoms are majorly consist of sulphur (S), nitrogen (N), carbon (C) and oxygen (O) all are combined to form different form of polymer. Polymers materials are divide into two classes as follow (Giles-Jr. and Wagner-Jr., 2005):

i. Thermoplastic
ii. Thermoset

A thermoplastic is being formed through repetition of softening process and re-solidification which involves addiction or subtraction of heat during the process. The thermoplastic could be formed through a manufacturing process such as injection moulding and extruding process. Thermoset is also formed through heating process that is being elevated to chemical process reaction called curing. The curing is a process in which new species will be formed as a solid. Reheating and softening process of thermoset does not require on cooling. However, thermoplastics could be recycled into different forms through reheating and softening process while thermosets are not usually recyclable except as filler to gain existing raw material. Also, thermosets is not usually heated above melting point and it can be formed through chemical reaction between two or more different components. New cross links are formed during matrix linkages process in the thermoset. The various thermoplastic materials are employed majorly in extrusion applications.

According to Giles-Jr. and Wagner-Jr., (2005), most of thermoplastics known are as follow:

i. Polyvinyl chloride
ii. Polyamide or nylon
iii. Polyphenylene sulphide
iv. Polyphenylene oxide/polystyrene blend
v. Polyethylene
vi. Polypropylene
vii. Polystyrene
viii. Acrylonitrile butadiene styrene
ix. Polycarbonate
x. Polyethylene terephthalate
xi. Polybutylene terephthalate

Epoxy is widely employed as thermoset. The epoxy consists of resin. The resin is hardened, mixed and cured to produce new cross link. Polyurethanes are produced by mixing isocyanate with a polyol. EPDM rubber is a thermoset material that can contain a cross-linking agent. The EPDM rubber consists of cross-linking agent that is extruded through lower temperature. The extrusion product of EPDM rubber is such as gasket around a car door. On extruding, the product is heated to increase cross-linking reaction of the solid state to form a material that is impervious to heat (Giles-Jr. and Wagner-Jr., 2005).

2.1.1 Polyvinyl Chloride (PVC)

This is one of the most widely used of all plastics. With the resin mixed with stabilizers, lubricants, fillers, pigments, and plasticizers, a wide range of properties is possible from flexible to hard types, in transparent, opaque, and coloured forms. It is tough, strong, with good resistance to chemicals, good and low temperature characteristics with flame-retardant properties. PVC does not retain good mechanical performance above 80°C (Idol and Lehman, 1999).

Most of plastics are composed of long chain molecules with very high molecular weights. This is formed depending on each monomers present in the plastics. Each polymer molecule may comprise of thousands of each unit of monomer of plastics. The monomers units present in the plastic formation are created through process called polymerisation. Monomer units may be either VCM polymerises or vinyl chloride monomer to form PVC. There are two or more diverse monomers coexisting in a haphazard format for instance styrene, butadiene and acrylonitrile are monomer units that are polymerise to form ABS copolymer (Giles-Jr. and Wagner-Jr., 2005).

2.1.2 Types of Plastics and Its Effect on Manufacturing Method

According to Wigotsky (2000) and Crawford (2000), polymers are a class of materials in which small molecular units ("mers") are joined together in a chemical process to create long chain-like molecules. Such materials are available in nature - resins from plants, skin and human nails- but it is the synthetic polymeric materials, often referred to as plastics that are of interest in this study. The unique structure of polymers has an influence on the manufacturing methods used for these materials and the inter-relationships between processing conditions and the morphology of these materials can affect, in a positive or negative way, the properties of the moulded part. It should be pointed out that although the words "polymer" and "plastic" are often used to mean the same thing, strictly speaking the polymer is the pure chemical substance created by the chemical reaction referred to above. In most cases the pure polymer has no commercial value on its own and it only becomes a useful material - the plastic - when it is combined with additives to make it thermally stable, to protect it from ultra-violet light, to improve its flow behaviour, etc. In the context of manufacturing methodologies, it is important to recognise the differences between the main classes of polymers.

Thermoplastics are the easiest to work with and are the more common materials representing over three-quarters of all the plastics in everyday use. These materials soften when heated and are easy to work mechanically into a complex shape that is retained when the material is cooled (Zhang, 2010).

2.1.3 Advantages of Plastic Manufacturing method

An advantage from the manufacturing point of view is that the material can be re-worked if it is re-heated and softened again. Of course this characteristic is not attractive in service where the thermoplastic loses its shape if it becomes hot in service. The other main class of plastic is the thermoset. This material is in a semi-finished state when it is supplied to the moulder. During the manufacturing stage, the application of heat and pressure to create the desired shape initiates an irreversible chemical change in the material. The structure of the thermoset becomes locked into a three dimensional network, referred to as "cross-linking", which causes it to become solid. This makes manufacturing more problematic because the part must be right first time.

There is no second chance to re-soften the material by heat if the shape produced is not what was intended. Of course this is a feature which is attractive to the end-user because the material is well suited to high temperature applications or situations where the part might become hot accidentally, e.g. electrical switches or saucepan handles. Originally the manufacturing methods that evolved for these two classes of materials were separate and distinct.

Thermosets favoured simple moulding technologies such as compression moulding in which there was easy access to all parts of the moulding equipment if the plastic became solid prematurely. Thermoplastics on the other hand had the advantage of being amenable to a very wide range of moulding methods, such as thermoforming, injection moulding, extrusion, blow moulding and so on. Their user friendly moulding behaviour was to a large extent the reason why they came to dominate the marketplace in applications where either type of material could have been used on the basis of their mechanical properties (Zhang, 2010). Nowadays the distinction between the processing methods for the two types of material is less clear. As will be seen in the following sections, the sophistication and preciseness of process control is now at the point where thermosets can be extruded, and injection moulded on equipment very similar to that used for thermoplastics. They can therefore reap the benefits of faster production methods whilst retaining the advantage of offering high temperature and more consistent properties to the end user. Thermoplastic materials have also moved into thermoset manufacturing sectors in order to reap the benefits of better economic at lower production volumes and, in particular, the opportunity to combine reinforcing fibres with thermoplastics in ways that are difficult using conventional moulding methods. Methods are also available to initiate cross linking reactions in thermoplastics as they are being moulded, to impart better mechanical properties in the end-product.

There are other types of polymers, the nature of which can affect the mechanical working used to create useful artefacts. Examples are elastomers, which exhibit the high elasticity of rubbers but the ease of manufacture of thermoplastics. Also, some polymers lend themselves to polymerisation (conversion of the mers into long chains) during moulding. This has the advantage that the base chemicals that combine to make the polymer can be injected simultaneously into a mould to create the polymer and the moulded study at the same time. As the base chemicals often have a significantly lower viscosity than the polymer, they flow more easily in the mould and so much larger studies can be created using less forces and therefore smaller moulding machines (Idol and Lehmann, 1999).

2.2 Designing for Manufacturability

According to Salvendy (2001), the main goal of design for manufacturability is to bring along producibility issues in early stage of product design. It will help to attract customers and also satisfaction of customers will be met in a given time at a competitive cost. The customers' requires satisfaction in the produced product based on efficiency, quality, durability and serviceability at any given time. In designing plastic, a functional designer can choose from upto thirty (30) distinct families of plastic to form a plastic material. Thermoplastic or thermoset are manufactured through following processes which are (Salvendy, 2001):

i. Thermoforming
ii. Calendering
iii. Rotational moulding
iv. Blow moulding
v. Compression moulding
vi. Transfer moulding
vii. Injection moulding
viii. Extrusion
ix. Casting,
x. Cold moulding,

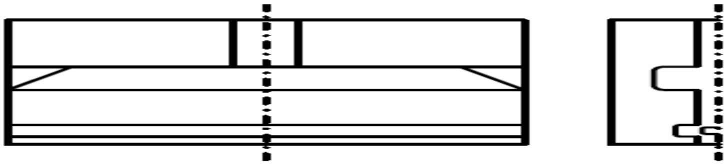
The functional designer gives best on how to produce this part perfectly based on design. The designer concerns with hardness, water absorption, outdoor weathering, and coefficient of linear thermal expansion of the product. The following properties such as deflection and temperature under load, and flexural yield, tensile, shear, and compressive strengths, elongation, flexural modulus and specific gravity and izod impact may also be looked into for producing a perfect design.

2.3 Plastics Sheet Production

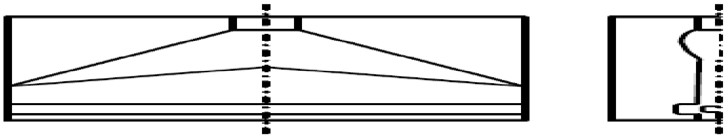
Plastics sheet production has three important processing steps: molten plastics preparation, sheet formation, and solidification. The molten plastics is established in an extrusion machine managing the production capacity, then the plastic sheet is formed by a slit die, and finally solidified in air or water before entering a rolling system controlling the final product thickness. Thus, the slit die governs the plastics sheet approximated thickness and the final product quality.

In general, the slit die is composed of two main sections (Michaeli, 1992 and 1984): manifold and die land. The manifold delivers the polymer melt across the die width and the die land forms the polymer melt to be a plastic sheet and allows the molten polymer to flow uniformly across the die lip. In some cases, a choker bar and flex lip (Wang, 2007) are attached at the die land end to equalize the molten-plastics flow across the die width**.** The slit dies have three main designs: Tee, fish tail, and coat-hanger die as in Figure 2.1. The Tee die is the first and the simplest design that does not contribute to the molten-plastics flow inside the die across the die width. Thus, the polymer melts flow very fast at the middle and slow near the die edges. The fish tail and coat-hanger dies are the developed designs helping the flow more uniform across the die lip. However, the fish tail die provides a very lengthy die land and thus a cumbersome die.

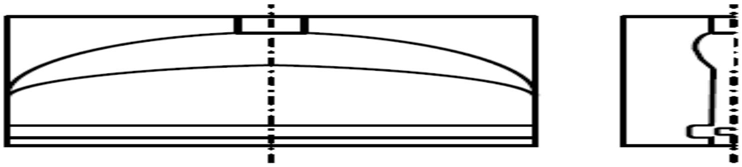
The coat-hanger die is the most versatile design. It can be designed to fit a compact production site. Figure 2.2 shows the coat-hanger die with its manifold and land without the choker bar. The manifold is a curved and round tube tapered from the middle to the die edges. The manifold curvature controls the die land length and eventually the total size of the die. In some cases, the manifold cross section may be designed in trapezoidal, rectangular, triangular or eye drop shape. Sometimes, the manifold and land are designed such that the polymer melt flows in only half of the cavity, while the other half is flat for readily machining and cost saving (Arunworradirok and Kolitawong, 2010). The design of coat-hanger die is not only useful for thin sheet and film productions, but also for pipe manufacturing and blow moulding (Winter and Fritz, 1986). In those processes, the polymer melt from the metering section in the extruder screw can be uniformly distributed to form an annular shape by using the coat-hanger die centrepiece.



(a) Tee die



(b) fish tail die



(c) coat-hanger dies

Figure 2.1: Slit Die Designs

Source: Arunworradirok and Kolitawong (2010).

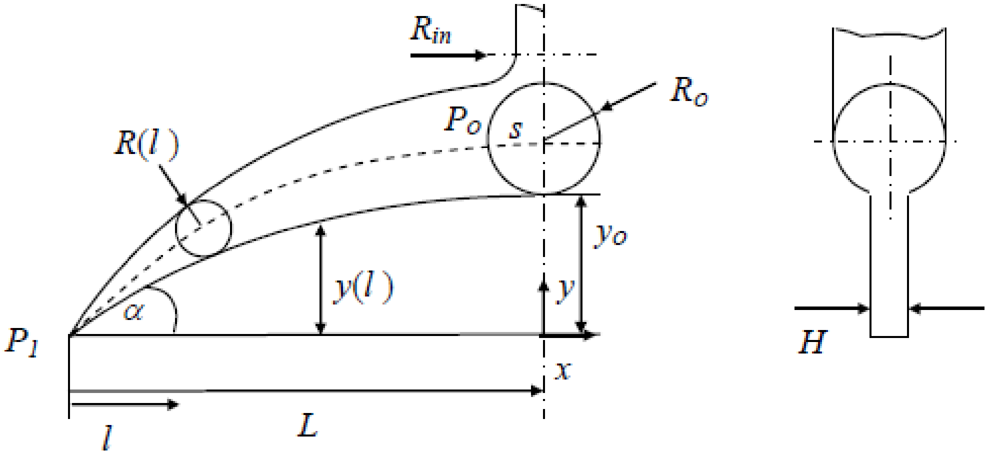


Figure 2.2: Coat-Hanger Die with Its Manifold and Land without a Choker Bar

Source: Arunworradirok, and Kolitawong (2010).

2.4 Extrusion

Extrusion is a plastic deformation process in which a block of metal (billet) is forced to flow by compression through the die opening of a smaller cross-sectional area than that of the original billet as shown in Figure 2.3.

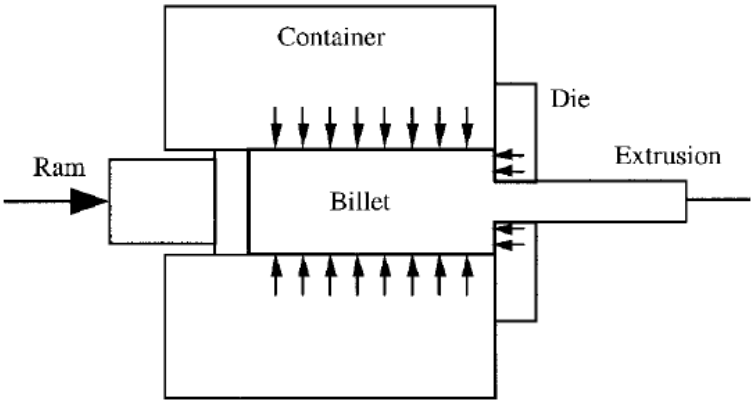


Figure 2.3: Principle of Extrusion

Source: Kalpakjian, and Schmid (2006).

Plastic extrusion is an indirect-compression process. Indirect-compressive forces are developed by the reaction of the workpiece (billet) with the container and die; these forces reach high values. The reaction of the billet with the container and die results in high compressive stresses that are effective in reducing the cracking of the billet material during primary breakdown from the billet (Kalpakjian and Schmid, 2006). Extrusion is the best method for breaking down the cast structure of the billet because the billet is subjected to compressive forces only. Extrusion can be cold or hot, depending on the alloy and the method used. In hot extrusion, the billet is preheated to facilitate plastic deformation.

Extrusion is a method for producing a solid plastic called resin. The resin is in structured as pellets or beads that are repeatedly introduced into heating compartment. The resin moved along a feeding screw which is driven by electric motor. The electric motor is control by speed and torque of the motor and this affect quality of the product being produced. The resin is transported through compression and melting stages of extruder screw and later and expelled out of in the compartment at a stable speed all the way through a die. The instant cooling of the resin or melted product requires re-solidification. The plastics are drawn continuously into a piece of uniform shapes through form die pattern.

The die pattern is re-designed and machined to achieve appropriate flow of the plastic melt in accordance to design-pattern shape. For instance, products such as blown film, pipe, coated paper, plastic filaments for brush bristles, carpet fibres, vinyl siding are produced through design-pattern shape. The extrusion is blown into film, wound, spun, folded, and rolled, plus a number of other possibilities and this depend on the end product of the process. Foodstuffs as well as Rubber are likewise to a certain extent repeatedly processed through extrusion. However, there is usually downstream processing system in which extruder will be fed into. Present study is based on design and fabrication of extruder and therefore, it will not talk about other formation or plastic process because plastic is majorly produced by extruder. Though metals such as aluminium are extruded could be formed using extrusion process. Through improved throughput rate of extruder and with new technologies other materials can also be extruded (Kalpakjian and Schmid, 2006).

2.5 Foam Extrusion

Foaming approaches can be implemented in processes such as batch foaming, foam extrusion, and injection foam moulding. It is worth noting that the foam extrusion dominates the commercial low-density thermoplastic foam production.

2.5.1 Foam Extrusion Process

A typical PBA-based foam extrusion generally comprises polymer melting, polymer and gas mixing, cooling, and shaping. Figure 2.4 shows a schematic of the necessary processes for foam extrusion along with its relevant mechanisms (Lee, Park and Ramesh., 2007).

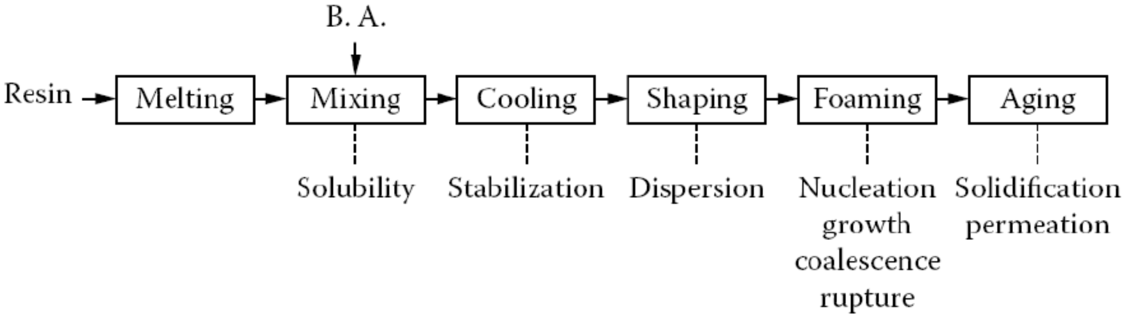


Figure 2.4: Forming Extrusion Units' Mechanism

Source: Lee, Park and Ramesh. (2007).

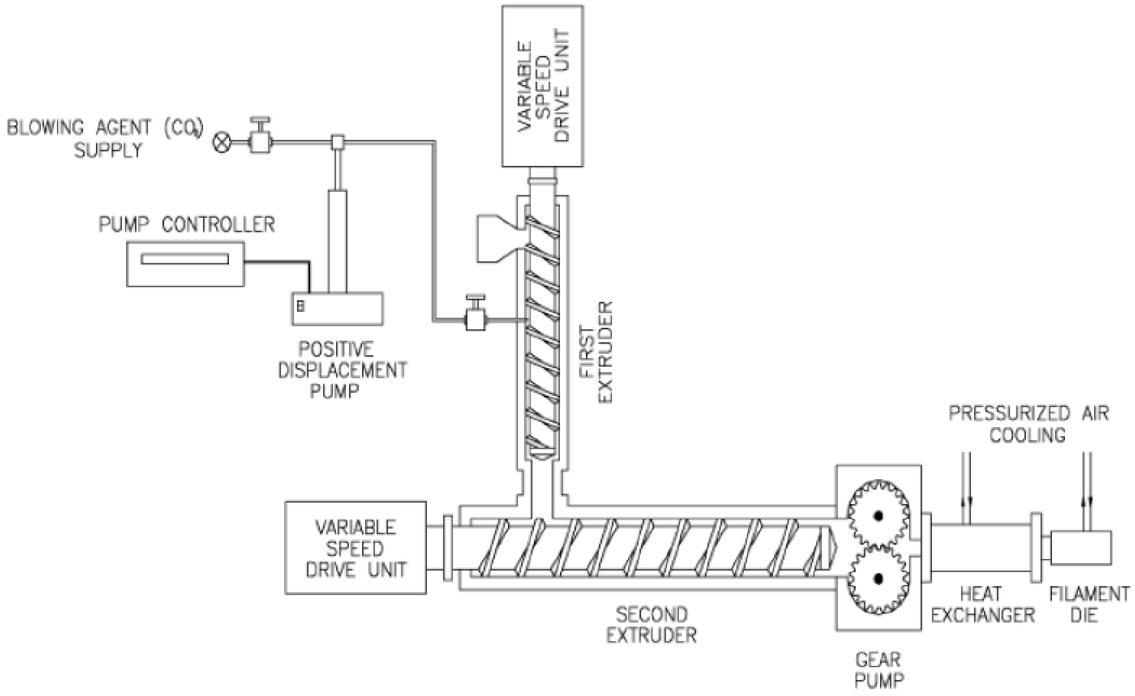


Figure 2.5: Schematic of Tandem Foam Extrusion System

Source: Zhang, (2010).

A schematic of a tandem foam extrusion system is outlined in Figure 2.5. Firstly, polymer resins are plasticised and blowing agents are injected directly into the polymer melt or pre-compounded polymer materials are passed in the first extruder. Inside the barrel the pumping action of the first extruder generates a very high pressure, which is essential to the dissolution and saturation of the blowing agents in the polymer melt. The second extruder provides mixing and initial cooling for the polymer melt and the gear pump controls the melt flow rate, independent of temperature and pressure changes. And then the single-phase polymer/gas solution is fed into the heat exchanger which provides further cooling to suppress cell coalescence. Lastly, the gas-saturated polymer melt enters the extrusion die, and foaming occurs due to pressure drops while the melt exits through the die (Throne, 2004).

2.5.2 Conventional Foam Extrusion

Detailed reviews of conventional polymeric foams and their processes have been given in many references (Throne, 1996). Foam products with various densities can be obtained in a conventional foam process. The state-of-the-art foams, however, possess characteristics of a fully-grown cell size greater than 100 μm (usually in the mm range), a cell population density lower than 106 $cells/cm^3$and a non-uniform cell size distribution (Seeler and Kumar, 1993). As result, the mechanical properties of the conventional foams are relatively poor.

The most commonly used blowing agents in conventional foam processing include fluorocarbons (FC), hydro-chlorofluorocarbons (HCFC), chlorofluorocarbons (CFC), n-pentane, and n-butane (Adamson, 1990). These agents can dissolve into the polymer melt in large quantities due to their high solubility. Therefore, a foam product with a high void fraction can be achieved at a relatively low pressure in the foaming system. In addition, the loss of blowing agent from the extrudate during expansion is small because the diffusivities of these agents are low due to their large molecular size (Klempner and Frish, 1991, Griskey, 1995, Shutov, 1996 and Gorski, 1996). These characteristics of the blowing agents allow the extrudate to expand significantly, and thus the final product has a low foam density. Despite the favourable properties of the conventional blowing agents, there are some serious environmental and safety concerns in utilizing them. CFCs and HCFCs are known to deplete the ozone layer and their use has been phased out (Dwyer, Zwolinski and Thrum 1990); other long chain blowing agents such as n-pentane and n-butane are hazardous because of their high flammability.

Moreover, due to the lower volatility of these blowing agents compared to CO_2 and N_2, the thermodynamic instability during foaming is relatively low, resulting in the production of low cell density foams.

2.6 Production and Control of Polymer Processing

According to Kazmer and Danai (2001), polymer processing management is recognised as a significant ways of increasing the efficiency as well as the reliability of thermoplastics products. Though there is no world single accepted standard for controlling defective product of manufactured plastic product (Kazmer and Danai, 2001). The plastic as earlier said are majorly produced through thermoforming, extrusion and injection moulding. Thermoforming such as blow moulding, plug-assist forming, vacuum forming, drape forming, male forming are produced in an uninterrupted process till pliable stages of the plastic is reached. The pliable stage has elastic modulus of approximately 0.5 MPa. The strain rate of pliable is approximately 100% per second if evacuated mould were to assume.

The heat from hot sheet is removed through mould heat conduction. The plastic mould is cooled with conditioned re-circulated water. The produced plastic is densely distributed at 10% to 90 % of the original layer. The density may vary within every six hundred seconds for a produced portion. Thermoforming process is a cyclical procedure while the processes of extrusions are a repeating and stable-state procedure. Within the process of extrusion, pellets from solid thermoplastics are introduced inside a revolving screw to be compressed becoming a compactly packed hard bed. The required mechanical power for its production is from electric motor. The electric motor is one to rotate the screw. There is tapered flight on the screw geometry. The tapered is designed to give the rate of dissipative melting to minimal flow restriction and better smooth flow. There will be uniform melt product that is obtained through a steady state process. The steady state is achieved through profile die which is designed for products exist. The product exists at uniform temperature and velocity.

The repeating products are introduced all the way through a series of cooling moulds to maintain and set the part into geometry. On achieving the geometry section which is sizes into different geometry during extrusion process continues. Most of the parts extruded are plainly square or round tubing; the procedure is has the capability to produce complex outlines, for instance structural components as well as casings of window. Moulding by injection is of different levels and includes plastication, injection, packing, cooling as well as ejection. The required specification is required to produce very intricate with good quality.

In a given range of temperature and pressure, injection moulding represents the process of extrusion for the generation of polymer melts and it quicker when compared with the process of thermoforming. Injection moulding and its variants co-injection, injection compression, gas assists moulding; pellets from thermoplastic are introduced into revolving screws and passed through melting for production of plastics. Uniform plastic melt will pass through extruder screw and moved along at controlled velocity –time ranges. This will help to evacuate the mould cavity. After solidification of the plastic melt has been achieved and the melt is strong enough to be checkout from the die, therefore the mould is made accessible and the plastic melt is removed. Hence, the subsequently cycles of melting of thermoplastic will be plasticised through extruder screw. The cycle times are varies and it is within four (4) seconds in compact discs production and three minutes (3) for automotive instrument panels production (Kazmer, and Danai, 2001).

2.6.1 Polymer Production

According to Nwokah and Hurmuzlu (2001), polymer production involves process control of injection moulding which is affected by the nonlinear dynamic behaviour of the polymeric materials, intricate connections that exist between the final products as well as the mould geometry qualitative characteristics. The general method for practising moulding process is presented in Figure 2.6.

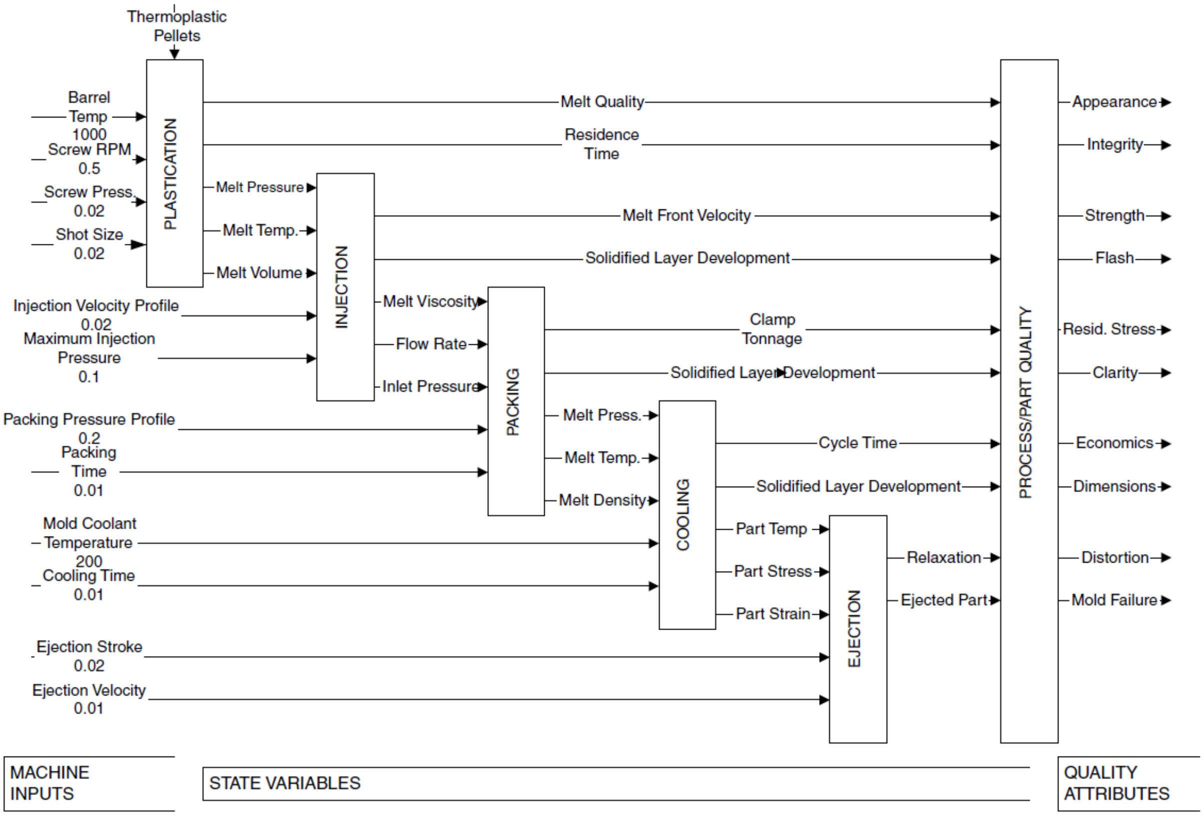


Figure 2.6: Injection Moulding Production Process

Source: Nwokah and Hurmuzlu (2001).

The injection moulding characteristics are shown on the left side in Figure 2.6 while quality measures are indicated on the right side. The process is consists of five division with different stages. The final process of each division does not determine the boundary or initial conditions of the next division. The each division influences final qualities of the moulded product of injection mould. Each single level of the moulding procedure by injection is intricate and authorizes comprehensive discussions pertaining to its behaviour.Plastication of the melted polymer is achieved by the synchronized shearing through rotating of an interior screw as well as the application of heat through an a barrel that is externally heated. Figure 2.6 shows that the inputs of plastication comprise rate of screw revolution, size of shot as well as pressure of screw plastication.

The plastication input is of vectors that are simplified instead of scalar quantities. For example, temperature of barrel is located at more than a few sites along the barrel. The multiple heater bands are required based on length of injection unit. The regulation of temperature of injection mould is achieved by either type J or K thermocouple implanted in the barrelled steel. The energy to every heater band is regulated using closed-looped logic controller that is programmable through the use of Proportional Integral Derivative (PID) control. The product residence time and quality is unswervingly affected by the standard of the moulded portion.

The main goal of the injection process is to complete the mould cavity with the polymer melt. The driving force of the screw is at different velocity of the order of 100cm/sec based on a particular time-velocity parameter. The profile of the velocity is picked so that the products can travel at comparatively standardized velocity. Amid the infusion of polymer, interaction of the cold mould wall with the hot polymer melts brings about the prompt creation of a solidified skin. Heat conduction to the mould is then adjusted against heat convection of the melts. This heat equalisation evens out the development of the frozen portion, which decreases the melts flow conductance. Whenever an extremely low velocity is chosen, the melts front would solidify prematurely. Whereas, whenever an extremely high velocity is chosen, the resin might result in high mould flash as well as deflection or degrading of the mould. The interconnectivity that exist between melts front velocity and the screw velocity profile is complicated as a result of the dynamics of acceleration of the melts and compressibility. It is quite difficult to determine the timed-velocity profile, actually, that majority of moulders utilise similar profile (gradual at commencement, quick in the center, and gradual at the finish) for every applications of moulding.

The circulated structure of the melts flow, as well as changing velocities with both position and time, likewise preclude concurrent control of the melts flow at diverse stages. The volumetric shrinkage of the solidified product with extra items should be force into the cavity of the mould. The packaging phase of the products requires pack and hydraulic pressure control behind the screw. The pressure is maintained and added to the final material that requires forcing into mould hollow until the portion has become solid.

Thus, the solidification of the product is an internal parameter of the moulding procedure which cannot be determined specifically. To focus on the right time of packing, different moulding attempts with different times of packing should be demonstrated as well as weighing of moulded portions. It ought to be observed that partial weight is likewise subject to the pressure and temperature of melts, therefore, an alteration in the inputs of machine might bring about incorrect times of packing. Post packing, the melted polymer is hardened though is extremely not solidified for partial discharge. Therefore, coolants are re-circulated at a predetermined temperature by the mold for the elimination of heat. The final phase in which cooling is taken place predominates the moulding cycle for half of its completion (Kazmer and Danai, 2001).

2.7 Polymer Modelling

The first basic study of polymer modelling and injection moulding procedure started with the empirical examination of Spencer of the advancement of melt flow. Williams and Lord also went into advance study aspect of the study through simulation of the injection moulding process. The simulation involves discretising of both the thickness and length measurement to monitor the propagation of melts front whereas at the same time demonstrating calculations of heat transfer. The examination is based on active development of a hardened layer of skin and in addition the polymer's compound non-Newtonian (shear dependent) which are rheological behaviour. In 1986, Kamal introduces sophisticated simulations of injection moulding through part design and process troubleshooting (Wang, 2007; Kamal, 1986).

2.8 Polymer Process Control

The basic method of controlling injection moulding is that no one of the last moulded portion features could be determined around the moulding system. However, there is still to be acceptable instrumentation that gives information on aesthetics or structural integrity prior of injection moulding process. Mostly, the injection mould is satisfied for quality by on-line state variable control as well as offline cycle to cycle adjustments of the machines defined point. The two parameters give certain pattern of management by introducing both continuous and discrete process of control as in Figure 2.7. The first level helps in regulating the machine actuators. This type control help give rise for adequate implementation of the programmed inputs of the machine as revealed in Figure 2.7. In the next level after the first, the stated factors for instance pressure of melt as well as temperature of melt are regulated to monitor predetermined profile and also the provision of improved precision regulation of the structure of the melts. At the final phase, the inputs of the machine are controlled to stabilise the standard of the portion by the improved group of points (Kazmer and Danai, 2001).

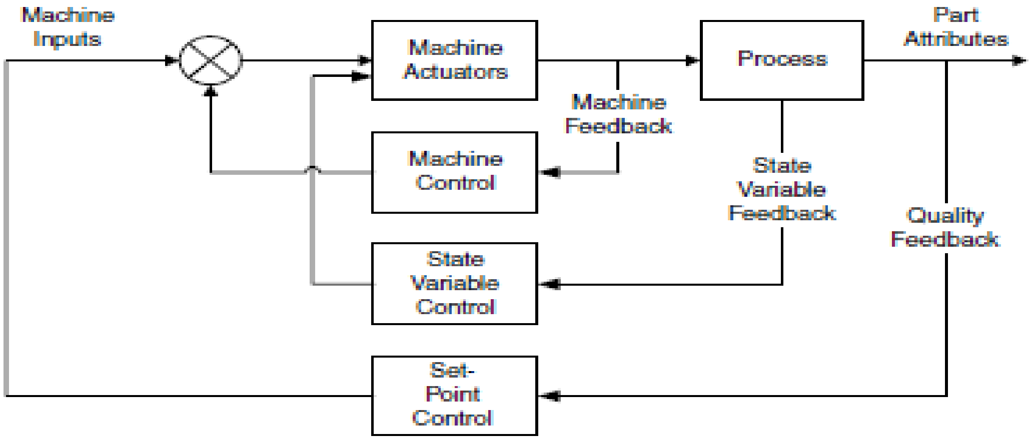


Figure 2.7: Production System Diagram of Injection Moulding Control
Source: Nwokah and Hurmuzlu, 2001.

There are three major process control level in polymer process and they are following:

i. Machine control: The majority of machine input is regulated using single-input/single output, proportional integral derivative (PID) control algorithms. The input mentioned in Figure 2.6 are such as the profile of the packing pressure, temperature of the melt, as well as the profile of the velocity of the injection is accorded due consideration as necessary.

ii. State variable control: In this case, the control of the machine is significant but it is the polymers material stages through temperature, morphology and pressure control is the most necessary (Coates and Speight, 1995). In the recent, technological developments has closed the gap between the parameters of the machine as well as the state of the polymer.

iii. Set point Control: The set point is obtained for quality achievement especially in a mass production by developing an empirical model that gives rise for set of experimental designed data (Luftig and Jordan, 1998).

2.9 Management Planning, Design and Control in Industry

An organisation needed to be planned, well designed into structure and controlled within division of labour.

2.9.1 Thermoplastics Industry and Division of Labour

Golany and Shtub (2001), division of work is an administration methodology focused around the separating of a procedure into an arrangement of little errands so each one undertaking might be appointed to an alternate laborer in the business. Division of work limits the extent of work every specialist need to learn empowering specialists to learn new employments rapidly and giving an environment where every laborer could be furnished with uncommon devices and methods needed to do his employment. A few favorable circumstances of division of work and specialization are:

i. the quick advancement of a high level of ability (specialization)

ii. the sparing of set-up time needed to transform starting with one kind of work then onto the next

iii. the utilization of extraordinary reason, typically exceptionally productive, machines, apparatuses, and methods produced for particular undertakings.

These profits don't aim to get free. Division of work obliges coordination of the yields created by the distinctive laborers into the last item. A typical approach to attain coordination is by a legitimate authoritative structure, a structure that characterizes parts and obligations of every individual and additionally the inputs obliged and the instruments and strategies used to deliver that individual's yields.

2.9.2 Thermoplastics Organization Structure

Associations are as old as humankind. Survival constrained individuals to sort out into families, tribes, and groups to accommodate fundamental needs (security, sustenance, cover, and so forth.) that a solitary individual experienced issues giving. Kingdoms and domains of the old world rose as more formal associations. While these associations had long haul objectives, different associations were made to attain particular novel objectives inside a constrained time allotment, for example, Pyramids, Great Wall of China, or the Jewish Temple, persuaded the advancement of impromptu associations. There is an expansive mixed bag of hierarchical plans; some are intended to help monotonous (continuous) operations, while others are intended to help exceptional one-time endeavour (Golany and Shtub, 2001). Organisation could be structured as follows:

i. Functional structure
ii. Project structure
iii. Matrix structure

2.9.2.1 Functional Structure

The functional organisation is intended to backing dreary exercises over a long (inconclusive) time of time. It is a various leveled structure in which parts are focused around the capacity or specialization of the specialists included. Capacities like advertising, fund, human assets, designing, creation, and logistics are normal. In huge associations, each one capacity is subdivided further, to the point that a legitimate compass of control is attained. For instance, the advertising office might be partitioned geologically: showcasing in Europe, the United States, Asia and Africa. Building divisions could be subdivided into electrical designing, mechanical building, and modern building.

In an utilitarian association, the part of every authoritative unit is to manage the work substance identified with its capacity. Albeit adjusting is obliged to characterize the accurate fringes and interfaces between the diverse capacities, division of work is (regularly) along the useful lines. Labourers in the same authoritative unit (same capacity) would have comparative information, training, and experience. A hindrance of this structure is its inflexibility in managing complex undertakings where distinctive capacities (or controls) must team up and the trouble in presenting change. The stream of data between (distinctive capacities') authoritative units may be troublesome, bringing about trouble in incorporation (Golany and Shtub, 2001).

2.9.2.2 Project Structure

The venture structure is intended to handle one-time, special, and non-intermittent attempts. It is focused around a team amassed for a restricted time to accomplish a predefined objective. The parts of the undertaking group may originate from diverse hierarchical units and have distinctive trainings and foundations (Salvendy, 2001). They have a typical objective to have venture achievement; and a typical pioneer "the undertaking supervisor". Associations managing tasks may receive an adaptable structure in which just a center gathering has a changeless structure while the vast majority of the association is relegated to extend bunches. Leeway of the undertaking structure is its adaptability; the venture group could be collected precisely as per the current workload. An alternate point of interest is the making of a solitary purpose of contact for the client; the task director has complete obligation regarding the undertaking and for client fulfilment. Collaboration and coordination between individuals originating from distinctive controls is simpler to accomplish when they fit in with the same venture, impart a typical objective, and have the same undertaking chief. The detriments of the task structure are identified with its brief nature; assets are not pooled and hence effectiveness and adequacy are difficult to attain. The constrained life of the venture's hierarchical structure makes uneasiness and instability about the future part of the colleagues, chiefly at the last phases of the task, and data between undertaking groups is not streaming effortlessly.

2.9.2.3 Matrix Structure

As per Salvendy (2001), associations included in progressing operations and various tasks at the same time create half breed structures that mix the utilitarian authoritative structure with the undertaking structure. In spite of the fact that a vast mixture of such structures exist, the greater part of these structures are focused around a lasting practical skeleton and brief undertaking structures. Each one undertaking has a task director (or facilitator) that serves as a purpose of contact for the clients and is in charge of the venture achievement.

2.10 Thermoplastic Pipe

The material to be used for thermoplastic pipe is polyvinyl chloride (PVC) rigid type which means it is an unplasticised PVC (UPVC). A major PVC weakness is its low thermal stability. As long as there is no dead space within the extruder, die, or adapters where resin can stagnate, and the processing temperatures are kept low, PVC does not degrade. However, over long runs degradation can occur, resulting in a dark streak initially that leads to total degradation and a dark, useless material. If the extrusion process is stopped, PVC in the barrel and die needs to be purged from the system. PVC is not hygroscopic and does not require drying prior to extrusion (Giles-Jr. and wagner-jr. 2005).

2.11 PVC Extrusion Processes

According to Giles-Jr. and Wagner-Jr., (2005) PVC extruder machine consists of different component and they are hopper, feed screw, barrel, extruder die and so forth. Plastic pellets or beads are fed into hopper and transported along feed screw travels along a barrelled compartment. The resin moves through the barrel, it is subjected to compression, friction as well as heated zones. The product will be resin melts which travel further and at the exit end of the screw. The resin melt enters a chamber designed to ensure an evenly distributed flow to the die.

Most equipment such as melt pump is used to control any pressure surges and as well as breaker plates serve to prevent any solid objects from passing through the die. The die is a precisely machined part with a patterned opening such that the extruded plastic takes that die pattern for its cross sectional area. The die used in the process must be well cleaned to prevent surfaces free from defects otherwise unwanted patterns will appear on the extruded product. Product from the die solidifies quickly. The end product is achieved by immersion in cooling water, air-cooling, or contact with chill rolls. Overheating the melt is to be avoided at all costs, or the product will not form properly on solidification. Once solid, the product material can be wound, spun, or cut in defined lengths depending upon its intended end-use

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The required materials for designing and constructing the extrusion machine are as follow:

i. Steel plate of thickness 1.2mm and 6mm
ii. Bearings
iii. Spur gear
iv. Belt
v. Heat element and glass fibre
vi. Bolt and nut
vii. Pump
viii. Electrode

ix. Electric motor
x. Corrosion resistant paint
xi. Steel pipe
xii. Grinding element or disk
xiii. Cutting disk
xiv. Electrical control switch button

3.1.2 Chemical Composition of PVC Pipe Material

The following are required to have good physical quality of PVC pipe:

i. Plastic pellet or resin (83.19 %)
ii. Stabilizer (2.0%)
iii. Titanium (iv) oxide (0.5%)
iv. Tetraoxo-sulphate (vi) acid (0.13%)
v. Black pigment (0.03%)
vi. Blue pigment (0.01%)
vii. Reactant agent (14.14%)

Resin is the powder (polymer) required to produce PVC pipe. Stabilizer is required to regulate thermal system of the extrusion. The stabilizers are achieved through mixing of PVC resin using a good mixer. This will help to bring about amount of heat required from stabilizer into the resin powder. Major additives are required to form the compound polyvinyl chloride. These additives function as stabilisers for heat, oxidative stability (TiO_2), UV stability, concentrates, flame retardants, fillers and reinforcements. Blue pigment is 0.01% required for colouration The PVC is blend and ingredients were mixed to form a product that will be fed into extruder screw through hopper. The product is melt, mix and delivered into die shape as an extrudate. On exiting the die the product is cooled and solidified in the desired shape. The product is then pulled away from the extruder at regulated speed for obtaining a good uniform section. The following steps are required for the PVC material processing accordingly:

i. Feeding of polymer to extruder: this allow for proper mixing of the material through hopper
ii. Extrusion by extrusion machine: this is the portion in which pipe production technology takes place. After feeding, polymers are melted or plasticated, conveyed forward, melt mixed, and formed into a shape.

3.1.1 The Extruder Machines Components

The aforementioned required materials are used for designing and fabricating PVC extrusion machine that consist of the following components.

i. Drive system
i. Feeding system
ii. cylindrical housing (barrel) and heating system
iii. Head and die assembly

iv. regulating (control) system

The drive system is of electric motor, gear, the screw (extruder), belt and thrust-bearing section which are assembled. The feeding system is the feed throat and hopper. The cylindrical housing and heating systems are of barrel and heating element. The head and die assembly consist of breaker plate and the die. Electrical switch button is main control system in the extruder.

3.2 Design Calculations of the Extruder Machine

In the study the extruder design are analysed based on components listed on section 3.1.1.

3.2.1 Basic Requirement for Extruder Design

The following are the basic requirement for extruder design (Giles-Jr.and Wagner-Jr., 2005). The volumetric output (ΔQ) of melt required in a die:

$$\Delta Q = \frac{\Delta P}{n} \tag{3.1}$$

Where:

ΔP = change in pressure

n = power law index

Extruder output (Q) or volumetric flow rate is equal to the volumetric drag flow rate (Q_D) minus pressure flow rate (Q_P) minus leakage flow (Q_f). The extruder output (PVC melt) is Non-Newtonian flow.

$$Q_D = \frac{WHV_z}{10}(4 + n) \tag{3.2}$$

$$v_z = \pi DNcos\varphi \tag{3.3}$$

$$Q_P = \frac{WH^3sin\varphi}{4\eta(1+2n)} \tag{3.4}$$

$$R = \Delta P/Q \tag{3.5}$$

$$Q = Q_D - Q_P - Q_f \tag{3.6}$$

$$Q = D^2Nh \tag{3.7}$$

The required mechanical power P_m is:

$$P_m = \frac{D^{n+2}N^{n+1}L}{h^n} \tag{3.8}$$

The required mechanical pressure gradient $\frac{\delta P}{\delta z}$ is:

$$\frac{\delta P}{\delta z} = \frac{DN}{h^2} \tag{3.9}$$

The die pressure P_d is:

$$P_d = \frac{DNL}{h^n} \tag{3.10}$$

Mean residence time t_r is:

$$t_r = L/DN \tag{3.11}$$

Where:

W = channel width

H = channel depth

D = diameter of extruder screw

N = speed of extruder in rpm

L = screw length

φ = die or helix angle

R = resistance to flow

h = depth of a channel in metering section

The volumetric output for annular die is:

$$Q_{die} = \frac{\Delta P\pi(R_1+R_2)h^3}{12\mathrm{L}\eta} \tag{3.12}$$

Circumference speed of the extruder v_e is:

$$v_e = \pi \mathrm{DN} \tag{3.13}$$

Shear rate in the extruder γ is:

$$\gamma = v_e/h \tag{3.14}$$

The apparent viscosity η_a of the fluid is:

$$\eta_a = \frac{shear\ stress\ (\tau)}{shear\ rate\ (\gamma)} \tag{3.15}$$

Where:

R_1 = radius at inside

R_2 = radius at outside

η = viscosity of polymer

3.2.1.1 Extruder Design

If the critical deflection were to estimate based on shaft geometry on bearing and gear points, the following formulae needed to be determined (Shigley and Nisbett, 2008):

$$\sigma_a = \frac{K_f 32 M_a}{\pi d^3} \qquad (3.16)$$

$$\sigma_m = \frac{K_f 32 M_m}{\pi d^3} \qquad (3.17)$$

$$\tau_a = \frac{K_{fs} 16 T_a}{\pi d^3} \qquad (3.18)$$

$$\tau_m = \frac{K_{fs} 16 T_m}{\pi d^3} \qquad (3.19)$$

If axial load is neglected and joining the stresses equation (3.16-3.19) is determined using distortion energy failure theory called von Mises stresses and stated as follow in solid circular shaft (Shigley and Nisbett, 2008):

$$\sigma'_a = ({\sigma_a}^2 + 3{\tau^2}_a)^{1/2} = \left[\left(\frac{K_f 32 M_a}{\pi d^3}\right)^2 + 3\left(\frac{K_{fs} 16 T_a}{\pi d^3}\right)^2\right]^{1/2} \qquad (3.20)$$

$$\sigma'_m = ({\sigma_m}^2 + 3{\tau^2}_m)^{1/2} = \left[\left(\frac{K_f 32 M_m}{\pi d^3}\right)^2 + 3\left(\frac{K_{fs} 16 T_m}{\pi d^3}\right)^2\right]^{1/2} \qquad (3.21)$$

Where:

σ'_a = von Mises alternating fluctuating stresses due to bending

σ'_m = von Mises midrange fluctuating stresses due to bending

The diameter of the shaft is determined using Goodman approach as follows:

$$d = \left(\frac{16}{n}\left\{\frac{1}{S_e}\left[4\left(K_f M_a\right)^2 + 3\left(K_{fs} T_a\right)^2\right]^{1/2} + \frac{1}{S_{ut}}\left[4\left(K_f M_m\right)^2 + 3\left(K_{fs} T_m\right)^2\right]^{1/2}\right\}\right)^{1/3} \quad (3.22)$$

The fatigue failure using modified Goodman approach is determined as follow:

$$\frac{1}{n_f} = \frac{\sigma'_a}{S_e} + \frac{\sigma'_m}{S_{ut}} \quad (3.23)$$

To predict for yielding, von-Mises maximum stress is employed:

$$\sigma'_{max} = [(\sigma_a + \sigma_m)^2 + 3(\tau_a + \tau_m)^2]^{1/2}$$

$$\sigma'_{max} = \left[\left(\frac{32K_f(M_a+M_m)}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs}(T_a+T_m)}{\pi d^3}\right)^2\right]^{1/2} \quad (3.24)$$

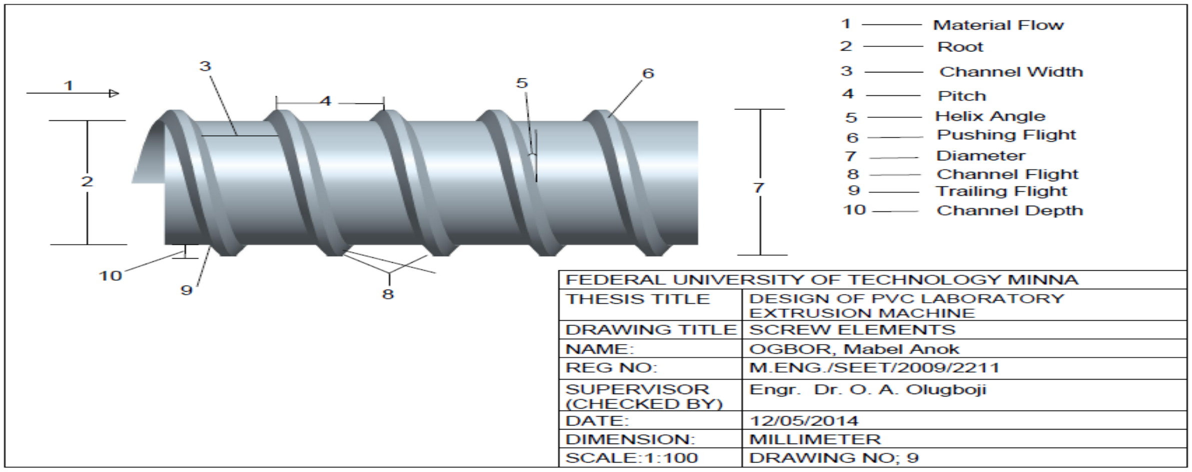
The yield strength is given as:

$$S_y = n_y \sigma'_{max} \quad (3.25)$$

Design of extruder based on rigidity is given by (Khurmi and Gupta, 2003):

$$T = \frac{G\theta J}{L} \quad (3.26)$$

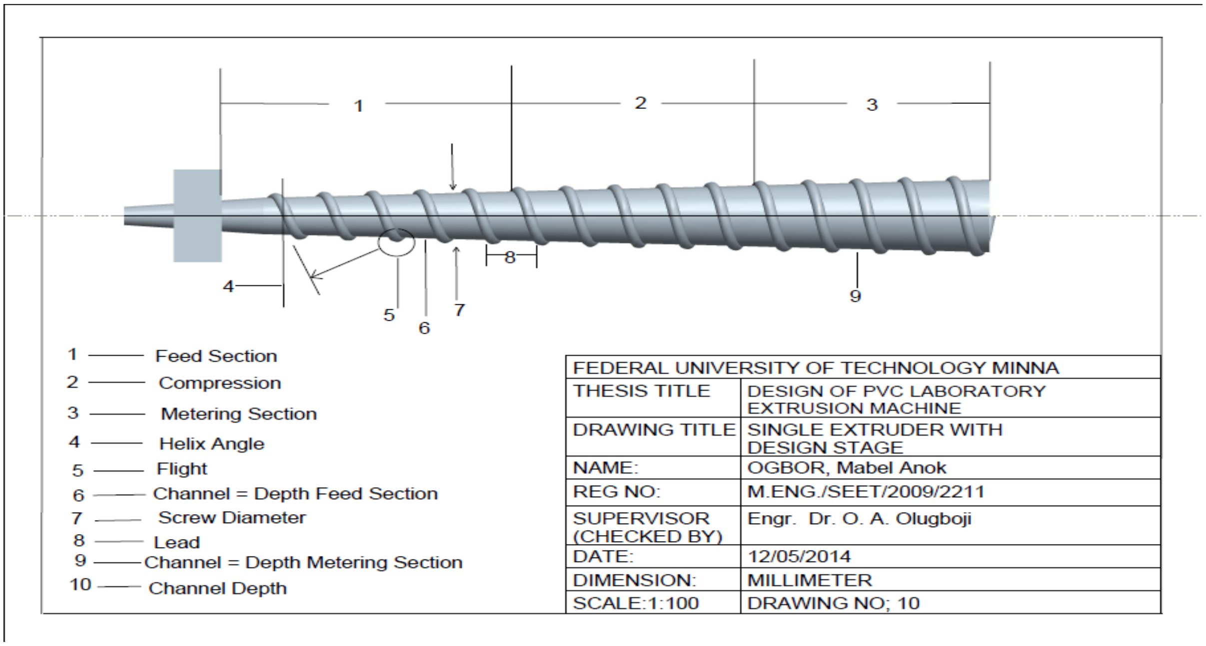
The single screw extruders are used to process heat sensitive and shear sensitive materials and may provide intensive mixing by kneading. Figure 3.1 shows the screw elements while Figure 3.2 is the sketching view of the extruder.



FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	SCREW ELEMENTS
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 9

Figure 3.1: Screw Elements

Figure 3.2: Single Extruder with Design Stages



FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	SINGLE EXTRUDER WITH DESIGN STAGE
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 10

The extruder compression ratio (Q) ratio is given as:

$$Q = \frac{lenght\ of\ extruder\ (L)}{diameter\ of\ extruder\ (D)} \tag{3.27}$$

3.2.2 Analysis of Extruder

The shaft used for the extruder is based on rigidity and other basic design parameters.

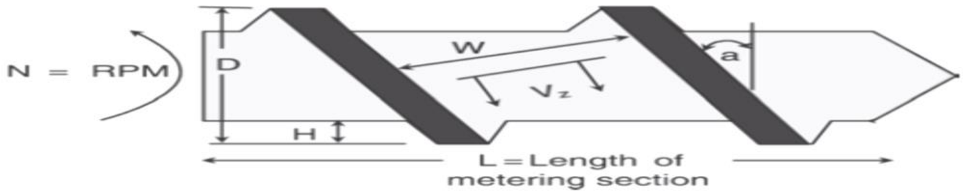


Figure 3.3: Extruder Screw Shaft

Source: Giles-Jr. and Wagner-Jr., (2005).

In Figure 3.3 the following design parameter are known:

Channel width, $W = 70\ mm$

Channel depth, $H = 30mm$

Root diameter, $d = 80\ mm$

Extruder diameter, $D = d + 2H = 140\ mm$

Helix angle, $\varphi = 30^o$

Moment of inertia of the shaft, $J = \frac{\pi d^4}{32} = \frac{\pi \times 0.08^4}{32} = 4\ \times 10^{-6}\ m^4$

Extruder compression ratio (Q), was determined as:

$$Q = 8 = \frac{lenght\ of\ extruder\ (L)}{diameter\ of\ extruder\ (D)} = L/140$$

The length of extruder (screw), $L = 8 \times 140 = 1120\ mm$

3.2.3 Design of Driving System

3.2.3.1 Determination of Motor's Power Rating

The power supplied by the electric motor for turning the single screw extruder is given (Sharma, 2003):

$$P = \frac{2\pi NT}{60} \tag{3.28a}$$

$$P = \frac{\sigma_l\, v}{\eta} \tag{3.28b}$$

Where:

P= Power transmitted by the shaft (W)

N = speed of shaft (rpm)

T = twisting moment on the extruder (Nm)

η= efficiency of the motor (0.98)

v = extrusion speed (m/s)

σ_l = extrusion load (N)

3.2.3.2 Design of Spur Gear

In the study, power and torque requirements help in determining the total length needed for system. According to Shigley and Nisbett (2008), speed or torque ratio from input to output is required to estimating the required gear length.

According to Khurmi and Gupta (2003), the maximum value of the bending stress required is determined as follows :

Let $\sigma_w = \frac{My}{I}$ (3.28c)

$$M = W_T h \quad (3.29)$$

$$y = t/2 \quad (3.30)$$

$$I = bt^3/12 \quad (3.31)$$

Substituting the equations (3.29-3.31) in equation (3.28c) gives:

$$\sigma_w = \frac{W_T h t/2}{bt^3/12}$$

$$\sigma_w = \frac{W_T h}{bt^2/6} \quad (3.32)$$

$$W_T = \frac{\sigma_w b t^2}{6h} \quad (3.33)$$

By introducing constant x and k as follows

$$t = xp_c \tag{3.34}$$

$$h = kp_c \tag{3.35}$$

Therefore, equation (3.33) becomes:

$$W_T = \frac{\sigma_w b (xp_c)^2}{6kp_c}$$

$$W_T = \frac{\sigma_w b p_c x^2}{6k} \tag{3.36}$$

Let $\frac{x^2}{6k} = Y$, and $p_c = \pi m$

Hence, equation (3.36) becomes:

$$W_T = \sigma_w b \pi m Y \tag{3.37}$$

$$Y = t^2/6hp_c \tag{3.38}$$

Equation (3.38) is the Lewis form factor or tooth form factor. The application of equation 3.8 is to consider bending of the tooth. The compression force due to the radial component was not considered because it is negligible. The application of Lewis Equation as a bending stress to determine gear teeth is given by Barth formula. This helps to determine varying effects that are severe whenever pitch line velocity improves.

$$\sigma_w = \sigma_o C_v \tag{3.39}$$

$$C_v = \frac{3}{3+v} \tag{3.40}$$

Where:

σ_o = allowable static stress (MPa)

C_v = velocity factor

v = pitch line velocity

Dynamic and wear tooth load is determine using Buckingham equation given by (Khurmi and Gupta, 2003):

$$W_D = W_T + W_\Delta \tag{3.41}$$

If, $$W_\Delta = \frac{21v(bC+W_T)}{21v+\sqrt{bC+W_T}} \tag{3.42}$$

$$W_D = W_T + \frac{21v(bC+W_T)}{21v+\sqrt{bC+W_T}} \tag{3.43}$$

Also, the wear tooth load is given by:

$$W_w = D_p bQK \tag{3.44}$$

$$Q = \frac{2VR}{VR+1} \quad \text{For external gear} \tag{3.45a}$$

$$Q = \frac{2VR}{VR-1} \quad \text{For internal gear} \tag{3.45b}$$

$$VR = \frac{T_G}{T_p} \tag{3.45c}$$

The pitch line velocity is determined from the relation (Shigley and Nisbett, 2008):

$$v = \frac{\pi DN}{60} = \frac{\pi mTN}{60} = p_c TN/60 \tag{3.46}$$

$$D = mT \tag{3.47}$$

Where:

Component	**20^0 full depth**	**20^0 full depth (mm)**
Addendum	1m	4
Dedendum	1.25m	5
Working depth	2m	8
Minimum total depth	2.25m	9
Tooth thickness	1.57m	6
Minimum clearance	0.25m	1
Root Fillet radius	0.4m	1.6

$m =$ Module (mm)

$D =$ Pitch circle diameter

$T =$ Number of teeth

In the study, the spur gear is analysed based on module (m) in Table 3.1.

$T_G = 44$ (Gear teeth), $T_p = 22$ (pinion teeth)

Table 3.1: Gear Specification

Source: Khurmi and Gupta (2003).

Gear ratio: $\frac{T_G}{T_p} = \frac{D_G}{D_p} = 44/22 = D_G/D_p = 2$

Gear module, $m_G = \frac{D_G}{T_G} = 3.98\,mm \cong 4mm$, this is nearest standard of module

Pitch circle diameter, $D_G = m_G T_G$

Pitch circle diameter of gear, $D_G = 4(44) = 176\,mm$

Pitch circle diameter of pinion, $D_p = 4(22) = 88\,mm$

The design tangential load (W_T) on the gear is obtained from the power transmitted (P) through electric motor (5HP) and pitch line velocity (v) of the gear by using the equation:

$$W_T = \frac{PC_s}{v}$$

According to Khurmi and Gupta (2003), the service factor (C_s); for enclosed well lubricated gear in a steady state, if the machine is to operate between 1 to 3hrs per day is 0.8.

The pitch line velocity, $v = \frac{\pi DN}{60} = p_c TN/60$

$f = 50Hz$, frequency of the motor

$D = 176\,mm,$ Pitch circle diameter

$N =$ Revolution per minute

$T =$ Time in seconds

$$N = \frac{2\pi}{T} = 2\pi f = 314 \ rev/min$$

$$v = \frac{\pi 176(314)}{60} = 2893.6 \, mm/s$$

$$\Rightarrow v = 2.9 \, m/s$$

The required power (P) is 6.93 kW and therefore tangential load (W_T) is:

$$W_T = \frac{PC_S}{v} = \frac{6930 \times 0.8}{2.9} = 1911.7 \, N$$

Therefore, maximum bending stress (σ_w) is:

$$\sigma_w = \frac{W_T 6h}{bt^2}$$

Thickness of the tooth in Table 4.2, $t = 6mm$

Half of tooth thickness, $y = \frac{t}{2} = 3mm$

Length of the tooth or working depth in Table 4.2, $h = 8mm$

Width of gear face, $b = 4m = 16mm$

$$\sigma_w = \frac{W_T 6h}{bt^2} = \frac{1911.7 \times 6 \times 8}{16 \times 6^2} = 159.3 \, N/mm^2$$

The permissible working stress for gear teeth using Barth formula, velocity factor is first determined as follow:

The velocity factor, $C_v = \frac{3}{3+v} = \frac{3}{3+2.9} = 0.51$

The allowable static stress for forged carbon steel heat treated (Khurmi and Gupta, 2003) is: $\sigma_o = 210\ MPa$

$$\sigma_w = \sigma_o C_v = 210 \times 0.51 = 107.1\ MPa = 107.1\ N/mm^2$$

The tooth form factor, $Y = \frac{t^2}{6hp_c}$

Circular pitch, $p_c = \pi m = 4\pi = 12.6\ mm$

$$Y = \frac{6^2}{6(8\times 12.6)} = 0.06$$

The corresponding dynamic factor C, corresponding to Y is 684 N/mm for gear deformation factor Table in accordance to Khurmi and Gupta, 2003.

The dynamic tooth load, $W_D = W_T + W_\Delta$

$$W_\Delta = \frac{21v(bC+W_T)}{21v+\sqrt{bC+W_T}}$$

$$W_\Delta = \frac{21\times 2.9(16\times 684+1020.7)}{21\times 2.9+\sqrt{16\times 684+1020.7}}$$

$W_\Delta = \frac{60.9(11964.7)}{60.9+109.4} = \frac{72865.23}{170.3} = 4278.6$ N;

$$\Longrightarrow\ W_D = 1911.7 + 4278.6\ = 6190.3\ N\ .$$

3.2.4 Design of Extrusion Die and Adapter

The entrance which gives chance to PVC melt to form shapes is extrusion die and carbon steel was used to fabricate this portion in a circular form as in Figure 3.4. The die is machined to allow shrinkage allowance when the PVC melt cools and re-solidifies. Adapter plate in Figure 3.4 allows the transitional forms from circular extruder to exit as approximately PVC shape.

The die opening is annular type as in Figure 3.4 in which the diameter of internal barrel is equal internal barrel diameter for sealing the barrel.

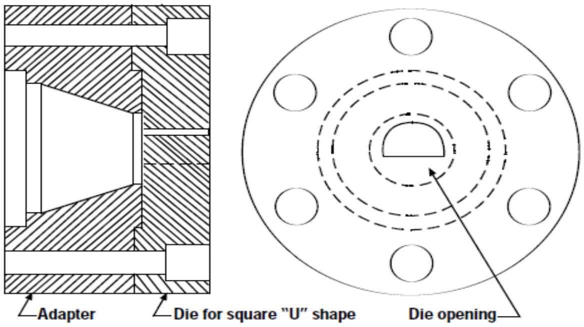


Figure 3.4: Detail Drawing Die and Adapter

Source: Nader, (2012).

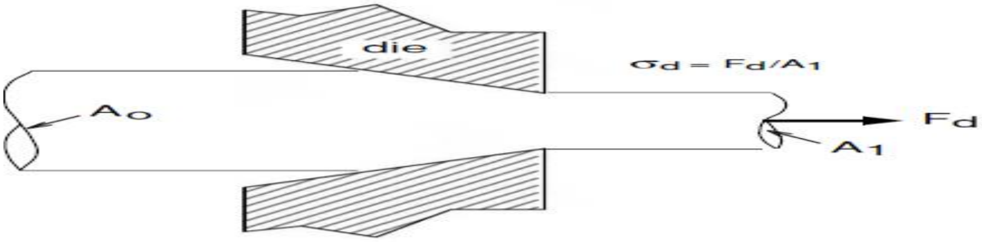


Figure 3.5: Skeletal View of Extrusion Dies
Source: Hosford and Caddell, (2007).

In this study the use of annular dies with in-line cross sectional area are analysed based on the entrance channel of the die is in-line with the exit channel as in Figure 3.5. Let V_o be the volume of resin (PVC) entering into the die equals exiting volume V_1 of the resin from the die.

$$V_o = V_1$$

$$A_o \Delta l_o = A_1 \Delta l_1 \tag{3.48}$$

The total external work W_e is given by (Hosford and Caddell, 2007).

$$W_e = F_e \Delta l \tag{3.49}$$

The work per volume is:

$$w_e = \frac{F_e \Delta l}{A_o \Delta l_o}$$

If $\Delta l \cong \Delta l_o$, the work per volume becomes:

$$w_e = \frac{F_e \Delta l}{A_o \Delta l} = \frac{F_e}{A_o} \tag{3.50}$$

In ideal process, extrusion pressure P_e must be equal to the workdone per volume for appropriate PVC pipe extrusion and hence we have:

$$w_e = P_e \tag{3.51}$$

$$w_i = \int \sigma \delta \varepsilon \tag{3.52}$$

($\delta\varepsilon$ change in length)

In reality the actual work is greater than ideal work, we have, extrusion pressure to be:

$$P_e > \int \sigma\delta\varepsilon \qquad (3.53)$$

$$w_e = \frac{F_e}{A_1} = \sigma_e \qquad (3.54)$$

3.2.4.1 Design of Extrusion Die and Breaker Plate

The extrusion die and breaker plate is designed with following parameters.

Internal barrel radius, $r_{bi} = 75\ mm$

Total radius of extruder with screw, $R = 42.5\ mm$

External barrel radius, $r_{be} = 150\ mm$

Annular die radius, $r_d = 20\ mm$

Die gap, $h = 10\ mm$

Extruder length, $L = 1120\ mm$

Barrel length, $L_b = 770\ mm$

Die land length, $L_d = 50\ mm$

Annular die external radius, $R_d = r_d + h = 20 + 10 = 35mm$

Annular die internal Area, $A_d = 2\pi r_d(L_d + r_d) = 2\pi \times 0.02(0.05 + 0.02) = 0.0088\ \mathrm{m}^2$

3.2.5 Feeding System

The feed hopper has square shape opening with tapered end, therefore cross-sectional area of pyramid shape is employed in the design.

Hopper width, $w_h = 300mm$

Hopper height, $hh = 250mm$

Taper radius end with circular opening, $r = 90mm$

Taper end height, $h = 50mm$

Total height of hopper, $H = hh + h = 50 + 250 = 300mm$

Base area of hopper $A = {w_h}^2 = 0.3^2 = 0.09\ m^2$

3.3 Fabrication Procedure of the Machine

In the study single screw extruder (transmission shaft) is fabricated to convey PVC powder and also to forward the PVC powder for heating and melting. The screw is fabricated to homogenise and mix the PVC powder and also to deliver the melt into the die. The single design extruder consists of three distinct zones, in which there are feed zone, transition zone and metering zone. Feed zone is a flight that conveys PVC powder or pellets away from the feed throat. However, the transition zones help in changing from feed zone as in unmelted products to melted product. The product called resin is totally compressed in the transition zone so that the product can easily transport into metering zone and which is the last part of production process. The metering section of the screw would allow the resin to force through the die.

The barrel is the housing of the extruder in which the barrel is wound by heating element for heating purpose. The barrel is a bimetallic and cylindrical shape which is used to increase the service life of extrusion. Barrels are made of carbon steel material. The heating element is located along the barrel so that the proper melting of resin can be done. The heater was mounted for reducing hot and cold point across the barrel length. Heaters cover the maximum barrel area and are tightly clamped around the barrel to prevent hot spots and provide uniform heating. The extruder is put into work by control button.

The barrel and heater help in heating and melting the polymer by controlling the temperature in the different zones, preventing material from overheating and degrading. The screw, in combination with the barrel, feeds PVC to the die, and builds pressure into the die. The extruder head assembly includes breaker plate, adapter to connect the die assembly to the extruder, and die. The breaker plate is a round disk which stops the spiralling action of the PVC melt coming off the screw by forcing the PVC in straight lines as it passes through the breaker plate. This provides a seal between the extruder and the die/adapter. The study provide for extruding of 40mm PVC pipe.

3.4 Computer Aided Design (CAD) Drawing for Extrusion Machine

In the study, machine element of the laboratory extrusion machine is modelled using Pro-Engineering software for both detail and assembly drawing. The following extrusion machine component is modelled for the study:

i. Gear, extruder, feed hopper, extrusion machine stand and
ii. cylindrical barrel

The CAD drawing of the component was in Appendix I on page 69 to 72.

3.5 Determination of PVC Melt Speed

The PVC melt in the barrel was based on circumference speed of the extruder.

Extruder speed, $N_i = 157\, rpm$

Circumference speed of the extruder v_e is:

$$v_e = \pi \mathrm{D} N = \frac{\pi 0.140 \times 157}{60} = 1.2\ m/s$$

PVC velocity in the barrel, v_z

$$v_z = \pi DNcos\varphi = 1.2 \cos 30 = 1\, m/s$$

3.6 Determination of Extrusion Flow, Shear Rate and Power

Power law index for PVC, $n = 0.3$

Channel depth, H = 30mm

Shear rate of the extruder, $\gamma_e = \frac{v_e}{H} = \frac{1.2}{0.03} = 40\ s^{-1}$

Shear rate of the PVC melt, $\gamma_{pvc} = \frac{v_e}{H} = \frac{1}{0.03} = 33\ s^{-1}$

m = Consistency index = 6 x 10^3 Pa.s

The viscosity (η_a) of the fluid is:

$$\eta = m\, {\gamma_e}^{n-1}$$

$$\eta = 6000 \times 33^{0.3-1} = 519\ Pa.s$$

Drag flow rate or maximum extruder output is:

$$Q_D = \frac{WHV_z}{10}(4 + n) = 0.07 \times 0.03 \times \frac{1}{10}\ (4.3) = 0.0009\ \mathrm{m}^3/s$$

Maximum Pressure of the screw is:

$$P_m = \frac{6\pi DLN\eta}{H^2 \tan\varphi} = \frac{6\pi \times 0.14 \times 1.120 \times (\frac{157}{60}) \times 519}{0.03^2 \times \tan 30} = \frac{4013.9}{0.00052} = 7.7\ MPa$$

Volumetric pressure flow rate is:

$$Q_P = \frac{WH^3 sin\varphi}{4\eta(1+2n)} \times \frac{\Delta P}{L} = \frac{0.07 \times 0.03^3 \sin 30}{4 \times 519\ (1.6)} \times\ 7.7 \times \frac{10^6}{1.120} = \frac{7.28}{3720.2} = 0.019\ \mathrm{m}^3/s$$

Expected extruder output (Q) or volumetric flow rate is:

$$Q = Q_D - Q_P = |0.0009 - 0.019| = 0.0181\ \mathrm{m}^3/s$$

Maximum extruder output (Q_m): $Q = Q_D = 0.0009\ \mathrm{m}^3/s$

Shear stresses of the extruder due to PVC melt, $\tau_e = \eta \times \gamma_{pvc} = 519 \times 33 = 17127\ Pa$

Heat capacity of PVC, $C = 0.96\ kJ/kgK$

PVC latent heat of fusion $L = 0.102\ \ kJ/kg$

Melt Temperature of PVC, $\Delta T = 180 - 25 = 155\ {}^{\mathrm{o}}\mathrm{C}$

Areas of annular die internal, $A_d = 0.0088\ \mathrm{m}^2$

Melt density of PVC, $\rho = 900\ kg/\mathrm{m}^3$

PVC velocity, $v_z = 1\,m/s$

Mass flow rate, $\dot{m} = \rho v_z A_d = 900 \times 1 \times 0.0088 = 7.9\,\frac{kg}{s}$

The required input power (P) for extruding the PVC is the product of volumetric flow rate (Q_m) and pressure drop (P_m) in the extrusion process.

$$P = Q_m \times P_m = 0.0009 \times 7.7 \times 10^6 = 6.93\,kW$$

Mechanical power scale up factor is:

$$P_m = \frac{D^{n+2} N^{n+1} L}{H^n} = \frac{0.14^{\;0.3+2} \left(\frac{157}{60}\right)^{0.3+1} 1.12}{0.03^{0.3}} = 0.0109 \times 3.49 \times \frac{1.12}{0.349} = \frac{0.0426}{0.349} = 0.122$$

Mechanical power, $P_m = 0.122 \times 6.93 \times 10^3 = 845.5\,W$

3.7 Determination of Extrusion Die Pressure

The die pressure P_d is: $P_d = \frac{DNL}{H^2} = \frac{0.14 \times (\frac{157}{60}) \times 1.12}{0.03^2} = \frac{0.41}{0.0009} = 455.6$ Pa

The cross sectional area of internal barrel is:

$$A_o = 2\pi r_{bi}(L_b + r_{bi}) = 2\pi \times 0.075(0.77 + 075) = 0.398\ \mathrm{m}^2$$

Maximum load is:

$$\sigma_m = P_m A_d = 7.7 \times 10^6 \times 0.0088 = 67.8\,k\mathrm{N}$$

Shear rate of PVC melt in the die, $\gamma_{die} = \frac{6Q_m}{\pi(R_d + r_d)h^2} = \frac{6(0.0009)}{\pi(0.035+0.02)0.01^2}$

$$\gamma_{die} = \frac{0.0054}{0.000017} = 318\, s^{-1}$$

The velocity at the inlet of the die is calculated using the drag flow as:

$$v = \frac{Q_m}{A_d} = \frac{0.0009}{0.0088} = 0.1\, m/s$$

Mass flow rate per hour, $\dot{m} = \rho v A_d = 900 \times 0.1 \times 0.0088 = 0.792\, kg/s$

The breaker plate is equal to the circumferential face of the barrel; hence the internal of the barrel is the same for plate diameter.

Plate radius, $r_p = r_{bi} = 75mm$

The cross section area of the plate $\left(A_p\right) = \pi {r_p}^2 = \pi 0.075^2 = 0.018\, m^2$

3.8 Machine Efficiency

The mechanical power output by the motor,

$$P_o = \frac{Torque\ (T) \times N}{9550} = motor\ efficiency\ \times input\ power\ (P)$$

$$P_o = \frac{Torque\ (T) \times N}{9.55} = 0.96\ \times 6930 = 6653\, W$$

Extruder $Torque\ (T) = 6653 \times \frac{9.55}{314} = 202\, Nm$

The term efficiency is calculated based on extruder output or workdone by the machine as:

$Input\ power\ (P_i) = 6653\, W$

Extrusion load $\sigma_m = 67.8\, k$N

Die land length, $L_d = 0.05\ m$

$$Ouput\ power\ (P_o) = \frac{\sigma_m L_d}{time} = \frac{67800 \times 0.05}{1\ seconds} = 3390\ W$$

$$\text{Efficiency, } \eta = \frac{output\ power\ \ (P_o)}{input\ power\ (P_i)} = \frac{3390}{6653} \times 100 = 51\ \%$$

3.9 Bill of Engineering Measurement and Evaluation

The bill of engineering measurement and evaluation for the extrusion machine is as given in Table 3. 2.

Table 3.2: Bill of Engineering Measurement and Evaluation of the Machine

MATERIAL	QUANTITY	PRICE (₦)
Shaft	1	6000
Spur gear	2	4000
Steel Plate (1.2mm)	4	18000
Steel plate (6mm)	9	12000
Bearing	2	2300
Belt	1	250
Square pipe (5 mm) and painting	2	7500
Control switch	1	2500
Heating element and resistor	2	3500

Heat resistant element (glass fibre)	1	3500
Bolt and nut	21	840
Air compressor (Pump)	1	10,000
Electric motor (6.93kW)	1	38,000
Electrode (Packet)	1	1500
Grinding and cutting disk	1	2000
Labour and Miscellaneous	1	65,200
Total		176, 890

Source: Market Price obtained from Minna

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Extruder Design Specification and Analysis

The design specification of the extrusion machine is based on the following data obtained from design calculation and shown in Table 4.1. The design data in Table 4.1 was used for fabricating of the PVC extruder machine.

Table 4.1: Design Specification of the PVC Extruder Machine

Parameter	Unit
Compression Ratio of PVC melt	8
Gear ratio	2
Number of pinion teeth	22
Root diameter of the shaft	80 mm

Extruder speed (N)	157 rpm
Shaft Modulus of Rigidity (carbon-steel)	79.3GPa

4.2 Extrusion Load

Service factor (C_s) of laboratory machine with enclosed lubricated gear system was designed to operate between 1 to 3hrs per day and the service factor is 0.8 (Khurmi and Gupta, 2003). The designed machine operates at maximum of three hours per day. The machine efficiency based on work done of the machine was 51%.

In Figure 4.1 the extrusion load was 244 MN, 195 MN, 156 MN, 125 MN, 99 MN after 1, 2, 3, 4 and 5 hours respectively. The extrusion load is affected by service factor of 0.8 in which the load produced per hour is reduced by the factor.

The results show that efficiency decreases with increase in hour of operation of the machine.

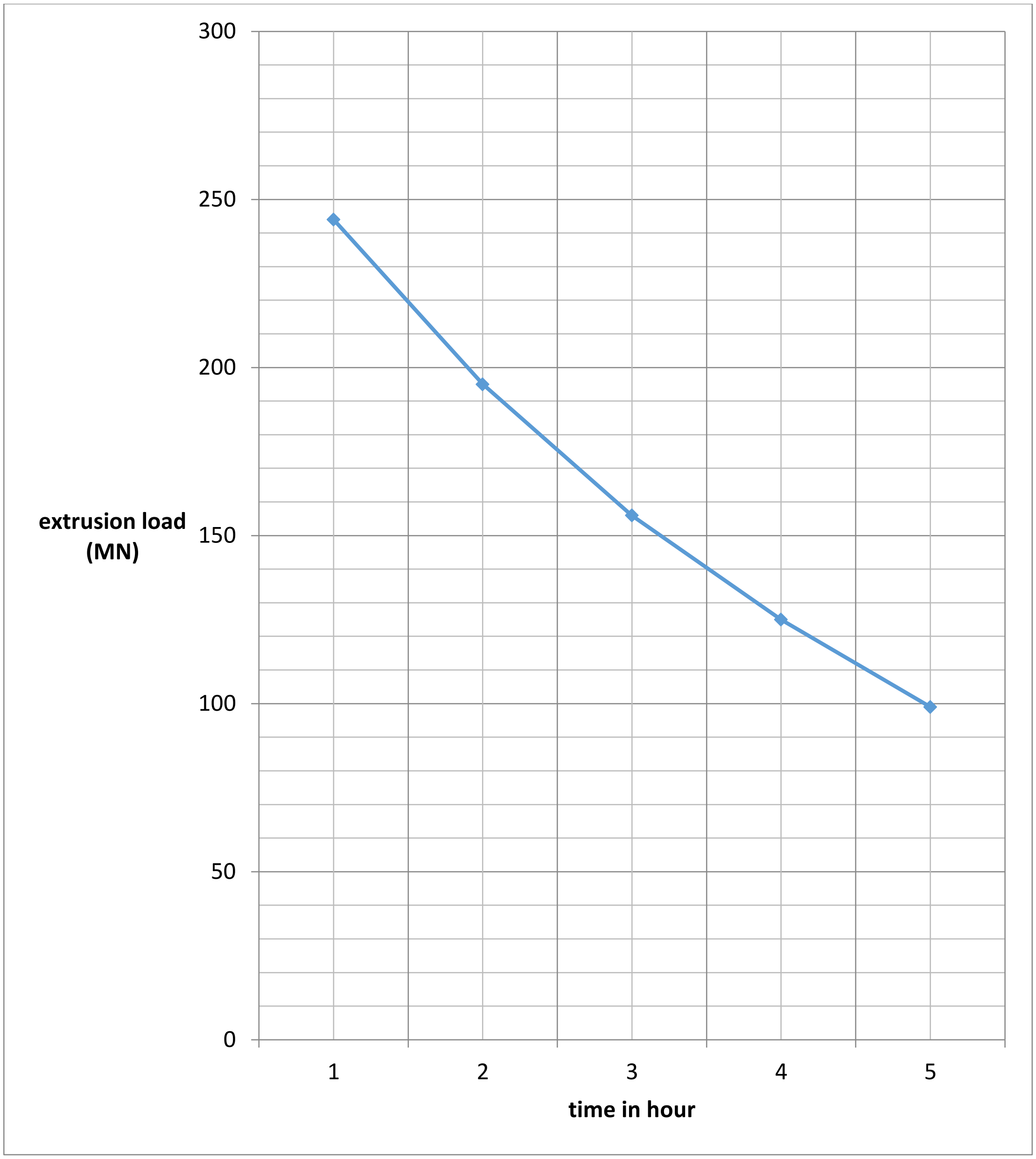


Figure 4.1: Extrusion load

4.3 Test Results

Power of 6.93 kW is transmitted from electric motor through spur gear into the extruder screw. The screw run at 157 revolutions per minute for generating enough power to convey, melt, mix, and pump the polymer to the extruder die. Spur gears are built into the design for provision of torque and speed variant in the extruder. The shaft is solid cylindrical with varying diameters which mounted to give room for positioning and support of bearings and gears. Speed reducer spur gear is applied in between motor and screw to reduce the speed to half, that is, ratio two to one.

The extruder is designed to compress the PVC melt to ratio of 8:1 and with root diameter and channel width of 80mm and 30mm respectively. The compression ratio is used to obtain extruder length of 1120 mm. This length helps to transport the extrudate through die diameter of 40mm. The extruder length covers the length of barrel (770mm) that is the feeding, transition and melting section of the extruder.

The maximum shear stress required for the PVC melt is 17 $\mathrm{kN/m^2}$ and this is the force per unit area required to sustain constant rate of movement. The extrusion pressure is at 7.7 MN/m^2 with extruder circumference speed of 1.2 m/s while plastic flow rate when loading the extruder is 1 m/s. The velocity drop at inlet of the die was 0.1 m/s.

The shear rate of extruder and PVC melt are 40 s^{-1} and 33 s^{-1}. The drag flow rate was 0.0009 m^3/s and it is produced through extruder screw rotation in the barrel. The flow of pressure or deceleration of polymer flow towards die toward was at 0.019 m^3/s. The breaker plate is fabricated to stop spiralling action of the polymer melt coming off the screw by forcing the polymer in straight lines as it passes through the breaker plate.

It is fabricated to provide a seal between the extruder and the die; therefore it was designed with the same diameter with that of barrel which was 770mm.

The PVC pipe is structured into circular shape by the annular die shape and placed at discharged point of the screw. Flow channel of die is designed with 40mm diameter with die gap of 10mm. The die pressure was 455.6 Pa. A pump is attached to this end for having uniform velocity of PVC at the die flow channel.

Plate I is the extruder of length 1120 mm with diameter of 55mm while Plate II is the extruder barrel both internal and external barrel of diameter 150 and 300 mm respectively. The length of the barrel is 770mm and the screw length of the extruder covers total length of the barrel for proper feeding, transition and melting of the resin. Plate III is 6.93kW electric motor that helps in driving the extruder. The extruder shaft is connected to a spur gear for speed reducing purpose. Plate IV is the assembled drawing of laboratory extrusion machine. The machine is designed for practising theoretical knowledge on pipe extrusion in mechanical engineering workshop. The machine has efficiency of 51% efficiency.

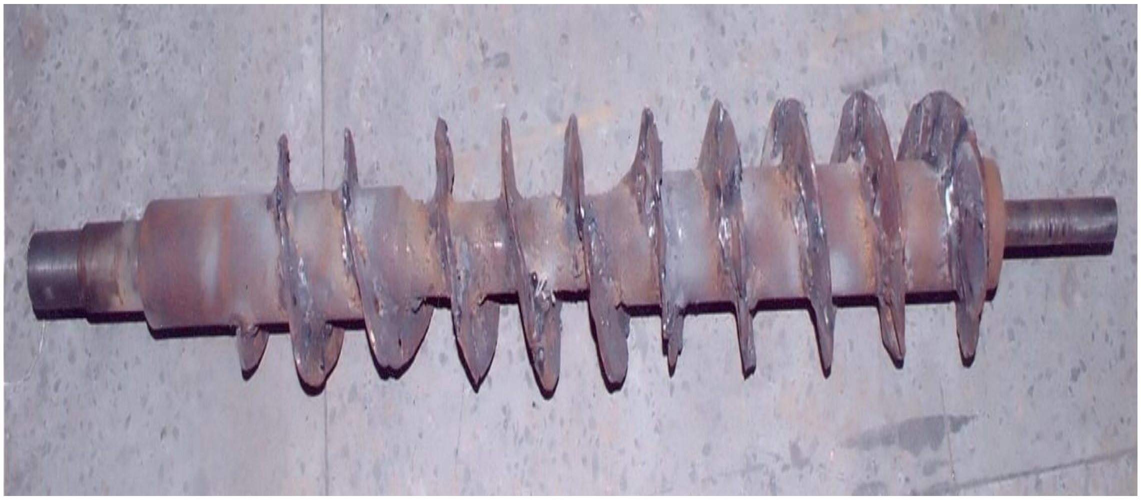


Plate I: The Screw Extruder Shaft

Plate II: Cylindrical Barrel for PVC Melts Extrusion

Plate III: Gear Drives and Electric motor

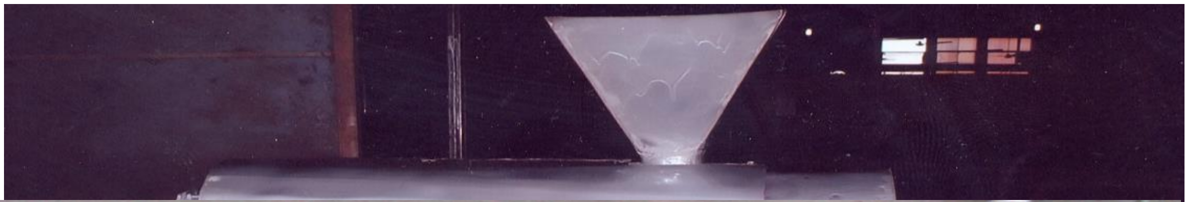


Plate IV: PVC Extruder Machine Assembly

Plate V: 40mm pipe

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The development of the extruder machine involves the design and fabrication of principal components which include the shaft, feeder or hopper, barrel, breaker plate and the annular die. Increasing of electric motor power gives more torque at a uniform extruder screw velocity. An increase in speed means gaining of energy and increase in productivity. According to Giles-Jr. and Wagner-Jr., (2005) the typical extruder has compression ratio for melting to be within the range of 18:1 to 40:1. The required temperature of resin (PVC melt) ranges from 140 to 180 ºC. In the present study, being an industrial prototype, the compression ratio used was 8:1. This was as a result of the screw diameter used for the fabrication of the extruder being 140mm. The drive turns extruder screw at a uniform speed of 157 rpm with an output torque of 202 Nm to process the polymer.

The extruder screw and produced barrel, feeds resin into the annular die so that there will be increase in pressure in the die for proper production of the PVC pipe. The extrudate of the PVC machine has flow rate of 0.0009 m^3/s ; extrusion pressure was at $7.7M\ Pa$ with extrusion speed of $1\ m/s$. The extrusion load is 244 MN after one of extrusion process. The machine has efficiency of 51 % based on the workdone of the machine, in which maximum of 244 MN of resin or PVC melt per hour can be extruded. The material used for the fabrication was soured locally. The results obtained during the test run of the machine showed that extruder machine will serve its purpose of training young engineers in the technology of PVC pipe production.

5.2 Recommendations for Further Study

The study has identified following areas for further study:

i. investigation of effect viscosity on PVC melt extrusion
ii. investigation of effect temperature and resin additive for pipe production
iii. analysis of extrusion pressure for pipe production
iv. determination of effect of cooling load on extrusion machine

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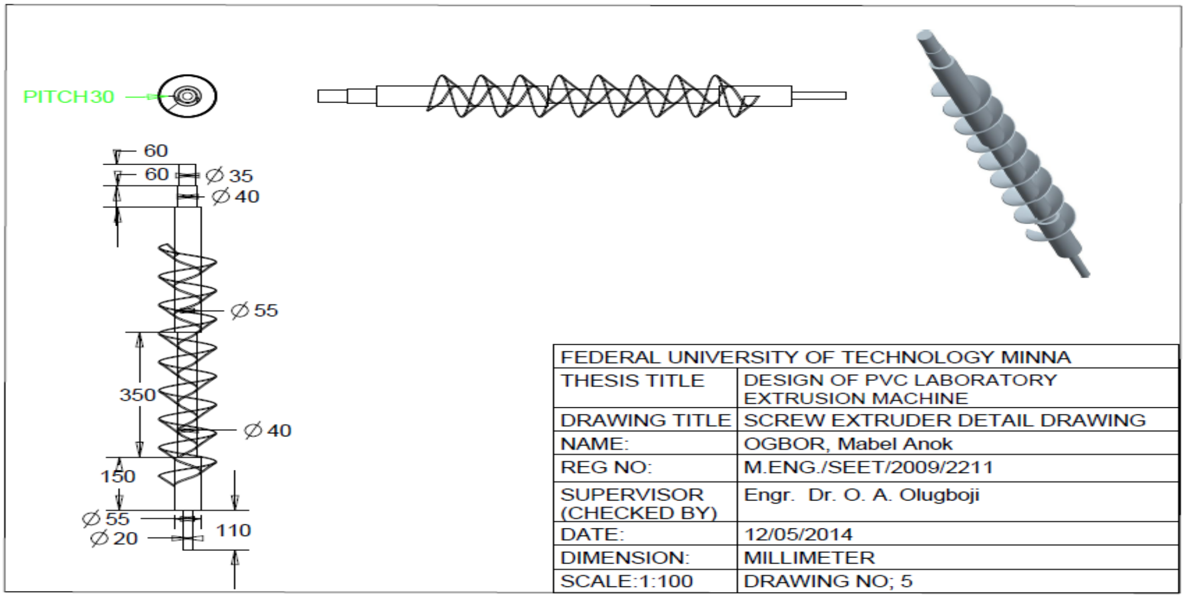
APPENDICES

APPENDIX I

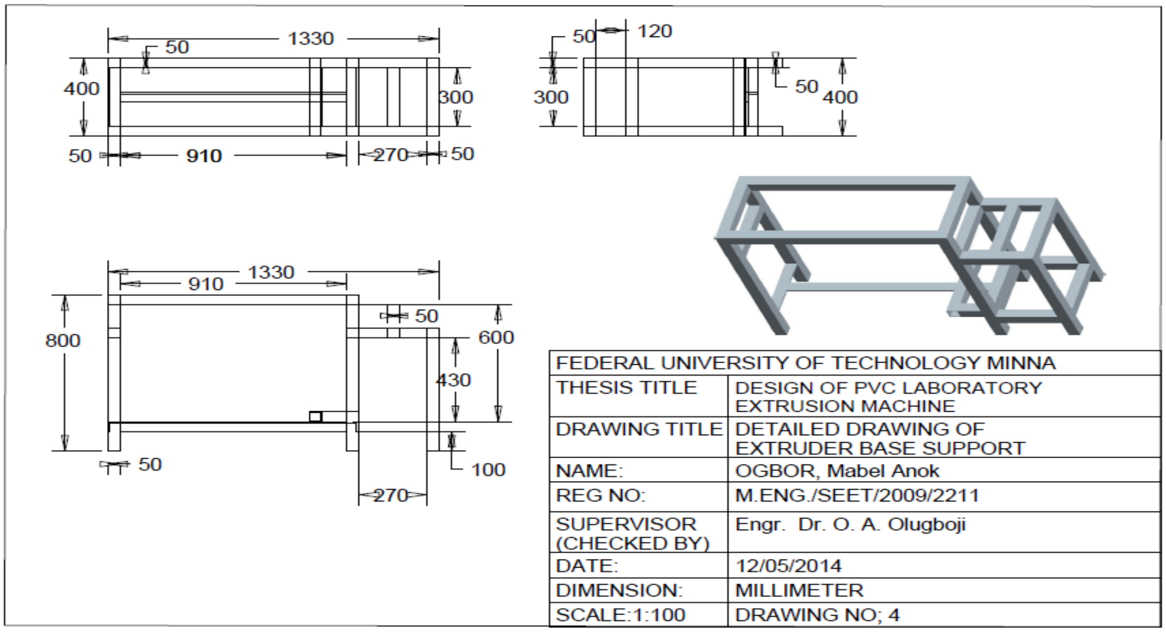
CAD DRAWING OF EXTRUSION MACHINE

The CAD drawings of the extrusion machine were as follow.



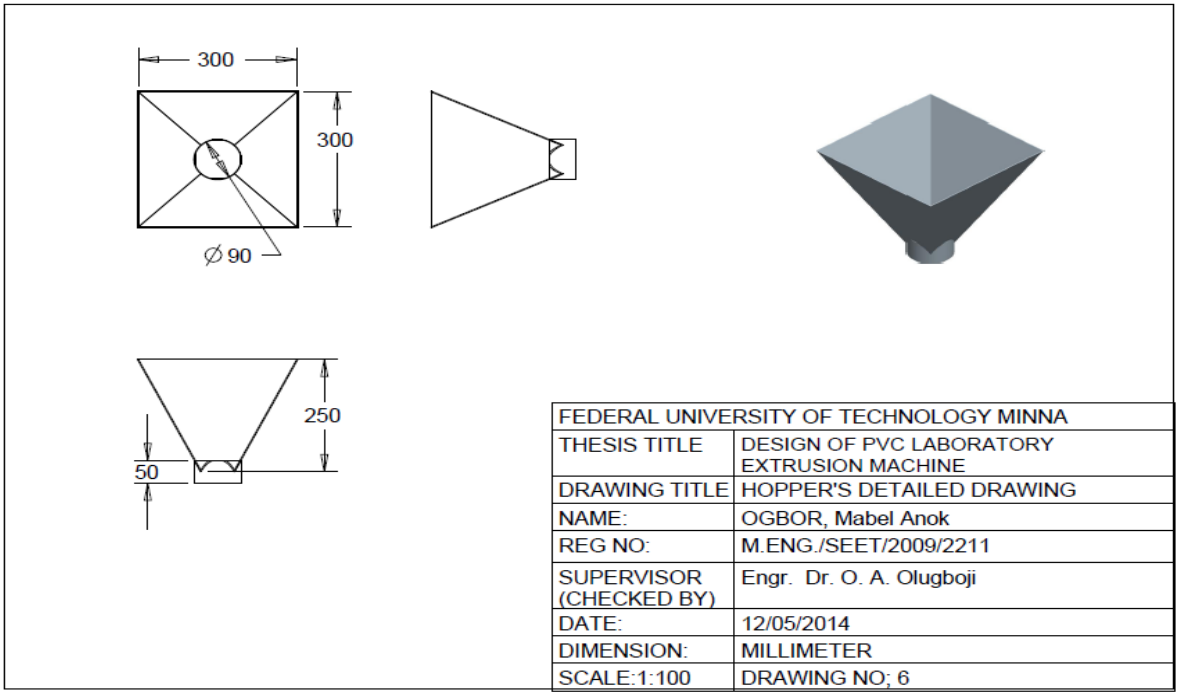
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	SCREW EXTRUDER DETAIL DRAWING
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 5

Figure I: Screw Extruder Detail Drawing



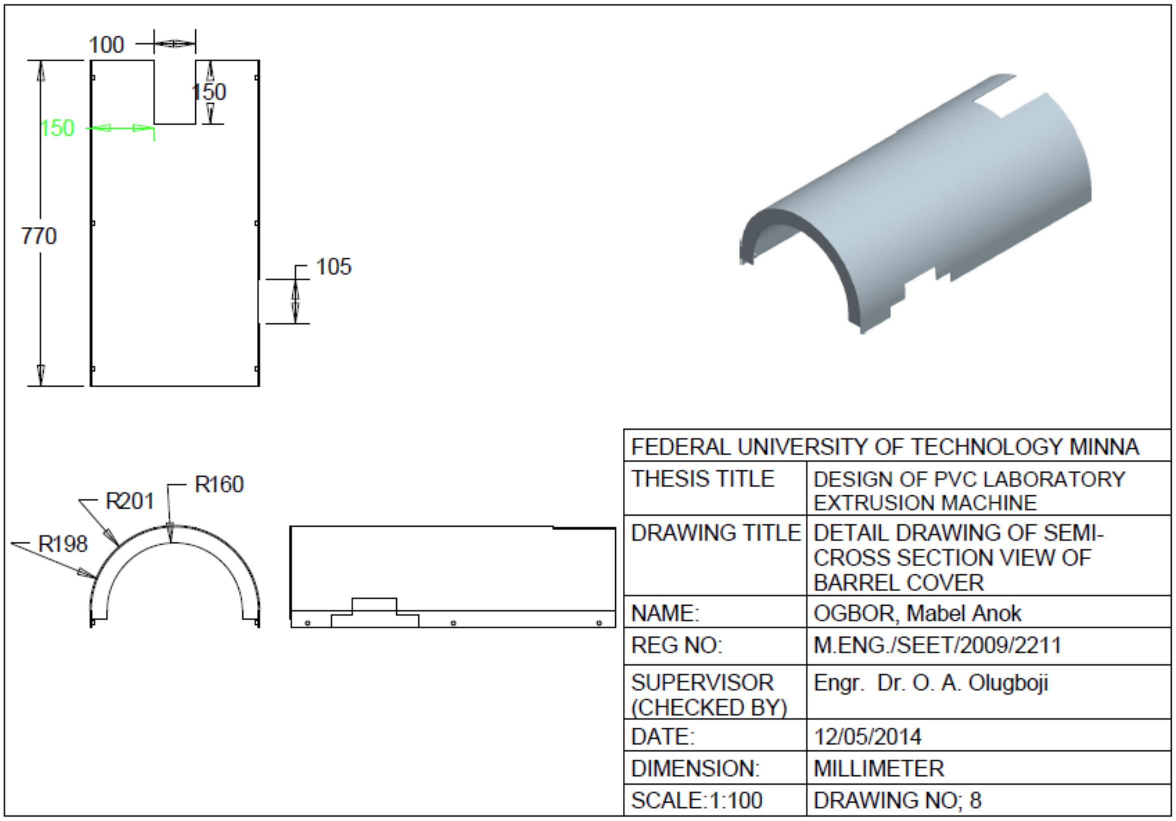
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	DETAILED DRAWING OF EXTRUDER BASE SUPPORT
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 4

Figure II: Detail Drawing of Extruder Base Support



FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	HOPPER'S DETAILED DRAWING
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 6

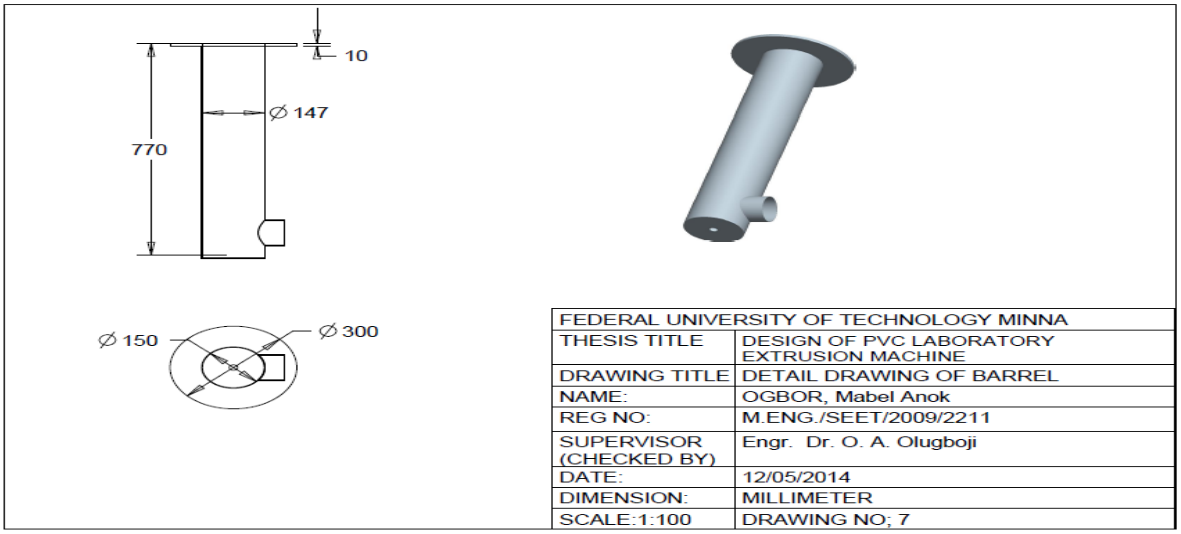
Figure III: Hopper’s Detail Drawing



FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	DETAIL DRAWING OF SEMI-CROSS SECTION VIEW OF BARREL COVER
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 8

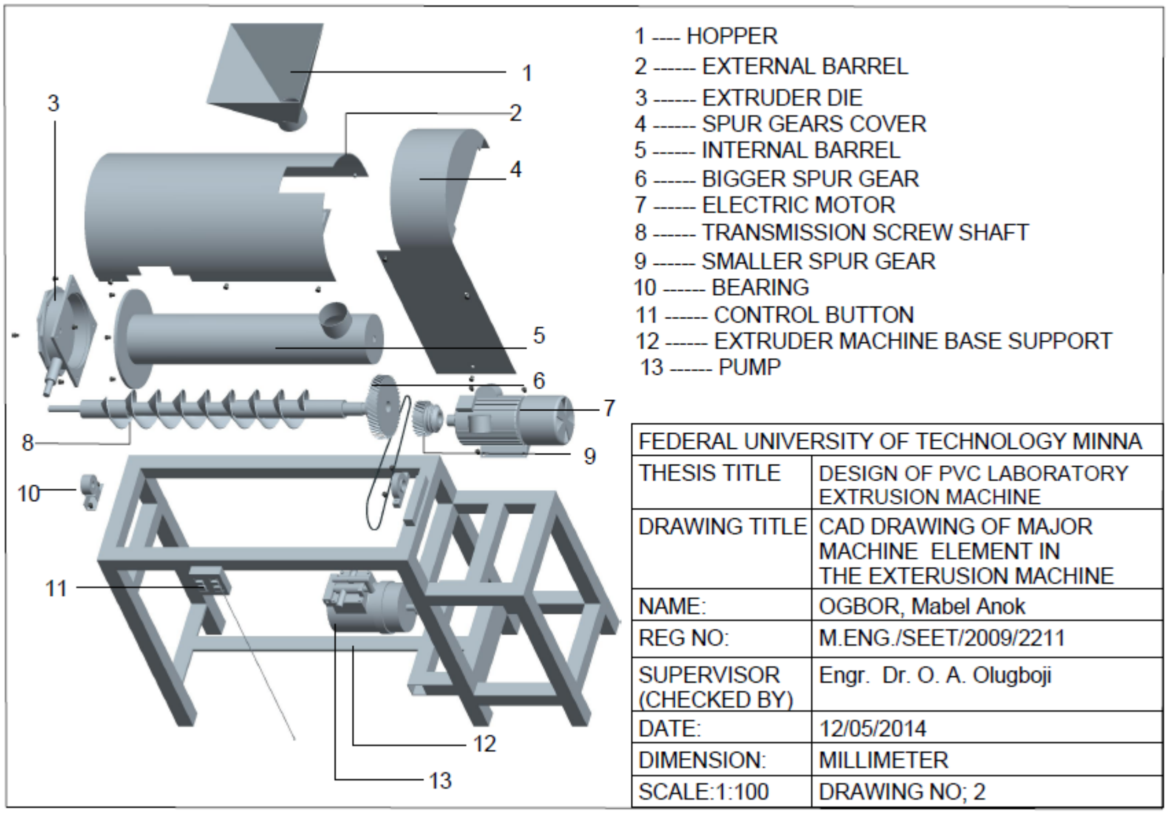
Figure IV: Detail drawing of semi-cross section view of barrel cover

Figure V: Detail drawing of barrel



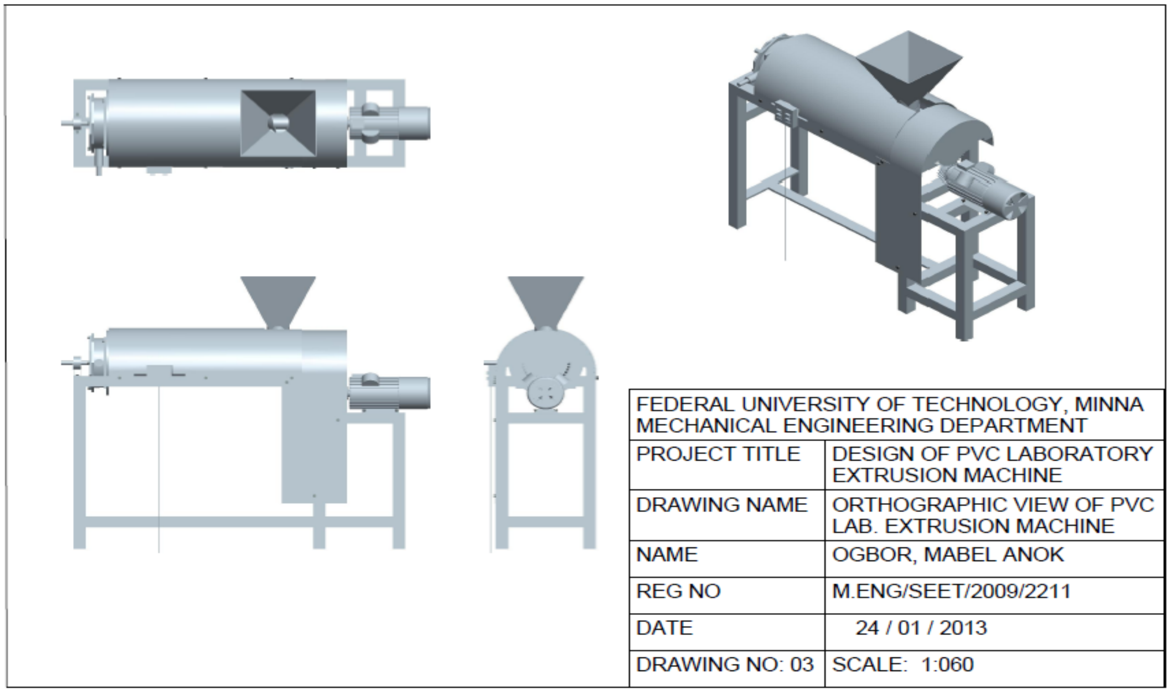
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	DETAIL DRAWING OF BARREL
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 7

Figure VI: CAD Drawing of Major machine element in the Extrusion Machine



1 ---- HOPPER
2 ------ EXTERNAL BARREL
3 ------ EXTRUDER DIE
4 ------ SPUR GEARS COVER
5 ------ INTERNAL BARREL
6 ------ BIGGER SPUR GEAR
7 ------ ELECTRIC MOTOR
8 ------ TRANSMISSION SCREW SHAFT
9 ------ SMALLER SPUR GEAR
10 ------ BEARING
11 ------ CONTROL BUTTON
12 ------ EXTRUDER MACHINE BASE SUPPORT
13 ------ PUMP

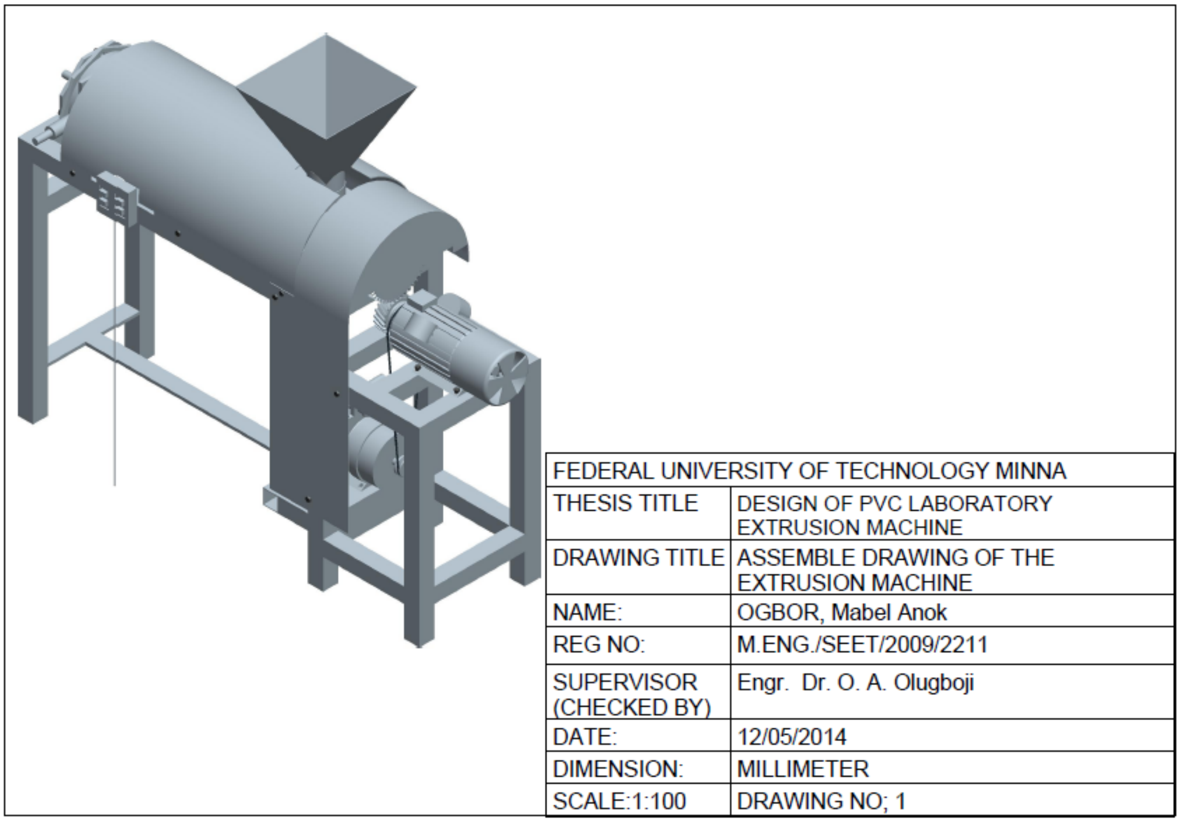
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	CAD DRAWING OF MAJOR MACHINE ELEMENT IN THE EXTERUSION MACHINE
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 2



FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA MECHANICAL ENGINEERING DEPARTMENT	
PROJECT TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING NAME	ORTHOGRAPHIC VIEW OF PVC LAB. EXTRUSION MACHINE
NAME	OGBOR, MABEL ANOK
REG NO	M.ENG/SEET/2009/2211
DATE	24 / 01 / 2013
DRAWING NO: 03	SCALE: 1:060

Figure VII: Orthographic View of the Extrusion Machine

Figure VIII: Assembly drawing of the extrusion machine



FEDERAL UNIVERSITY OF TECHNOLOGY MINNA	
THESIS TITLE	DESIGN OF PVC LABORATORY EXTRUSION MACHINE
DRAWING TITLE	ASSEMBLE DRAWING OF THE EXTRUSION MACHINE
NAME:	OGBOR, Mabel Anok
REG NO:	M.ENG./SEET/2009/2211
SUPERVISOR (CHECKED BY)	Engr. Dr. O. A. Olugboji
DATE:	12/05/2014
DIMENSION:	MILLIMETER
SCALE:1:100	DRAWING NO; 1

APPENDIX II

PVC EXTRUSION PLATE

Plate VI: PVC Extrusion Process and Procedure

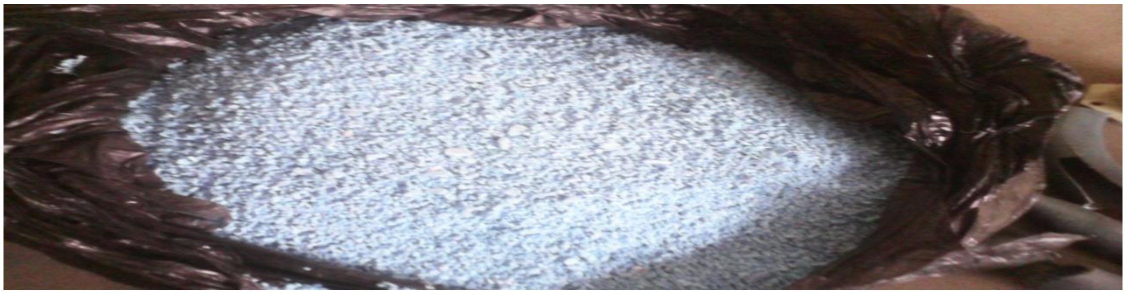


Plate VII: PVC Melt Product