Dissertation Report

Master in Product Design Engineering

Processing, characterization and simulation of Extrusion process

Romeo Sebastián Rivadeneira Quelal

Leiria, March 2019

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Processing, characterization and simulation of Extrusion process

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Dissertation developed under the supervision of Doctor Carlos Alexandre Bento Capela, professor at the School of Technology and Management of the Polytechnic Institute of Leiria and co-supervision of Doctor Rui Miguel Barreiros Ruben, professor at the School of Technology and Management of the Polytechnic Institute of Leiria.

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Acknowledgements

The reason of my life and inspiration

it is the love to my family.

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Resumo

Inovação na extrusão de termoplásticos é a implementação de uma solução nova ou significativamente melhorada para a empresa, novo produto, processo, método organizacional, com o objetivo de reforçar a sua posição competitiva, aumentando o desempenho e conhecimento. Esta tese integrará um processo de inovação e desenvolvimento de produtos cujo objetivo principal é atender às necessidades de um determinado cliente, para o desenvolvimento de um novo produto por uma empresa de extrusão de termoplásticos. Ao fazer um breve estudo sobre os principais princípios e definições de extrusão de termoplásticos e sobre o departamento de desenvolvimento de produtos, irá integrar ambas áreas para criar um processo sistemático para o desenvolvimento de um novo produto e melhorar consideravelmente a fase de desenvolvimento em termos de inovação, qualidade no desenho de produto, valor futuro dos produtos no mercado, qualidade e confiabilidade.

Todos os requisitos serão medidos e bem analisados para serem transformados em indicadores técnicos. Estes requisitos permitem identificar todos os parâmetros de extrusão, como o tipo de parafuso, termoplástico adequado, temperatura da câmara e do fuso, desenho das ferramentas de extrusão, taxa de compressão do fuso, entre outros. O desenvolvimento de produtos e processos de inovação em produtos de extrusão termoplástica, traz vantagens para empresas que fornecem soluções mais rápidas que a concorrência, utilizando experiência e conhecimento constante como arma para garantir produtos com alta qualidade. A fase de desenho de um projeto é considerada como a tarefa mais demorada, no entanto, ao longo de todo este trabalho de estudo e projeto, também deve ser acompanhado por ensaios ou testes. Tais testes ou ensaios foram realizados por uma linha de extrusão, localizada no laboratório de mecânica do IPL. A linha de extrusão, acima mencionada conta com uma extrusora, tina de arrefecimento e puxo.

O projetista de produtos de plástico deve-se preocupar com a capacidade do processo e o nível de detalhe necessário para a aplicação. Além dos requisitos fundamentais de projeto, o custo torna-se o fator mais significativo na seleção do processo ideal para a aplicação. Um processo de inovação e design bem desenvolvido dará uma grande vantagem à indústria de extrusão, devido ao seu objetivo principal que é desenvolver uma equipa multidisciplinar e colaborativa que envolva gerenciamento, projeto e produção.

Palavras-chave: extrusão, desenho, desenvolvimento, termoplásticos, inovação.

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Abstract

Thermoplastics extrusion innovation is the implementation of a new or significantly improved solution for the company, new product, process, organizational method, with the aim of strengthening its competitive position, increasing performance and knowledge.

This thesis will integrate an innovation and product development process which its main purpose, it is to attend certain client´s requirements for a new product development by a thermoplastic's extrusion company. By making a brief study over the main principles and definitions of thermoplastics extrusion and over product development department, will integrate both areas in order to create a systematically process for a new product development and can greatly enhance the development stage in terms of innovation, product design quality, future products value in marketplace, quality, and reliability.

All the requirements will be measured and well analysed to be transformed into technical indicators. These requirements allow to identify all extrusion parameters like type of screw, proper thermoplastic, die and screw barrel´s temperatures, die shape, screw compression ratio, among others. Product development and innovation process on thermoplastic extrusion products, brings advantages to companies providing solutions faster than the competition using experience and constant knowledge as a weapon to guarantee products with high quality. Design stage it is considered as the most time-consuming task, however, throughout these entire labours of study and design, should be also back up with a significantly and well supported tests in an extruder. Such tests or essays were performed by an extrusion line, located at the IPL´s mechanical lab. The aforesaid extrusion line counts with an extruder, cooling bath, and puller.

Plastic product designer must be concerned with the ability of the process to produce the level of detail necessary for the application. Beyond the fundamental design requirements, cost becomes the most significant factor in selecting the optimum process for the application. A well-developed innovation and design process will give extrusion industry great revenue, due to their principal goal is to develop a multidisciplinary and collaborative team that involves management, designing and production.

Keywords: Screw, extrusion, design, development, thermoplastics, innovation

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List of acronyms

2D	Object designed on two dimensions
3D	Object designed on three dimensions
ABS	Acrylonitrile butadiene styrene
CA	Cellulose acetate
CAD	Computer aided design
CAM	Computer aided manufacturing
CR	Compression Ratio
DFSS	Design for Six Sigma
DFZ	Depth feed zone Channel
DMZ	Depth Metering Zone Channel
F	Root diameter in the feed zone
FD	Screw outside diameter including the gauge blocks in the feed zone
HDPE	High Density Polyethylene
ID	Internal Diameter
LDPE	Low density polyethylene
M	Root diameter in the metering zone
MD	Metering zone Diameter
OD	Outside Diameter
PP	Polypropylene
PVC	Rigid Polyvinyl Chloride

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1. Introduction

Nowadays there are many industries which are involved on new products development, which have been implying to create teams that its principal objective is to attend new tendencies and special client's requirements. Plastic extrusion industry has evolved significantly nowadays and have been following engineering areas producing plastic products such as pneumatics and hydraulics due to extrusion versatile applications.

Extrusion it is well known as an efficient way to produce many shapes and is essential in both industrial and domestic product applications. The plastic is melted from pellets and then solidified, which make thermoplastics perfect for extrusion. Companies take advantage of these properties of this type of plastic due to make it good for recycling both scrap pieces and post-consumer goods.

For many companies, product design and development are the most important process to develop because are usually dominant revenue generators. Compared with other types of processes, such as production process and financial transaction processes, the product development process is usually a much more technically sophisticated, costly, and time-consuming process.

The lean product development process is a customer value-driven product development process that can develop products with maximum customer value with minimum wastes in resources and high speed. Lean product development will make the product development process faster and more effective and will consume less resources and cost.

Extrusion industry has an interest in focus on innovation and efficiency which are translated on the cost of workforce and other resources required for the product development.

Plastic product designer must be concerned with the ability of the process to produce the level of detail necessary for the application. Beyond the fundamental design requirements, cost becomes the most significant factor in selecting the optimum process for the application.

Product cost has three interrelated components: part cost, labour cost, and tooling amortization. Labour is related to process selection because some plastics processes permit the combining of parts to eliminate labour cost.

1.1. Objectives

In this study it is intended to realize a study over the extrusion of thermoplastics, its characteristics and parameters form a practical point of view, implemented on a new product development. Analyse and measure all the product requirements to consider to extrudate different plastics.

Make essays and practical experiments to determinate the proper extrusion equipment and parameters to guarantee that the new product achieves its mechanical properties and to assure real application on industry. Determinate the proper thermoplastic to process and the extruder screw configuration.

Identify and correct problems using a test and evaluate design tool for correcting problems and reduce technical risks during extrusion essays.

Introduce a product design methodology implementing on a product development extrusion company process and tooling design process.

Design the optimum die tube-shape and dimensions to obtain the required characteristics and quality of the extrudate developing a strategy for effective die design in tube extrusion. Translate all the voice of a costumer into technical requirements that will complement the tooling design.

2. State of the art

Modern product development needs to collaboratively manage many conflicting and complex requirements in a rapidly changing environment. Best practices must focus on meeting todays requirements of reduced cycle time; higher manufacturing quality; greater design flexibility for expanded or optional features demanded by the customer; lower cost and higher reliability. Thus, a collaborative multidiscipline team effort is required to achieve these goals [1].

Plastic Extrusion industry has implemented several new tendencies on new product development and has overcome technical challenges. Due to its versatile production and to its advantages, plastic extrusion industry keeps growing and overcoming new challenges.

Main Plastic extrusion industries invest on new equipment to produce technical plastics, which require more sophisticated equipment and technical knowledge. Plastics which can be used for applications ranging up to 350 °C.

The most common extruded products are PVC water and sewer pipes. In industrial use, other plastics transport liquids and gasses that PVC may not be able to handle, nonetheless PVC remains, for its low-cost production. Also, there are micro-medical tubes that can have an outer diameter of less than 0.00254 cm. Plastic tubing is essential for transporting oxygen in intensive care units, fuel in small gasoline engines, and soda in a drinking straw [1].

2.1. Product development

A modem product development process needs to establish a corporate culture in which everyone involved can freely and effectively communicate to collect knowledge, detect and resolve problems or suggest areas for improvement.

The key objective is to improve communication between the many involved people including management, designers, product support, vendors and customers. This practice enables a collaborative and multidiscipline product development approach.

A principal company goal is to develop a superior product development process that excels on all product development metrics, so it can bring great revenue to the company. To figure out what is the superior product development process, we need to know how the products are designed.

2.1.1. Product value

Product value is the most important performance metric. Unfortunately, it is a lagging performance metric, which means that we won’t know it exactly before the launch of the product. It can be ultimately measured by the total profit generated by this product. It should be proportional to the product total sales volume. However, the product value is related to many factors [2].

- How well the voices of the customers are captured and deployed: If we develop a hit in the marketplace, this product will generate a lot of profit.
- Creativity and uniqueness: If we create a first-of-its-kind product and nobody else can provide the similar product, we will command the market price.
- Quality, reliability, and robustness: If our product has consistent, repeatable performance under various usage conditions and can last a long time, our product will be very successful. Quality, reliability, and robustness can be measured before the launch of the product by product testing or even product performance simulation analysis.

2.1.2. Product development lead time

Most companies consider their product development lead time to be exceptionally important for determining the performance of their product development activities. Product development lead time is particularly important because this metric determines the speed with which new products can be introduced into the marketplace. Companies that have high speed in product development can introduce new products more often and adapt more quickly to changes in customer tastes. This ultimately translates to a larger market share for the company. Lead time is usually measured in months, and it can range from fractions of a month to tens of months, depending on the complexity and skill of a company’s product development [2].

2.1.3. Efficiency

In attempting to reduce product development lead times, however, few companies can afford to ignore the efficiency of their product development. In product development, efficiency is the cost of workforce and other resources required for the product development [2].

Therefore, the innovation of a new product could include significant improvements, as new functionalities of the product and new attributes [3].

2.1.4. Life-cycle cost

Life-cycle costs for a product may include development costs, production costs, sales and distribution costs, service, support, and warrantee costs, and disposal costs. Some companies even include the costs due to pollution during the production and use of the product as part of the holistic analysis of the life-cycle cost. Product development has a particular vested interest in keeping the life-cycle cost for any product as low as possible.

On a longer time, scale, product value, product development lead time, efficiency, and life-cycle costs will contribute a great deal to the level of customer satisfaction, market share, and revenues that the company will have. These will in turn translate to profitability and influence the organization’s long-term business viability.

2.2. Development and innovation

The Management of research, development and innovation Portuguese norm, define a model of innovation for knowledge economy, that has the objective to be used as a reference for companies in the transition for knowledge economy, see Figure 1 [3].

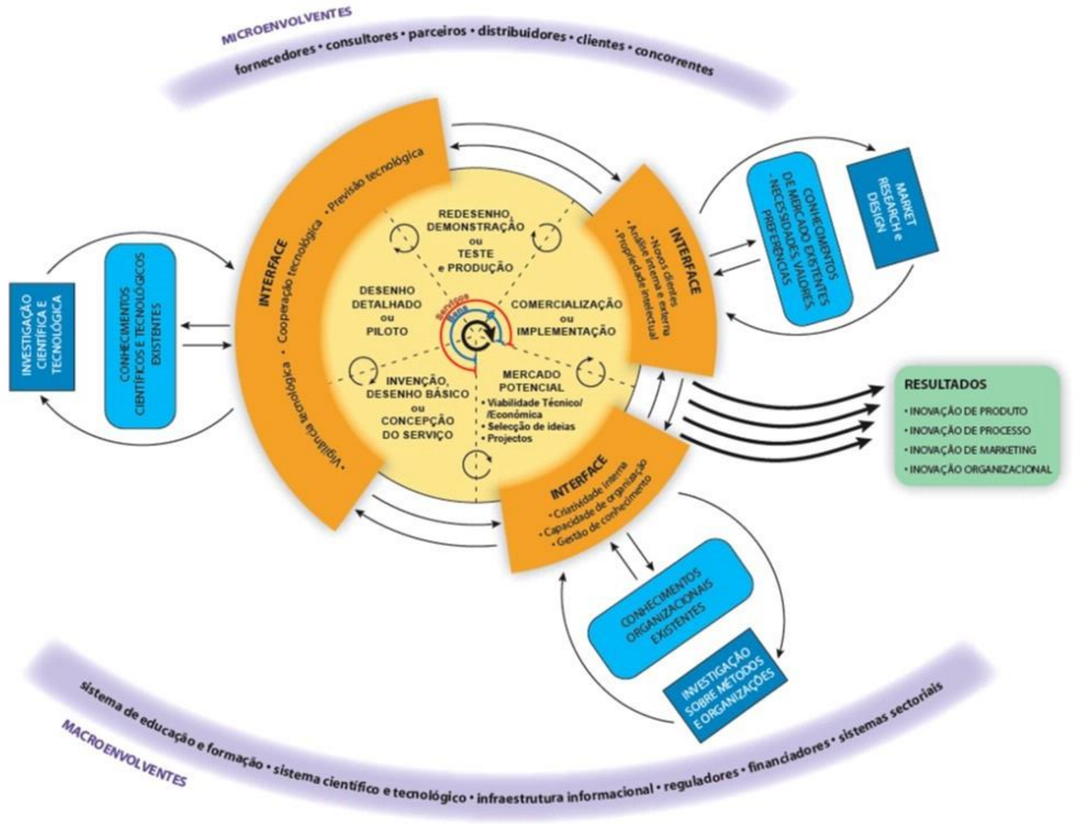

Figure 1 – Reference Model [4]

The creation of therefore said model has been created to considered only as a scientific and technological process to understood as innovation of products and processes, and its applications on sectors of high technological and immediate intensity. Innovation activities are not only circumscribed to the scope of technology, being these many times accompanied, or even preceded, by innovations at organizational level and marketing. Precisely, these two types of process innovation were introduced on the OECD Oslo Manual [5].

The model proposes basics patterns in the form of three interfaces, that define and share productive economic knowledge between the innovative entity and its work environment. These interfaces are essential to an effective innovation management.

The necessary facilities to develop the innovation projects can be available internally and can be part of the existing components of the company structure or not obtained externally. On the other hand, new requirements must be developed through research activities. These knowledge (management, scientific-technological or market) and a corresponding research (research on strategies and organizations, scientific and technological research, studies of market and design) are consider another way of innovation.

Results of research and development activities, expected or unexpected, can also be used as a direct source of innovation, so that it will be respected. On the other hand, the results of the innovation process will inform and allow us to interact with the research activities, constituting this in another way that we can continue to innovate.

The integrated vision of this model contemplates the influence of the surrounding and allows a systemic and interactive vision of innovation in which the external environment to the organization conditions the relevant opportunities to medium and long term.

Innovation is the implementation of a new or significantly improved solution for the company, new product, process, organizational method or marketing, with the aim of strengthening its competitive position, increasing performance, or knowledge [4].

2.3. Product development process

Most companies have similar technologies to their competition and most designs and services can be copied or duplicated. The key then is to implement new innovative solutions faster than the competition. Knowledge is the competitive weapon. Knowledge management and intellectual property provide competitive advantage.

A proper development process helps to assure future production and manufacturing quality that it is often measured as the percentage of products that meets all specified design and manufacturing requirements during a specified period [1].

The traditional design process can be divided into seven linked and often overlapping phases;

1. Requirements definition
2. Conceptual design
3. Detailed design
4. Test and evaluation
5. Manufacturing
6. Logistics, supply chain, and environment.

All the aforesaid phases will be described below.

2.3.1. Requirements definition

The first phase of the design process is to identify the overall needs of the user and define the business and design objectives for the product.

Requirement definition is the process of identifying, defining, and documenting specific needs for the development of a new product. It is the first step in the product development cycle. The major objective for this step is to identify, consolidate, and document all the features that the product could have into a feasible, realistic, and complete specification of product requirements.

During this early activity, a universe of potential ideas for the product is narrowed to practical requirements. Product requirements or specifications are the final output of this early phase of product development [6].

2.3.2. Conceptual design

The conceptual design process is the identification of several design approaches or alternatives that could meet the defined requirements, performance of trade-off analyses to identify the best design approach to be used, and to then develop design requirements based on the selected approach.

It begins when a need for a new product is defined and continues until a detailed design approach has been selected that can successfully meet requirements.

In addition, design goals and requirements are allocated to the lowest levels needed for each member of the design team and then finalized during this process. Trade-off studies, analyses, mathematical models, simulations, and cost estimates are used to choose an optimum design approach and technology. Products of the conceptual design phase include guidelines, design requirements, program plans, and other documentation that will provide a baseline for the detailed design effort, All the "what ifs" become "how's" and dreams become assignments. It is during this phase that the initial producibility, quality, and reliability design requirements are documented.

2.3.3. Detailed design

Detailed design is the process of finalizing a product's design which meets the requirements and design approach defined in the early phases. Critical feedback takes place as the design team develops an initial design, conducts analyses, and uses feedback from the design analyses to improve the design.

Design analysis uses scientific methods, usually mathematical, to examine design parameters and their interaction with the environment. This is a continuous process until the various analyses indicate that the design is ready for testing. Many design analyses are performed, such as stress analysis, failure modes, producibility, reliability, safety, etc. These require the support of other personnel having specialized knowledge of various disciplines. During this stage, the product development team may construct prototypes or laboratory working models of the design for testing and evaluation to verify analytic results.

The detail design stage therefore requires the most interaction of the many disciplines and design professionals. Communication and coordination become critical during the evaluation and analysis of all possible design parameters. This does not imply a design by committee approach but rather an approach in which the product development team is solely responsible for the design and uses the other disciplines for support [6].

2.3.4. Test and evaluation

Test and evaluation are an integrated series of evaluations leading to the common goal of design improvement and qualification. When a complex system is just designed, the initial product design will probably not meet all requirements and will probably not be ready for production. Test and evaluation are a "designer's tool" for identifying and correcting problems and reducing technical risks. A mature design is defined as one that has been tested, evaluated, and verified prior to production to meet "all" requirements including producibility. Unless the design's maturity is adequately verified through design reviews, design verifications, and testing, problems will occur because of unforeseen design deficiencies, manufacturing defects, and environmental conditions. A goal of every test and evaluation program should be to identify areas for design improvement, which improve producibility and reliability and reduce technical risks [6].

2.3.5. Manufacturing

The product development effort does not end when the product is ready for production. Problems found in production require the design team to perform analyses. Additional team efforts continually try to reduce manufacturing costs and improve quality throughout the product’s useful life.

2.3.6. Logistics, supply chain, and environment

The design team role does not end when the product or service is sold. Products often require delivery, installation, service support, or environmentally friendly disposal. Logistics is a discipline that reduces life cycle installation and support costs by planning and controlling the flow and storage of material, parts, products, and information from product conception to product disposal. For many companies, logistic costs surpass all other direct costs. Supply chain is the “flow” and includes all the companies with a collective interest in a product’s success, from suppliers to manufacturers to distributors. It also includes all information flow, processes and transactions between vendors and customers [6].

Packaging’s purpose is to reduce shipping costs, increase shipping protection, provide necessary information, minimize the environmental impact and keep the product, delivery personnel, and customer safe. A product’s integrity may be compromised upon delivery unless the package is able to properly protect the product during distribution and storage. Operational problems may result in alternative maintenance techniques, customer comments, and other field environment issues that were not readily known during the design stage. Design and management personnel can evaluate how well the system works in the field to determine what problems justify corrective action A rational balance between economic product development and environmental responsibility is a difficult task in product development. The difficulty of the problem includes the many environmental and governmental issues involved and the unknowns in directly relating design decisions to environmental results. The idea behind design for the environment (DFE) is to consider the complete product life cycle when designing a product [6].

2.3.7. Basic design considerations

To avoid unpleasant surprises which can cause a design to fail, it is necessary to know everything possible about the conditions which the product will be exposed to in its lifetime. Armed with that information, the plastics designer can determine if the design, material, process, and tooling are appropriate for the application. That is, at least to the limits of the available information. A certain degree of risk is inherent in plastics design because the cost in time and resources is too great to permit the accumulation of enough information to eliminate that risk. Higher levels of risk are acceptable where tooling investment is low and where product failure results only in very low levels of property loss. As the cost of failure increases, more resources are devoted to risk reduction and greater safety factors are used [6].

When product failure could result in serious injury or loss of life, exhaustive testing and greater safety factors are employed. Most product structural failures result from conditions the designer did not anticipate. Thus, the first order of business is to establish the design parameters. This is achieved by the rather tedious process of considering all the conditions the product will be exposed to. A checklist is a useful means of reminding the designer of all these conditions [6].

2.4. Extrusion industry

Extrusion is a worldwide process that has been used in thermoplastic industry since early 19th century and has been satisfying necessities of the market with its advantages.

Could be also called a polymer conversion operation in which a solid thermoplastic material is melted or softened, forced through an orifice or die of the desired cross section, and cooled. The process is used for compounding plastics and to produce tubes, pipes, sheet, film, wire coating, and profiles. All extrusion lines include a melt pump called an extruder, but other equipment is specific to the process [6].

There is also the coextrusion process where two or more varied materials are extruded from two separate extruder barrels and then brought together in a complex die to achieve a tube or profile. Not many materials lend themselves to this process because temperature and chemical differences often preclude good bonding [7].

The extrusion process is used whenever extended lengths of a product are required, or when many short pieces are required that can be cut from such extended lengths. The product or material delivered by an extruder, such as film, pipe, and coating on wire, is known as the extrudate.

Some pieces produced by extrusion are presented on Figure 2.

Figure 2 – Common plastic extruder products [6]

Common extrusion processes are the production of pipe, profile, wire coating and filaments. Coextrusion permits multiple-layer extrusion of film, sheet, pipes, tubing, profiles, and extrusion coating. A wide variety of shapes can be made by extrusion including rods, channels, and other structural shapes; tubing and hose; sheeting and film.

One of the main uses for extrusion is the manufacture of pipe and tubing. Common materials for pipe include polyethylene, rigid polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polypropylene (PP) and cellulose acetate (CA). Tubing is commonly made from polyethylene (PE), flexible PVC, ABS, and nylon.

Coating paper, metal foil, fabric, or other materials is another large application of the extrusion process called extrusion coating. Commercial packaging is one of the many product lines in which it is applied. Polyethylene-coated paper to make milk cartons represents the largest consumption of coated materials. The process for extrusion coating is like the cast extrusion process except that only one extruder is used, and the substrate is heated. Another difference is that the extruded melt and the substrate are forced together by means of a rubber roll that exerts pressures as high as 1800kg/m [7].

2.5. Extrusion process general definitions

2.5.1. Single-screw Extruder

A single-screw extruder consists of a screw in a metal cylinder or barrel. One end of the barrel is attached to the feed throat while the other end is open. A hopper is located above the feed throat and the barrel is surrounded by heating and cooling elements. The screw itself is coupled through a thrust bearing and gear box, or reducer, to a drive motor that rotates the screw in the barrel. A die is connected to the “open” end of the extruder with a breaker plate and screen pack (or a screen changer) forming a seal between the extruder and die. Heat applied to the barrel melts the material and lowers its viscosity. With the correct combination of heat and pressure, extrudate is forced out the die in the desired shape [6].

The key components in a single screw extruder are shown in Figure 3. A single screw extruder has five major equipment components:

- Drive system
- Feed system
- Screw, barrel, and heaters system
- Head and die assembly
- Control system

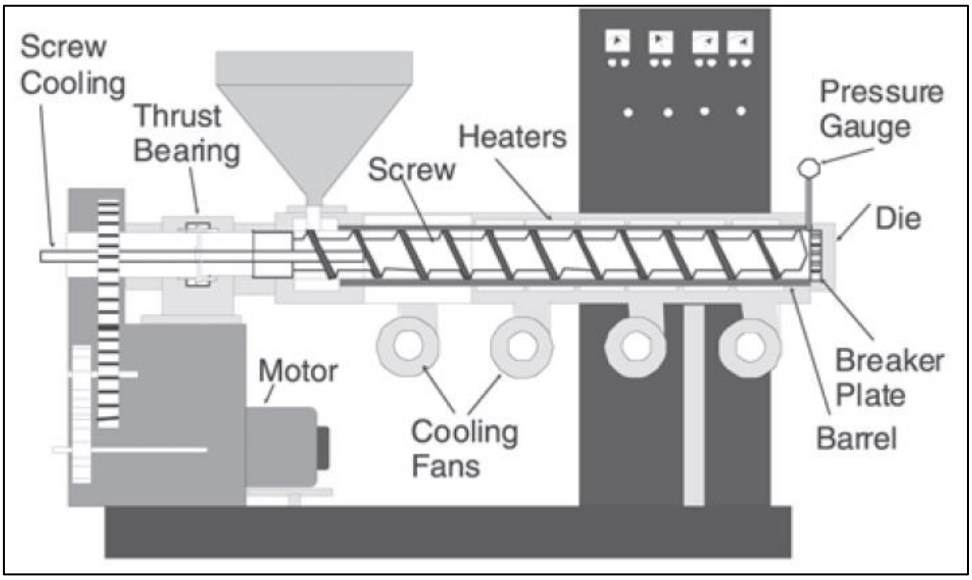

Figure 3 – Single screw extruder [8]

The drive system comprises the motor, gear box, bull gear, and thrust bearing assembly. The feed system is the feed hopper, feed throat, and screw feed section. The screw, barrel, and heating systems are where solid resin is conveyed forward, melted, mixed, and pumped to the die.

Extrudate is transported and shaped in the adapter and die, respectively. Finally, the control system controls the extruder electrical inputs and monitors the extruder feedback.

Computer-designed extrusion controls not only run and monitor the extruder, but also can control the entire extrusion process with feedback loops that automatically change feeder settings, puller speeds, screw speeds, etc., to maintain product quality [8].

There are some extruders containing two or more screws. Most extruders in use today, are of the type known as a single-screw extruder.

2.5.2. Extruder screw

Extruder screws fit into the barrel and are supported by the thrust bearing. The screw's shank length fits into the thrust bearing, while the flighted length contacts the plastic. Extruder screws are specified by their outside diameter, and the L/D ratio, which is the flight length (L) divided by the screw diameter (D). The longer the length, the better the plastification. The greater the diameter, the more capacity the screw will have at any given rpm. The higher the L/D, the higher will be the surface available for shearing, mixing, and plasticating the pellets. Current practice is to use screws with L/D values of 12:1 to as high as 36:1. The screw L/ D is also the designation used to classify barrels, because the screw fits the barrel with very little clearance. Screw features are shown in Figure 4.

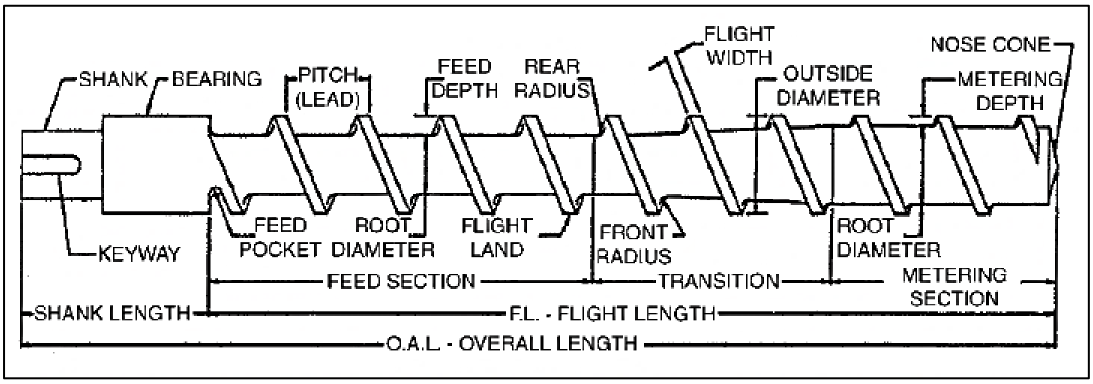

Figure 4 – Common Screw features [8]

Single screw extruder typically has three different sections, as shown in Figure 5. **The feed section** has deep flights to transport powder or pellets away from the feed throat, this section picks up the finely divided polymer from the hopper and propels it into the main part of the extruder. **The transition section** changes gradually from deep flights with unmelted pellets to shallow flights containing the melt. Resin is compressed in the transition section during the melting process. Some external heat must be applied, but much is generated by friction. **Metering** is the last screw section and has the shallowest flight depths, also contributes to uniform flow rate, required to produce uniform dimensions in the finished product, and builds up enough pressure in the polymer melt to force the plastic through the rest of the extruder and out of the die.

Screw nomenclature is defined below and shown in Figure 5.

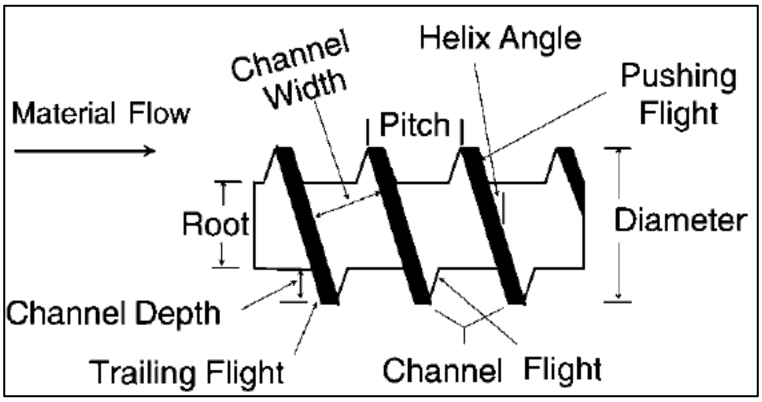

Figure 5 – Definitions of screw elements [8]

Channel depth: Distance from the top of the flight to the root.

Channel: Space between flights.

Trailing flight flank: Back edge of flight.

Pushing flight flank: Front edge of flight.

Pitch: Distance between consecutive flights.

Helix angle: Angle flights make from a line perpendicular to the screw shaft.

Screw diameter: Distance between furthest flights across the screw shaft.

Keyway: End of screw containing the key that fits into the shaft surrounded by the thrust bearing.

Root diameter: Distance from the channel bottom on one side to the channel bottom on the opposite side.

Length: Distance from hopper to screw tip.

2.5.3. Compression ratio

Compression ratio is the volume available in the first flight at the hopper to the last flight at the end of the screw. The screw compression ratio is critical in processing different polymeric materials. While it is desirable to have one general purpose screw that will process all materials efficiently at high rates, in practice this does not occur because different polymers have different viscoelastic properties.

Generally, screws with a high compression ratio should be operated at slower screw speeds of 10–50 rpm, whereas screws having a compression ratio of less than 3:1 can be operated at higher screw speeds of 50–150 rpm [7].

Some polymers run better on screws with a 2.5:1 compression ratio, while other materials process better on screws with a 3.5:1 or 4:1 compression ratio. Gauge blocks are used to measure the outside screw diameter to determine screw wear. Gauge blocks are placed across the top and bottom of the flights (as shown in Figure 6) using callipers or a micrometer to measure the total distance. The gauge block thickness is subtracted from the measurement to obtain the outside screw diameter [8].

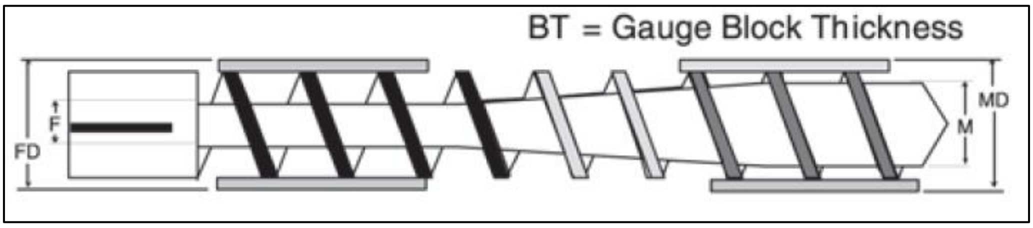

Figure 6 – Screw compression ratio calculation [8]

DFZ = Depth feed zone Channel, described in Equation 1.

DMZ = Depth Metering Zone Channel, described in Equation 2.

CR = Compression Ratio described in Equation 3.

F = Root diameter in the feed zone.

M = Root diameter in the metering zone.

FD = Screw outside diameter including the gauge blocks in the feed zone.

MD = Screw outside diameter including the gauge blocks in the metering zone.

$$DFZ = (FD - 2BT) - F \quad (1)$$

$$DMZ = (MD - 2BT) - M \quad (2)$$

$$CR = DFZ/DMZ \quad (3)$$

It is important to be able to measure the screw compression ratio and know which screw works best with different polymers, which will impact significantly with the extrusion performance.

2.5.4. Extrusion barrel

The barrel is a metal cylinder that surrounds the screw. One end fastens to the feed throat, and the opposite end connects directly to the die adapter. Extruder barrels must withstand pressures up to 70 MPa. Extruder barrels typically have length-to-diameter ratios of 24:1 to 36:1 [8].

Because melting occurs over a longer transition zone, longer barrels provide increased output. However, the longer screw requires larger drive systems and produces greater screw deflection.

The extruder breaker plate acts as a seal between the extruder barrel and the die adapter, thus preventing leakage of the melt. The breaker plate also supports the screen pack, develops head pressure (restricts flow), and converts the rotational motion of the melt to axial motion. See Figure 7 for some examples of a breaker plate.

A rupture disk is located at the extruder barrel just before the breaker plate. When the extruder pressure exceeds the disk's rate value, the rupture disk opens, thereby reducing the pressure. These are required for operator safety. Breaker plates are designed according to the screw diameter.

Figure 7 – Extruder breaker plate [8]

The extruder screen pack filters melt for contamination and gel particles, generates head pressure, and minimizes surging. Five or more screens are used in typical screen pack designs. The screens are rated by the number of holes per millimetre or inch. The screens become finer as they approach the breaker plate. Selection of screen sizes depends on the material and extrusion process. Increasing the number of screens or the mesh size increases the pressure developed during extrusion.

2.5.5. Extrusion Die

The extrusion die is a streamlined orifice that effectively reduces the heat-softened plastic mass being delivered through it to a predetermined exit shape. Such dies can produce a virtually unlimited variety of shapes. The extrusion process is designed to continue the flow of material at a uniform and uninterrupted rate to the land, or forming section of the die, and to avoid flow shadows.

Obstructions to flow, such as enclosed flow pockets or wide variances in the approach angle, should be avoided as far as possible. In general, if the approach angle is too abrupt, material will be entrapped, and surging will result. If, however, the approach angle is too gradual, die restriction will result in low-production output.

The angle of approach (or entrance angle) is the maximum angle at which the molten material enters the land area of the die, measured from the centreline of the mandrel. The angle of approach for any extruded material is an inverse function of its viscosity as it passes through the die. If the land is too short, it is difficult to maintain the shape being extruded. If the land is too long, it creates an excessive backpressure, which restricts production. Because section thickness is a direct function of die restriction with the cross-sectional limits of any given extrusion machine, the ratio of the land length to the part thickness is a valuable consideration in determining the optimum land length for any given material.

In an extrusion die, the land is the straight section through which the plastic flows just before it emerges. A mandrel is the centre finger of a pipe or tubing die.

The die is the element at the end of the extruder that determines the shape of the product being produced. The dies for each type of product are different.

The die block is the part in an extrusion die that retains the forming bushing and core. In the extrusion of pipe or tubing, the die bushing is generally the female part of the die and is attached to the die body by adjustable screws. Thus, small changes can be made in the wall thickness if required. A divergent die is a die in which the internal channels leading to the orifice are diverging (applicable only to dies for hollow bodies) [7].

2.6. Extrusion die design

The design of extrusion dies is based on the principles of rheology, thermodynamics, and heat transfer. The strength of the material is the determining factor in the mechanical design of dies. The major quantities to be calculated are pressure, shear rate, and residence time as functions of the flow path of the melt in the die. The pressure drop is required to predict the performance of the screw. Information on shear rates in the die is important to determine whether the melt flows within the range of permissible shear rates. Overheating of the melt can be avoided when the residence time of the melt in the die is known, which also provides an indication of the uniformity of the melt flow [9].

2.6.1. Shear rate

The shear rate it it’s a common property of plastic materials to evaluate on extrusion industry. The viscosity shear rate it is determinate by international standard ASTM D3835. Typical processing temperatures in extrusion are in the range of 300 to 380°C. Extrusion should be done at low shear rates because of the polymer’s high melt viscosity and melt fracture at low shear rates [6].

Shear rate between the screw flight and the barrel wall of an extruder is calculated using Equation 4 [10].

$$\dot{\gamma}(ScrewChannel) = \frac{\pi \times \mathrm{Fd} \times N}{h} \tag{4}$$

Where $\dot{\gamma}$ = Shear rate in the screw channel sec^{-1}

D = Screw Diameter

N = Screw Speed

h =Channel Depth

The channel depth also known as the distance from the top of the flight to the root, and it is given by:

$$h = \frac{MD-M}{2} \tag{5}$$

Calculation of shear rates in the die land area depends on the die shape.

Shear rate in annular dies, (pipe and tubing) is given by:

$$\dot{\gamma}(AnnularDie) = \frac{6\dot{Q}}{\pi(Ro+Ri)h^2} \tag{6}$$

Where:

Ri and Ro = Inner and outer radius

h = Die gap

Q= Volumetric flow rate

The die gap it is the distance between the mandrel and the die.

The volumetric output on an annular die is calculated by:

$$Q(AnnularDie) = k \times \frac{\Delta P}{n} \tag{7}$$

Where:

$$k = \frac{Cm \times h^3}{12 \times L} = \text{geometrical constant} \tag{8}$$

$$Cm = \pi(Ri + Ro) = \text{the mean circumference} \tag{9}$$

Replacing on Equation 7 we have that the Volumetric output is defined by:

$$Q(AnnularDie) = \frac{\pi \times (Ri+Ro) \times h^3}{12 \times Lc} \times \frac{\Delta P}{n} \qquad (10)$$

Where:

$$n = Polymer\ Viscosity$$

ΔP it is the pressure drop across the channel and it is given by:

$$\Delta P = 2 \times \tau \times \frac{Lc}{R} \qquad (11)$$

$$\tau = \text{Shear Stress} = \frac{F}{A} = \text{Force applied per unit area}$$

Lc= Length of the Channel

R= Radius of the Channel

The aforesaid equations are evaluated using the shear rate versus viscosity curve is given in Figure 8.

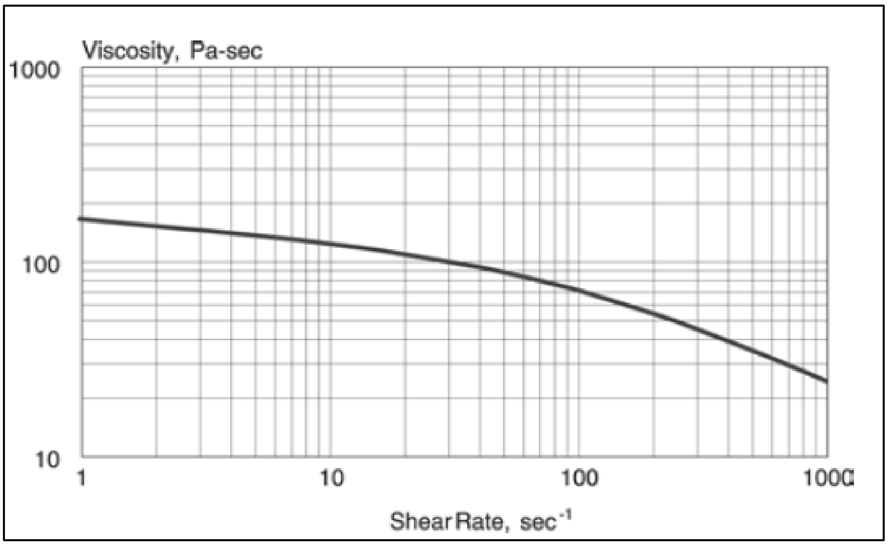

Figure 8 – Shear rate versus viscosity for 12 MFI PP [10]

2.6.2. Extruder die used in pipe and tubing extrusion

The extrusion head or die is determined by the diameter and wall thickness required in the final product. A single-layer pipe or tubing die is shown in Figure 9. The extrudate enters directly from the extruder through the breaker plate into the die. Large dies require a die stand or cart to support the die weight and prevent distorting the extruder barrel. An adapter may be present between the extruder and the pipe or tubing die, versus the direct connection shown in Figure 9. The entrance cone distributes the melt uniformly around the mandrel. The mandrel or center section is held in place by spokes radiating out from the mandrel, called a spider ring with the individual spokes referred to as spider legs. The spider legs support the mandrel weight and the shearing forces from the high upstream pressure. The number of spider legs is determined by the die size and the individual spider leg size [7].

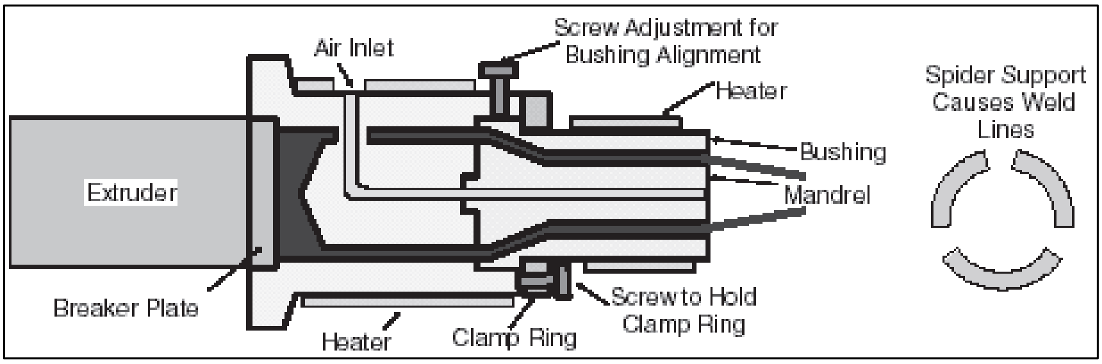

Figure 9 – Tubing die [2]

2.7. Auxiliaries

2.7.1. Extrusion drive motor

Extrusion drive motors must turn the extrusion screw, minimize the variation in screw speed, permit variable speed control (typically 50–150 rpm), and maintain constant torque. In selecting drive motors, the three major factors are (1) base speed variation, (2) the presence or absence of brushes, and (3) cost. The speed variation of a drive motor is based on the maximum speed available for the motor. Because this variation does not change when the speed is reduced, screw speed, which is generally 5–10 percent of motor speed, varies more than the motor speed [7] [8].

The power required to heat polymer from the feed throat to the molten state is given by:

$$Power = mC_p\Delta T + m\Delta H_{fusion} \tag{12}$$

Where:

m =Mass Flow rate in kg/h

C_p =Heat Capacity in $\frac{kJ}{kg}$ °C

ΔT = Difference in temperature between the feed and melt temperature in °C.

ΔH_{fusion} = Heat of fusion for the polymer matrix in $\frac{kJ}{kg}$

2.7.2. Extrusion feed hopper

The extrusion feed hopper feeds material to the extruder. Single-screw extruders are usually fed gravimetrically through standard conical or rectangular hoppers. A spiral hopper improves dry flow, whereas vibrating pads or hammers are sometimes attached to hoppers to break up the feedstock. Vacuum feed hoppers reduce the trapped air that hinders proper feeding. In crammer feeders, an auger forces material into a barrel. There are also found in market hopper dryer which are a combination feeding and drying, where hot air flows upward through the hopper containing the feed pellets [7].

2.7.3. Puller

A caterpillar-type puller or capstan for tubing is used to pull the product from the die through the sizing rings or tube and the cooling tank. Between the cooling tank and the puller may be an on-line laser micrometer to measure the pipe diameter, wall thickness, and ovality, and a length counter to monitor the length produced, which sends a signal to a moving saw to cut the product. The pipe is seen exiting the vacuum sizing chamber and entering a combination puller/cutter; in the first station the pipe is pulled by a caterpillar-type puller to a cutting station, after cutting, the tube is ejected from the cutting station. The laser micrometer can be used to feed a signal to a microprocessor that can adjust the puller speed or extruder screw to change the pipe or tubing dimensions if they are out of specification. If the diameter is too large, the extruder screw speed must decrease or the puller speed increase. However, if the pipe diameter is too small, the opposite corrective action is taken; either the extruder screw speed is increased, or the puller speed decreased. If the wall thickness is too thin, the puller speed is decreased, while the opposite corrective action is used if the pipe is too thick [7].

2.8. Plastic extruder products production

The extrusion of polymeric materials to produce finished products for industrial or consumer applications is an integrated process shown in Figure 10, with the extruder comprising one component of the entire line. If the extruder temperature profile is set incorrectly, the product ingredients are not properly formulated, the cooling on the extruder feed throat is not running properly, the melt temperature at the end of the extruder is incorrect, the cooling bath temperature is not set correctly, the puller at the end of the line is running at the wrong speed, or any other incorrect operating condition or combinations of conditions, the product may not meet customer specifications.

Each step in the process adds value; consequently, the product reaches its maximum value at the end of the line.

An improper setting at the beginning of the process may cause the product to be unacceptable at the end of the line after significantly more value has been added. Speeds of the different process steps must be matched to ensure product compliance [8].

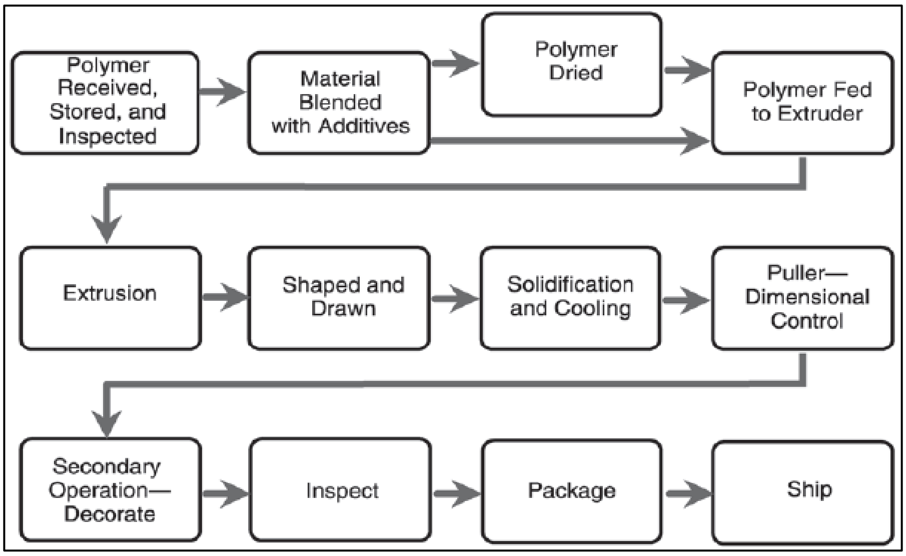

Figure 10 – Basic extrusion process schematic [8].

Polymeric material is received, inspected, and stored. Prior to extrusion, the polymer may be blended with additives (stabilizers for heat, oxidative stability, UV stability, etc.), pigments or concentrates, flame retardants, fillers, lubricants, reinforcements, etc., to produce the desired product property profile. Some resin systems must be dried prior to extrusion to eliminate polymer degradation due to moisture. Other resins, which do not normally require drying, may have to be dried if they are stored in a cold warehouse and brought into a warm environment, causing moisture to condense on the surface of the pellets, flake, or powder. Once the polymer or blend is properly dried and ingredients mixed, the formulation is fed to the extruder, where it is melted, mixed, and delivered to the die to shape the extrudate. After exiting the die, the product is cooled and solidified in the desired shape and pulled away from the extruder at constant velocity to attain the appropriate cross section. Secondary operations, i.e., flame treatment, printing, cutting, annealing, etc., can be done in line after the puller. Finally, the product is inspected, packaged, and shipped [8].

In addition to the basic extruding operation, the process may include many post-extruding operations such as forming round to oval shapes, cutting section to length, blowing the part to a larger or different shape, machining the extrusion, and punching. When combined with the various post-extrusion operations, the extrusion process is a most useful and versatile technique. The extrusion process can also result in the highest rate of output per hour of any plastic process [8].

2.8.1. Pipe and tubing extrusion

Pipe and tubing are profile´s extrusion with dies designed to produce round cross sections. A pipe and tubing extrusion line are very similar to a profile line with a vacuum sizing cooling unit, puller, and cutter. Products can be rigid or flexible and vary from something very small, such as a catheter tube used in medical applications, to large-diameter pipe used to transport water or other fluid. Pipe or tubing can be wound up as a continuous product or cut to length. Pipe and tubing can be coextruded for added value and to meet specific end-use requirements. Figure 11 shows some monolayer and multiple layer pipe and tubing products.

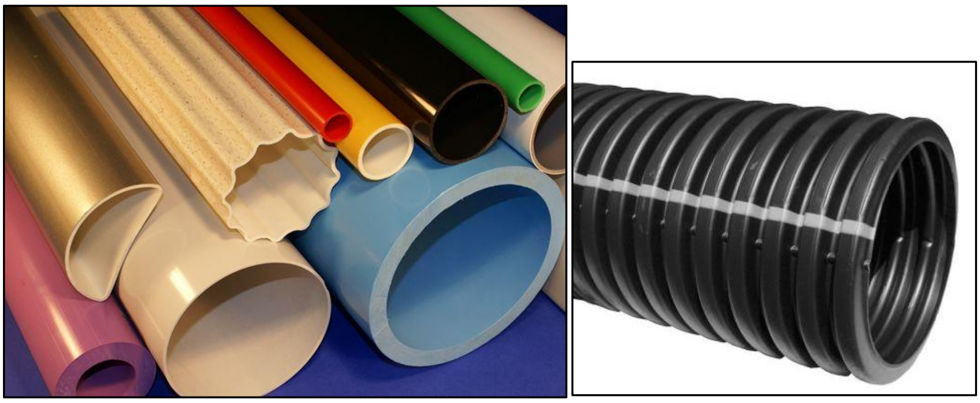

Figure 11 – Types of tubes and tubing [10]

Large volumes of pipe are made from PE, rigid PVC, ABS, and nylon. Tubing is produced from most thermoplastic resins. Flexible tubing is made from elastomers, crosslinked PE, flexible PVC, and polyurethane, while rigid tubing is made from commodity resins to reinforced engineering resins.

The key components in a pipe and tubing line are like a profile line. The cooling section may use a vacuum sizing tank or mold blocks attached to a caterpillar belt for corrugated pipe. Figure 10 shows the components in a pipe and tubing line. The extruder used depends on the polymer [8].

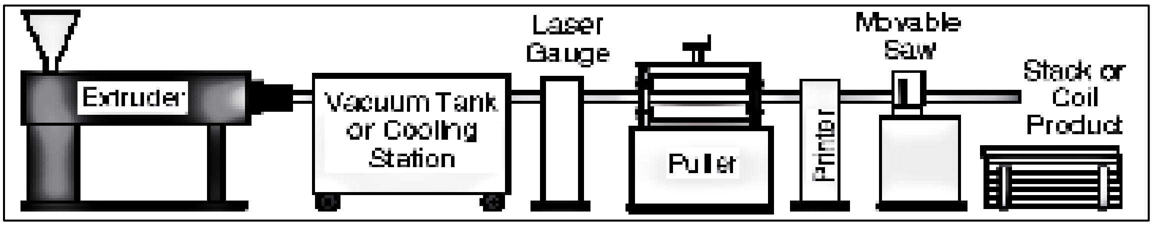

Figure 12 – Tubes and tubing extrusion line production [8]

For small tubing, 0.5–3.5-inch single screw extruders are quite common. As the pipe diameter requirements become greater, the extruder diameter increases substantially, to where a 48-inch diameter pipe may be produced on an 8 or 10-inch diameter single screw extruder. Counterrotating twin screw extruders and conical extruders are common in processing rigid PVC pipe and tubing. Conical twin screws have positive pumping action that provides outstanding mixing and high head pressure for in-line compounding PVC resin powder with the appropriate additives and plasticizers. A process improve could be a laser gauge monitors the pipe outside diameter (OD) and ovality, and a printer is used to identify the pipe and its specifications [8].

The dimensions of plastic pipe and tubing are characterized by Equations 13 and 14 for the wall diameter ratio and the wall cross sectional area.

$$DR = \frac{OD}{ID} \tag{13}$$

$$A_W = \frac{\pi(OD^2 - ID^2)}{4} \tag{14}$$

Parameters defined by the aforesaid equations are controlled by varying the puller speed or the extruder output.

Either modification changes the draw down ratio. The only way to vary parameters defined by Equations 13 and 14 independently is to change the die cross sectional area. To change the parameters defined by the equations, a series of dies or at least die parts are required to change the cross section.

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3. Plastic product development

The study and development on the study will focus on the process aforesaid for product development and will be described as real case scenario implemented on a development department on an extrusion company.

3.1. Requirements definition

The product requirement of the client it is a tube that will act as a straw on a hand sprayer as the one referenced on Figure 13, with a filling capacity of 100ml. The sprayer will be used to apply water, herbicides, pesticides, and fertilizers. The main functionality of the tube will be to help the pump to absorb the fluid from the bottom of the bottle.

Figure 13 – New product description [11]

The tube must guarantee an outer diameter of 10mm, an inner diameter of 9mm and a length of 150mm. The tolerances of these dimensions are 0,05mm. The tube neither will be under stress or under pressure. Must guarantee an ideal seal on the cap junction. The tube must be rigid (55 ShA +/-5) but not flexible. The product will not be subjected to high temperatures. Durability and cost should be considerate as well.

3.2. Conceptual Design

The design department or the development department function it is to integrate and validate all the requirements, as a multidisciplinary team must apply all the knowledge obtain from previous project. The first step on conceptual design it is to determinate properly the client requirements into a functional requirement that will be translated into technical and practical issues.

3.2.1. Design considerations

One important question that the development team must ask, it is whether are able to develop such product or not. By assigning a new variable on this product it is if is a new product in the market, and no one else has tried before, or it is a new product for the company to be developed and studied, but the company has capacity to produced just by designing a new tool. In the aforesaid case, the product it is a common tube, just with certain requirements to achieve.

There should be a backup information in the development on the new product, therefore it is important to create a base design of the intended product that will be used to design and fabricate the die/tooling of the product. Also, this design will be used by the production department to assure the quality of the product during essays. See Figure 14 for the 2D design developed on Solidworks. See appendices for detailed designs.

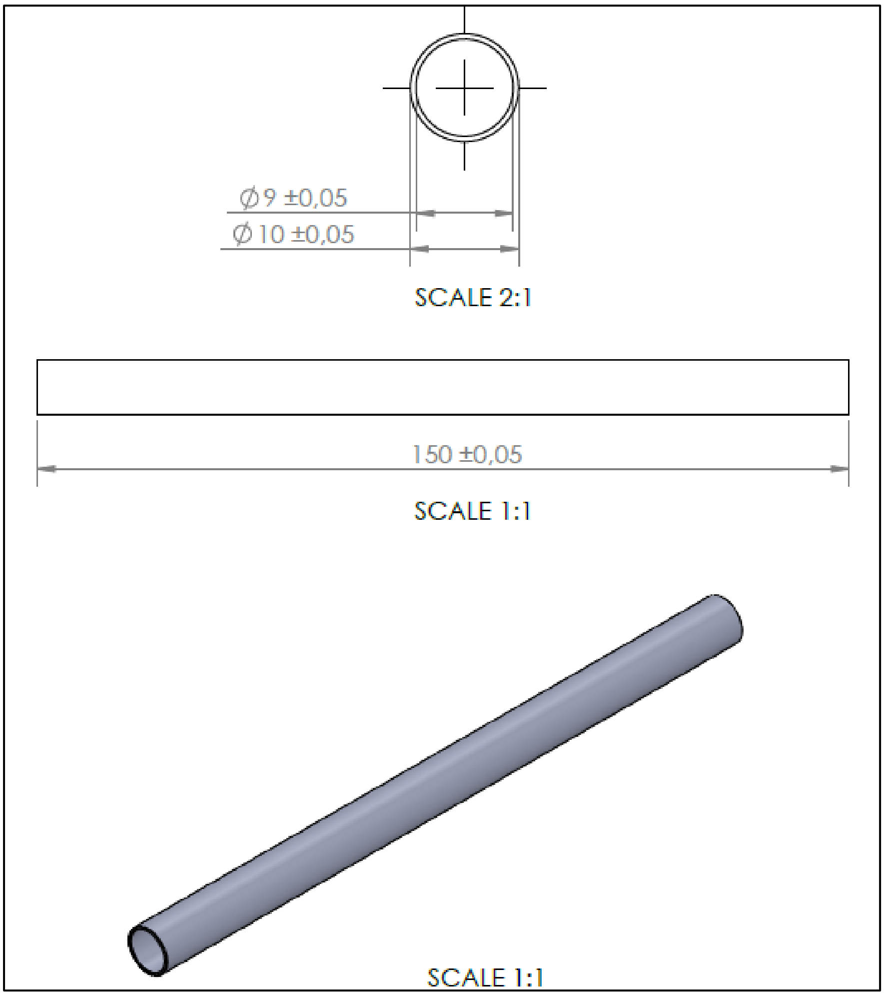


Figure 14 – Conceptual Design of the new product

This design must be validated by the client and by the involved team. Conceptually speaking the thermoplastic, has not being yet selected, however we could assure all the necessities of the product, so the raw material could be selected properly. This variable it is crucial, due to the importance on the selection of the screw that will melt and transport the plastic.

3.3. Detailed design

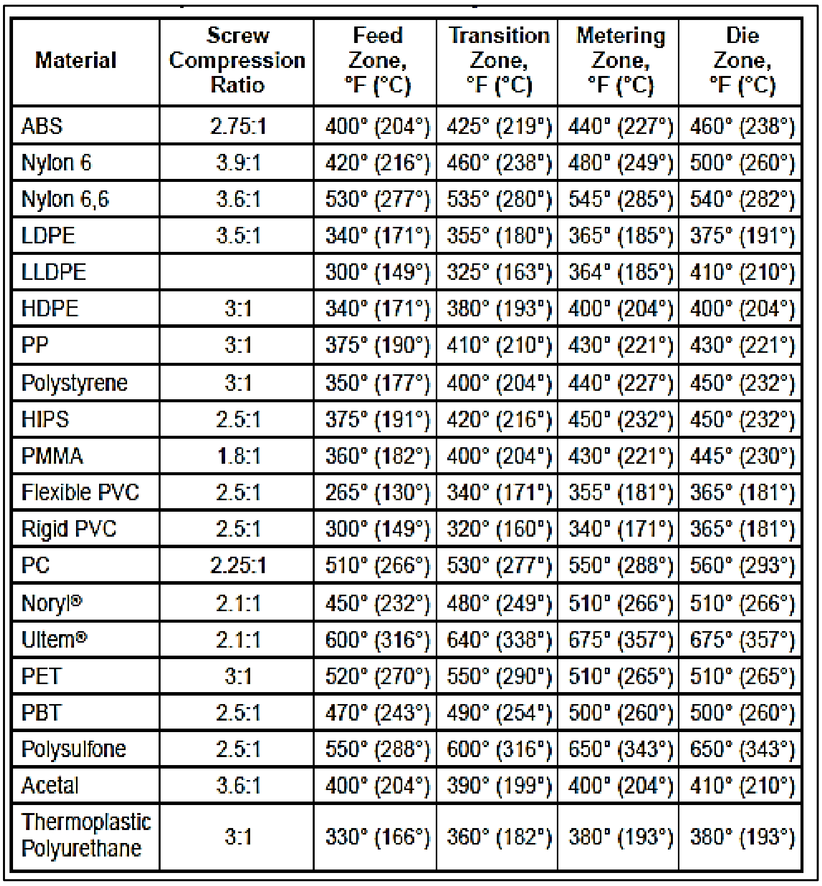
All the requirements of the client will be transformed on technical specifications of the product and will determinate the equipment capacity to create a competitive product that insert incomes to company.

3.3.1. Thermoplastic selection

The plastic raw material it is presented as in pellets or granulated plastic. The more suitable raw material selection for the pretended tubes will be selected according with the extruder screw compression and for the application of the tubes.

Figure 15 shows the several types of setpoints for various resin systems, for a "standard" processing conditions and screw compression ratios.

Depending on the resin modification (flame retardant additives, impact modifiers, fillers and reinforcements, UV stabilizers, etc.), extruder L/D, die design, screw design, etc., the actual processing conditions may vary from those recommended-on Figure 15 below.



Material	Screw Compression Ratio	Feed Zone, °F (°C)	Transition Zone, °F (°C)	Metering Zone, °F (°C)	Die Zone, °F (°C)
ABS	2.75:1	400° (204°)	425° (219°)	440° (227°)	460° (238°)
Nylon 6	3.9:1	420° (216°)	460° (238°)	480° (249°)	500° (260°)
Nylon 6,6	3.6:1	530° (277°)	535° (280°)	545° (285°)	540° (282°)
LDPE	3.5:1	340° (171°)	355° (180°)	365° (185°)	375° (191°)
LLDPE		300° (149°)	325° (163°)	364° (185°)	410° (210°)
HDPE	3:1	340° (171°)	380° (193°)	400° (204°)	400° (204°)
PP	3:1	375° (190°)	410° (210°)	430° (221°)	430° (221°)
Polystyrene	3:1	350° (177°)	400° (204°)	440° (227°)	450° (232°)
HIPS	2.5:1	375° (191°)	420° (216°)	450° (232°)	450° (232°)
PMMA	1.8:1	360° (182°)	400° (204°)	430° (221°)	445° (230°)
Flexible PVC	2.5:1	265° (130°)	340° (171°)	355° (181°)	365° (181°)
Rigid PVC	2.5:1	300° (149°)	320° (160°)	340° (171°)	365° (181°)
PC	2.25:1	510° (266°)	530° (277°)	550° (288°)	560° (293°)
Noryl®	2.1:1	450° (232°)	480° (249°)	510° (266°)	510° (266°)
Ultem®	2.1:1	600° (316°)	640° (338°)	675° (357°)	675° (357°)
PET	3:1	520° (270°)	550° (290°)	510° (265°)	510° (265°)
PBT	2.5:1	470° (243°)	490° (254°)	500° (260°)	500° (260°)
Polysulfone	2.5:1	550° (288°)	600° (316°)	650° (343°)	650° (343°)
Acetal	3.6:1	400° (204°)	390° (199°)	400° (204°)	410° (210°)
Thermoplastic Polyurethane	3:1	330° (166°)	360° (182°)	380° (193°)	380° (193°)

Figure 15 – Types Setpoints for Various Resin Systems [8]

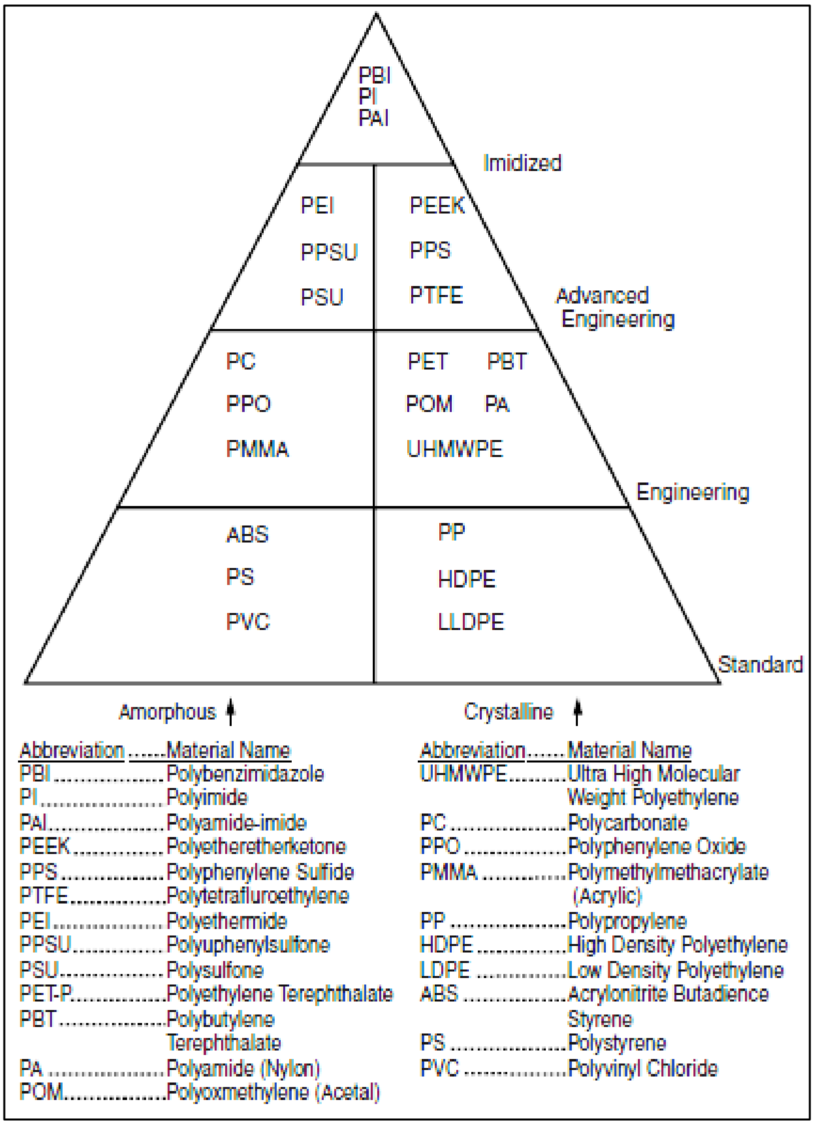
It is said that there are some 30,000 to 35,000 plastic compounds on the market, that number is enough to stagger the mind of the designer trying to make a material selection. Fortunately, only a small percentage of them are serious contenders for any given application.

Some of them were developed specifically for a single product, particularly in the packaging industry. Others became the material of choice for certain applications because of special properties they offer which are required for that product or process.

A bit of research should reveal if there is a material of choice for any given product application.

The cost of plastics, generally, increases with a corresponding improvement in thermal properties (other properties, typically, go up as well).

The lowest cost plastics are the most widely used. The triangle in Figure 16 it is organized with the least temperature-resistant plastics at the base and those with the highest temperature resistance at the top. Therefore, the plastics designated “Standard” at the base of the triangle, often referred to as commodity plastics, are the lowest in cost and most widely used. They can be used in applications with temperatures up to 150°C [12].

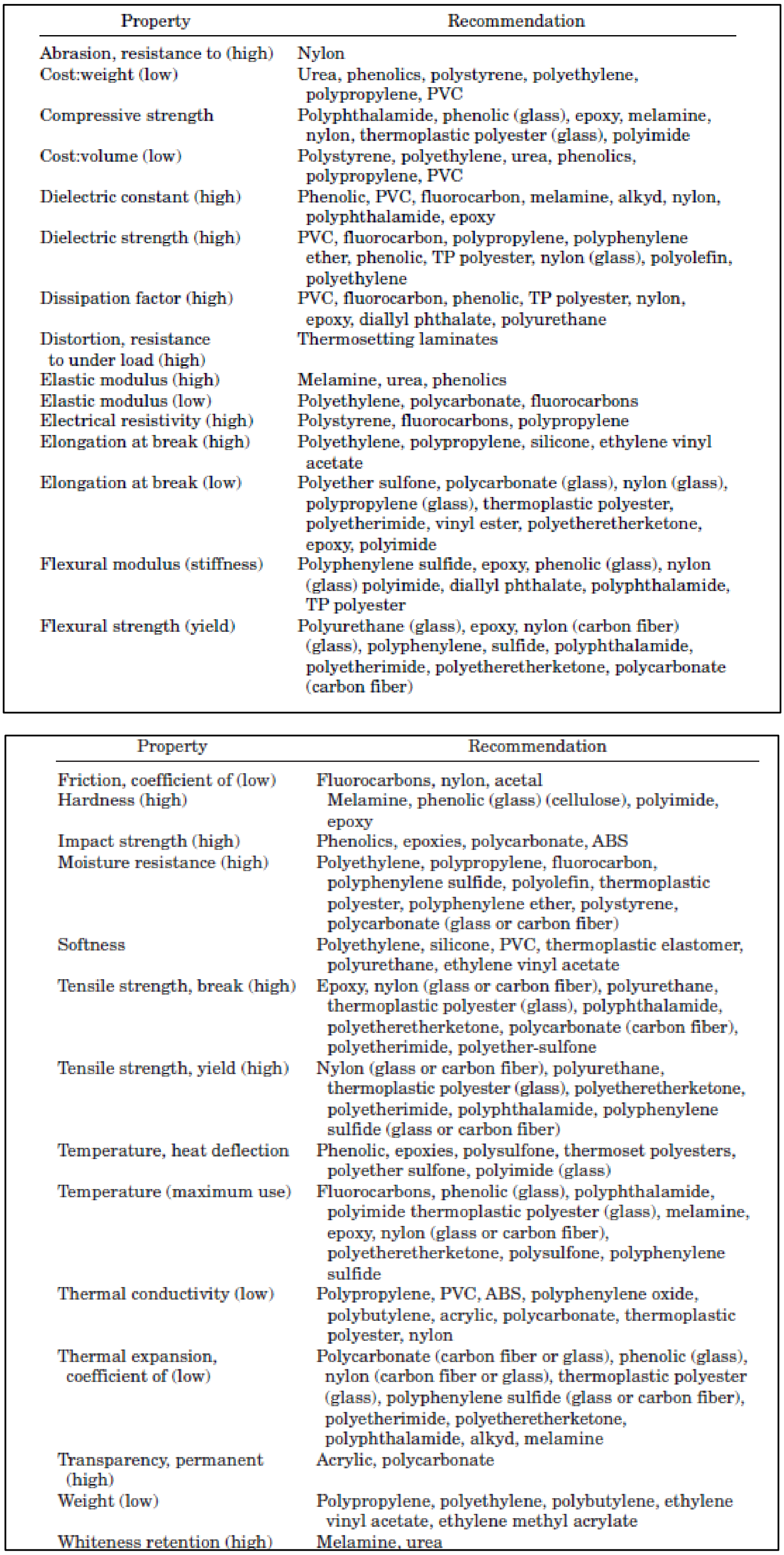


Abbreviation	Material Name
PBI	Polybenzimidazole
PI	Polyimide
PAI	Polyamide-imide
PEEK	Polyetheretherketone
PPS	Polyphenylene Sulfide
PTFE	Polytetrafluroethylene
PEI	Polyethermide
PPSU	Polyuphenylsulfone
PSU	Polysulfone
PET-P	Polyethylene Terephthalate
PBT	Polybutylene Terephthalate
PA	Polyamide (Nylon)
POM	Polyoxmethylene (Acetal)

Abbreviation	Material Name
UHMWPE	Ultra High Molecular Weight Polyethylene
PC	Polycarbonate
PPO	Polyphenylene Oxide
PMMA	Polymethylmethacrylate (Acrylic)
PP	Polypropylene
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
ABS	Acrylonitrite Butadience Styrene
PS	Polystyrene
PVC	Polyvinyl Chloride

Figure 16 – Classification of thermoplastics [12]

The Figure 17 lists many of the principle properties and some of the polymers which are noted for those properties. The list might be incomplete on this table, nonetheless should at least provide a beginning for the design stage. They are primarily listed in their natural state without reinforcements, such as glass or carbon fibers. These reinforcements can be used to increase mechanical strength, however for the intended product, it is not needed to increase mechanical strength.



Property	Recommendation
Abrasion, resistance to (high)	Nylon
Cost:weight (low)	Urea, phenolics, polystyrene, polyethylene, polypropylene, PVC
Compressive strength	Polyphthalamide, phenolic (glass), epoxy, melamine, nylon, thermoplastic polyester (glass), polyimide
Cost:volume (low)	Polystyrene, polyethylene, urea, phenolics, polypropylene, PVC
Dielectric constant (high)	Phenolic, PVC, fluorocarbon, melamine, alkyd, nylon, polyphthalamide, epoxy
Dielectric strength (high)	PVC, fluorocarbon, polypropylene, polyphenylene ether, phenolic, TP polyester, nylon (glass), polyolefin, polyethylene
Dissipation factor (high)	PVC, fluorocarbon, phenolic, TP polyester, nylon, epoxy, diallyl phthalate, polyurethane
Distortion, resistance to under load (high)	Thermosetting laminates
Elastic modulus (high)	Melamine, urea, phenolics
Elastic modulus (low)	Polyethylene, polycarbonate, fluorocarbons
Electrical resistivity (high)	Polystyrene, fluorocarbons, polypropylene
Elongation at break (high)	Polyethylene, polypropylene, silicone, ethylene vinyl acetate
Elongation at break (low)	Polyether sulfone, polycarbonate (glass), nylon (glass), polypropylene (glass), thermoplastic polyester, polyetherimide, vinyl ester, polyetheretherketone, epoxy, polyimide
Flexural modulus (stiffness)	Polyphenylene sulfide, epoxy, phenolic (glass), nylon (glass) polyimide, diallyl phthalate, polyphthalamide, TP polyester
Flexural strength (yield)	Polyurethane (glass), epoxy, nylon (carbon fiber) (glass), polyphenylene, sulfide, polyphthalamide, polyetherimide, polyetheretherketone, polycarbonate (carbon fiber)
Friction, coefficient of (low)	Fluorocarbons, nylon, acetal
Hardness (high)	Melamine, phenolic (glass) (cellulose), polyimide, epoxy
Impact strength (high)	Phenolics, epoxies, polycarbonate, ABS
Moisture resistance (high)	Polyethylene, polypropylene, fluorocarbon, polyphenylene sulfide, polyolefin, thermoplastic polyester, polyphenylene ether, polystyrene, polycarbonate (glass or carbon fiber)
Softness	Polyethylene, silicone, PVC, thermoplastic elastomer, polyurethane, ethylene vinyl acetate
Tensile strength, break (high)	Epoxy, nylon (glass or carbon fiber), polyurethane, thermoplastic polyester (glass), polyphthalamide, polyetheretherketone, polycarbonate (carbon fiber), polyetherimide, polyether-sulfone
Tensile strength, yield (high)	Nylon (glass or carbon fiber), polyurethane, thermoplastic polyester (glass), polyetheretherketone, polyetherimide, polyphthalamide, polyphenylene sulfide (glass or carbon fiber)
Temperature, heat deflection	Phenolic, epoxies, polysulfone, thermoset polyesters, polyether sulfone, polyimide (glass)
Temperature (maximum use)	Fluorocarbons, phenolic (glass), polyphthalamide, polyimide thermoplastic polyester (glass), melamine, epoxy, nylon (glass or carbon fiber), polyetheretherketone, polysulfone, polyphenylene sulfide
Thermal conductivity (low)	Polypropylene, PVC, ABS, polyphenylene oxide, polybutylene, acrylic, polycarbonate, thermoplastic polyester, nylon
Thermal expansion, coefficient of (low)	Polycarbonate (carbon fiber or glass), phenolic (glass), nylon (carbon fiber or glass), thermoplastic polyester (glass), polyphenylene sulfide (glass or carbon fiber), polyetherimide, polyetheretherketone, polyphthalamide, alkyd, melamine
Transparency, permanent (high)	Acrylic, polycarbonate
Weight (low)	Polypropylene, polyethylene, polybutylene, ethylene vinyl acetate, ethylene methyl acrylate
Whiteness retention (high)	Melamine, urea

Figure 17 – Thermoplastics recommendation by application [6]

The most suitable materials used on production for commercial tubes are: Polypropylene, Polyethylene, Polycarbonate and Polyurethane, nonetheless, to guarantee the proper selection, a Pugh Matrix will be used to achieve the ideal requirements of the aforesaid tube. A Pugh Matrix or decision matrix it is apply to evaluate various alternatives against a baseline, also it is commonly used in engineering for making design decisions by a qualitive technique [2].

The principal requirements of the product, that are translated on functional requirements and are achieved by performance and characteristics of the thermoplastics are:

- No subjected to stress or pressure
- Rigid
- Not flexible
- Not high temperatures
- Durability
- Cost

The aforesaid requirements will qualify vs a group of possible thermoplastics that by the recommendation of the fabricants and performance properties. Nonetheless, the design team should also include and define requirements according to the engineering process to be executed, which in this case will be the Screw Compression Ratio.

The screw compression ratio is critical in processing different polymeric materials. While it is desirable to have one general purpose screw that will process all materials efficiently at high rates, in practice this does not occur because different polymers have different viscoelastic properties. The compression ratio it is the ratio of the feed channel depth to the meter channel.

Using equation 1, 2 and 3, will evaluate compression ratio of the screw on analysis.

DFZ= Depth feed zone Channel, described in Equation 1.

DMZ= Depth Metering Zone Channel, described in Equation 2.

CR= Compression Ratio described in Equation 3.

$F = 20mm$

$M = 38mm$

$FD = 40mm$

MD= 40,5mm

BT=1

DFZ= 18

DMZ= 0,5

CR= 3:1

The aforesaid values were obtained by measure and calculate form the screw and barrel from the extruder to be used on the essays. The rest of the details of the extruder will be described in the next milestones. The compression ratio it is 3:1, parameter that will determinate which plastics are able to work with.

Based on the pyramid on Figure 16, shown before, and attending the requirement of being low cost, the chosen thermoplastic will be from the base of the pyramid or from the “standard” plastic family. The plastics are; ABS, PS, PVC, PP, HDPE, LLDPE.

Once the requirements are translated into functional ones and the possible thermoplastics are chosen, will be analysed by a Pugh Matrix described on Figure 18 below.

Decision Factors		**ABS - Acrylonitrile butadiene styrene**	**PP - Polypropelehene**	**HDPE - HighDensityPolyethelene**	**LDPE - LowDensityPolyethelene**	**PC - Polycarbonate**	**PS - Polystyrene**	**PVC**
Criteria	**Wt.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Low Elastic modulus	5,0	4	8	4	5	8	4	4
Rigid	3,0	8	6	8	9	6	5	8
Not flexible	4,0	5	9	9	9	6	6	5
Temperature Performance 20°C to 35°C	4,0	8	8	8	8	8	8	8
Compression Ratio	5,0	4	9	6	7	6	9	6
Moisture Resistance	3,0	9	9	9	9	9	9	9
Weighted Scores		143,0	**198,0**	169,0	182,0	171,0	163,0	153,0

Figure 18 – Raw material selection matrix

Based on the criteria and the qualified results, the most suitable thermoplastic is PP, which will be used to experiment the performance of the screw and the extruder die.

3.3.2. Equipment

Generally, on extrusion industry the companies sell the extruder together with the entire line of production, which includes; extruder, cooling bath/ vacuum bath, puller and coiler. In the development process, to validate the proper plastic and product dimensions a Luigi Bandera extrusion line will be used. This extrusion line it is located on the mechanical lab of IPL.

The extruder has a ratio of L/D:25/1, see Figure 19, below.

Figure 19 – Single Screw Extruder

On Figure 20 there is the description of the dimensions on the screw and barrel. This calculation will be used further during the design. The measurements were done using a flight micrometer and a calliper. These values are used for further design specification of product and process.

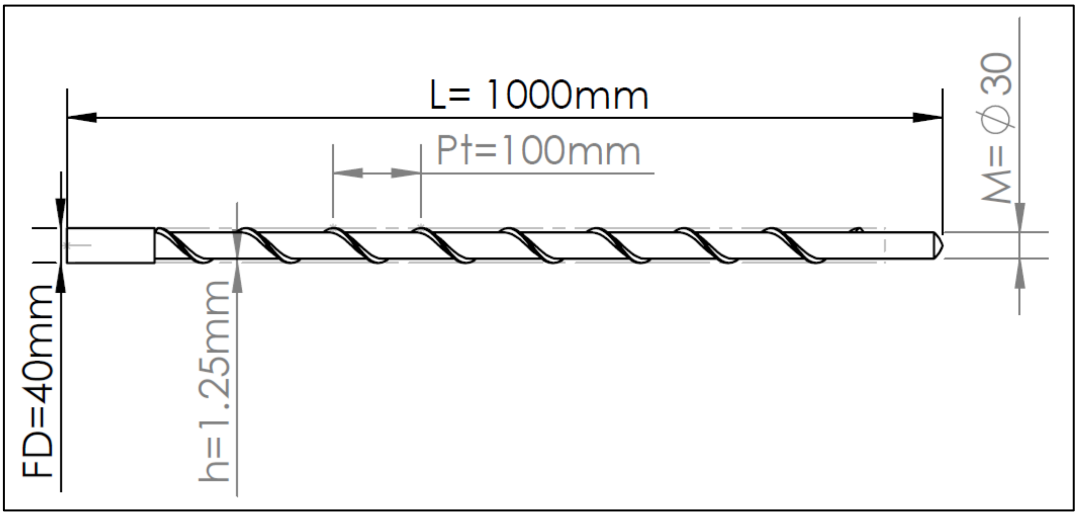


Figure 20 – Extruder Screw Design (Scale 1:10)

On extrusion industry it is common to perform a practical activity to validate the Volumetric flow rate of the extruder. It is a procedure that it is based on insert the plastic material and to calibrate the extruder on temperatures that assure the molten plastic with enough conditions to reach the puller conveyor without breaking. After this, extruder velocity must be up the maximum which it is 60 rpm. Under the mentioned conditions, it is necessary to count a minute of the molten plastic, these will produce a volume of molten plastic on the floor. In conclusion, the objective is to measure the volume of molten plastic created, on one minute. For PP the extruder has volumetric flow rate of 18kg/h and for LDPE a 15kg/h.

Temperatures used on the experiment are the ones recommended by the producer of the material, nonetheless this might vary depending on the speed of the extruder. The temperatures used were; Zone1: 165, Zone2; 185, Zone3; 185, Zone4; 185. As can be observed on Figure 21.

Figure 21 – Heating Zones

The extruder has 4 resistances, the first three zones are used to heat the feed, transition and metering section and the zone 4 it is the one corresponding to the extruder outlet, which has two thermal resistance in parallel, one it is located on the die and the other one it is located on the die head.

The cooling bath or tank it is a standard equipment with a 183cm of length, with a volume of 45 L, as seen in Figure 22. This cooling bath has a vacuum bomb included, nonetheless this bath will be used only to cooling the tubes.

Figure 22 – Cooling Bath/Tank

This tank requires a supply of cooling water which it is directly dispensed to the tank from the chilled water system which utilize a simple inlet/outlet of the water through the process with no recirculation in the tank, because there is no water-reservoir used on this process. See Figure 23 for the chiller from Green Box used on the process. The optimal temperature for cooling polyethylene was 15 °C. Water is circulated through the tube to remove heat from the molten plastic pipe as it solidifies.

Figure 23 – Chiller Green Box

The Puller used it is also a standard one from Bandera´s firm, see Figure 24, to keep the process moving, the extrudate requires a bit of help from a puller to maintain tension in the process. The product goes through the cooling stage until it is cool enough to pull without breaking the web. The longer the cooling length and the longer the calibration tooling length, the higher the pull force required to maintain the process. The product leaves the extruder at a given kg per hour. That equates to a given linear speed based on product weight. That speed needs to be accurately maintained or the product weight and/or quality will vary and may cause out of specification product. This puller has a maximum velocity of 25 rpm, and it could pull tubes or profiles at 15 cm of width, this will also depend on the material that has been used due to the friction created to the belt of the puller.

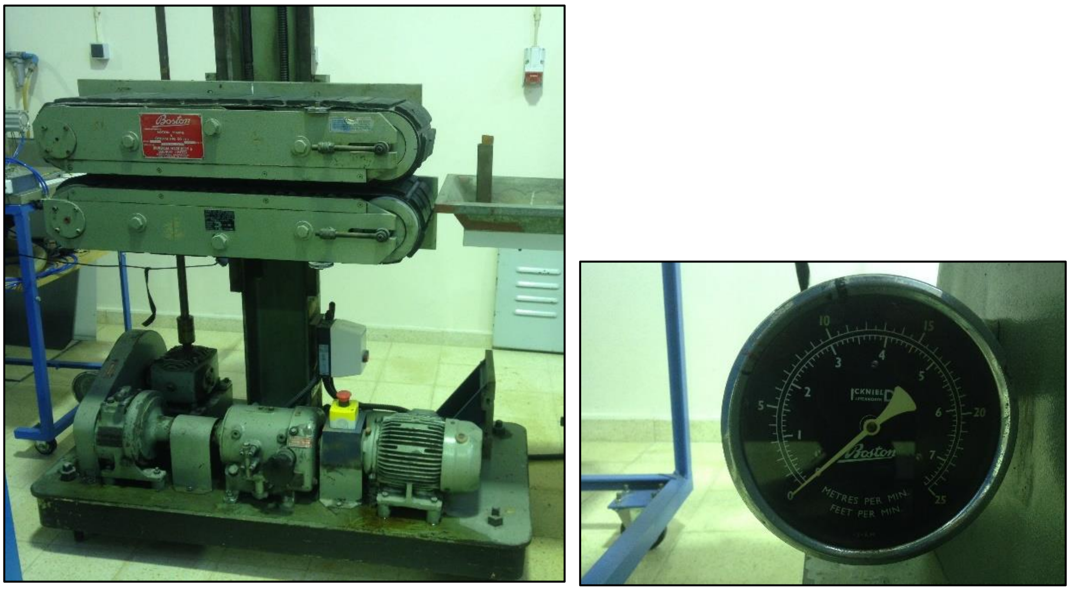


Figure 24 – Standard Bandera´s Puller

As many of the pullers on extrusion, has a gripping system which allows to pull the extrudate plastic in order to maintain a constant process established that will assure product specification, if the gripping or clamping it is too high, might damage the product, but if the gripping it is not enough might stop the process and break the linkage between the extrudate and the puller.

3.3.3. Extrusion process Calculations

Based on previous calculations, and by the selection of the thermoplastics to be analysed, several calculations to guarantee proper test and evaluation will be determinate below.

Using Equation 4, the shear rate is:

$$h = \frac{40,5\ [\mathrm{mm}] - 38\ [\mathrm{mm}]}{2} = 1{,}25\ [\mathrm{mm}]$$

$$\dot{\gamma} = \frac{3.1416\ \times 40[\mathrm{mm}\,] \times 60[\mathrm{rpm}]}{1{,}25[\mathrm{mm}\,]} = 100\ s^{-1}$$

Extrapolation data showed previously on of Figure 8 we can determinate that the viscosity at $100sec^{-1}$ is approximately $80sec^{-1}$.

Using Equations 6, 10 and 11 to define the shear rate on annular dies for a PP standard thermoplastic with a melt density of 0,75 g/cc we could determinate the pretended values [7].

$$\Delta P = 2 \times \frac{600\ [\mathrm{N}]}{\pi \times (40\ [\mathrm{mm}])^2} \times \frac{38\ [\mathrm{mm}]}{20\ [\mathrm{mm}]} = 0{,}45 \frac{N}{mm^2}$$

As previous said, the volumetric flow rate for PP with the pretended extruder is 18kg/h, value that will be converted as shown:

$$Q = \frac{18kg}{h} \times \frac{1\ h}{3600\ s} \times \frac{1\ cm^3}{0.75\ g} \times \frac{1000\ mm^3}{1} = 6666{,}66 \frac{mm^3}{s}$$

With the volumetric flow rate, it is already possible to calculate the die shear rate, but before this, it is possible to calculate n=Polymer Viscosity replacing volumetric value on its formula.

$$n = \frac{\pi \times (Ri + Ro) \times h^3}{12 \times Lc} \times \frac{\Delta P}{Q}$$

$$n = \frac{3{,}1416 \times (9\ [\mathrm{mm}] + 10\ [\mathrm{mm}]) \times (1{,}25\ [\mathrm{mm}])^3}{12 \times 38\ [\mathrm{mm}]} \times \frac{0{,}45 \left[\frac{N}{mm^2}\right]}{6{,}66 \left[\frac{mm^3}{s}\right]} = 0{,}01727\ \frac{N}{mm^2} s$$

$$n = 0{,}01727\ \frac{N}{mm^2} s \times \frac{1\ PA.m^2}{1\ N} \times \frac{1000000mm^2}{1\ m^2} = 17{,}25\ PA.s$$

$$\dot{\gamma} = \frac{6 \times 6666{,}66 \frac{mm^3}{s}}{3{,}1416 \times (10mm + 9mm) \times (1{,}25mm)^2} = 428{,}87\ s^{-1}$$

This does not yield the absolute shear rate or viscosity because the resistance to flow by the die is not included. From Figure 8 the viscosity in the die lip area is approximately 65 Pa-sec.

The wall diameter ratio it is given by Equation 12:

$$DR = \frac{10\ mm}{9mm} = 1{,}11$$

The wall cross sectional area it is given by Equation 13.

$$A_W = \frac{3{,}14{,}16(10^2 - 9^2)}{4} = 15\ mm^2$$

The power required to heat polymer from the feed throat to the molten state is given by Equation 12, and it is calculated below. The calculation will be at the maximum level of volume rate of PP, that it is 18kg/h and temperatures from 25 °C to 235 °C.

The PP Heat Capacity is 2,1 $\frac{kJ}{kg}$ ℃ and ΔH_{fusion} is 102 $\frac{J}{g}$.

$$Power = 18\frac{kg}{h} \times 2{,}1\ \frac{kJ}{kg}\ ℃\ \times (235 - 25)℃\ + 18\frac{kg}{h} \times 102\frac{J}{g}$$

$$Power = 7{,}93\ \frac{kJ}{h} + 18{,}56\frac{kJ}{h}$$

$$Power = 26{,}5\frac{kJ}{h}$$

In order to convert to kW, divide power by 3600s.

$$Power = 26{,}5\frac{kJ}{h} \times \frac{1h}{3600s} = 7{,}36\ kW$$

Since 1kW it is equal to 1,36HP

$$Power = 7{,}36\ kW \times 1{,}36\ \frac{HP}{kW} = 10\ HP$$

In conclusion, it takes 7,36kW per hour to process 18 kg/h of PP resit at 235 °C. Since extrusion equipment is not 100% efficient, it actually takes more energy than calculated to process the PP, since some of the heat is lost to the surroundings and the motors and drives are not 100% efficient, nonetheless for the pretended experiment the extruder driver motor has a nominal power of 15 HP, which means that a production on the aforesaid characteristics will guarantee a long-term efficient, avoiding over effort to the extruder.

3.3.4. Tooling

Tooling is a critical aspect of the total plastic product design picture because a plastic part can be no better than the tooling that created it.

While it is not necessary for the product designer to be able to design a tool, a fundamental knowledge of tooling is essential, not only for the design of the part, but for the process selection as well.

Most differences between the design of plastic parts and the design of parts made of other materials are way heat and pressure related. Heat and pressure are used to create the parts and their effects on the part plus the effects of the subsequent cooling of the parts to room temperature require consideration in the design phase.

To guarantee a product on specification, the designs of the extruder head, die, spider and mandrel must be validated. In extrusion industry, each extruder has a head, that it can adapt standard die dimensions, that’s why it is recommended to size new tooling according to current extruder head dimensions. This standardization also helps to perform production set-ups easier.

The development process of the tooling also contemplates the design of the die. Generally, in extrusion industry the clients are the owners of the tooling, nonetheless are developed by the extrusion company.

3.3.4.1. Extruder Head

The current extruder head was altered for the test of the new product, see Figure 24 for the design of the Extruder Head.

The new plastic product it is a holed tube, therefore the alteration on the extruder head was to create an air inlet that will allow tube to “breathe”, in order to maintain the shape of the wanted tube. An M6 thread was made for the aforesaid purpose.

To size 10mm tube, air pressure was used to expand the pipe against the sizing tube. Also, pressure air is inserted through the die mandrel with a precise pressure control using an air flow regulator, see Figure 25.

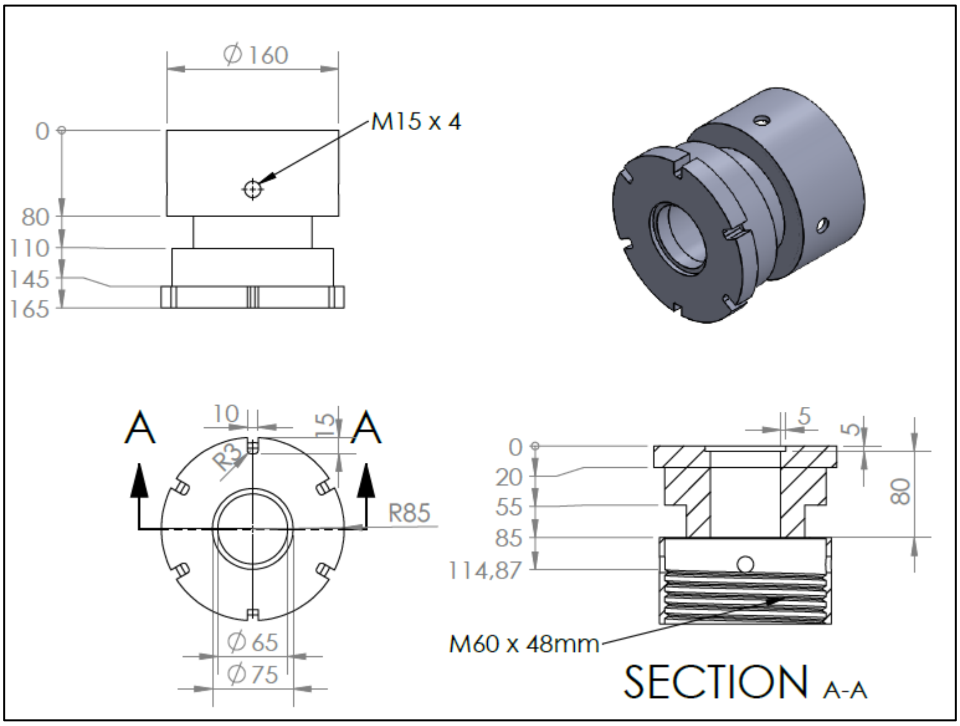


Figure 25 – Extruder head design (Scale 1:5)

The head design allows to easily mount with the extruder by six M14 hex head screws, also in order to stabilized and direct the extrudate on the outlet, the head permits to tight up 3 screws for tune up, as can be observed on Figure 26.

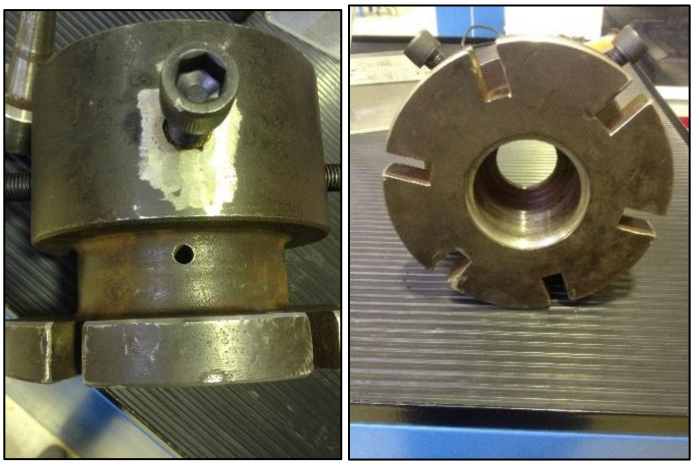


Figure 26 – Extruder head

3.3.4.2. Extruder Spider

The extruder spider it is part of the extrudate head, has four flow canals that permits the plastics to be oriented properly through the outlet, see Figure 27. Has a M12 thread on the top to chance a adapt a mandrel to different sizes.

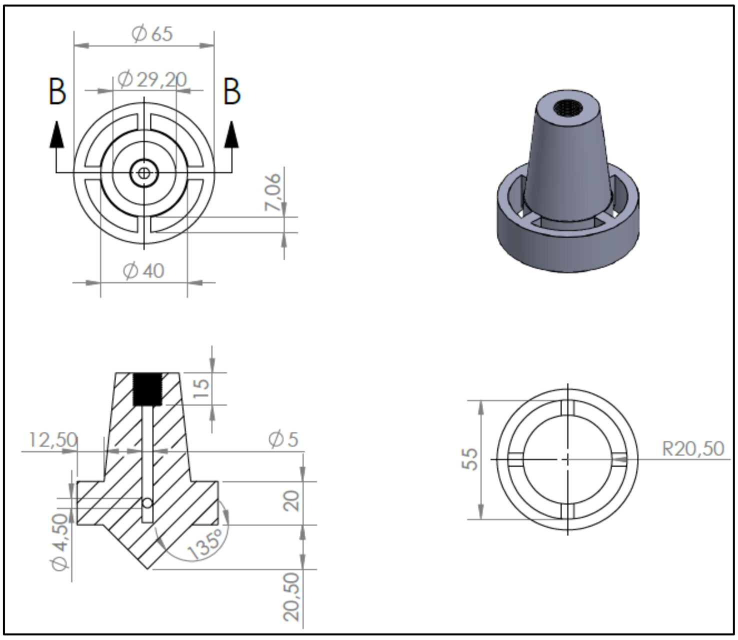


Figure 27 – Extruder Spider Design (Scale 1:2)

3.3.4.3. Extruder Mandrel

The mandrel which it is threaded in the aforesaid spider, has a 9,6mm diameter on the outlet. This diameter it is calculated by the intended tube, see Figure 28 and Figure 29. In the bottom has a M12 thread to be easily adapt to the spider.

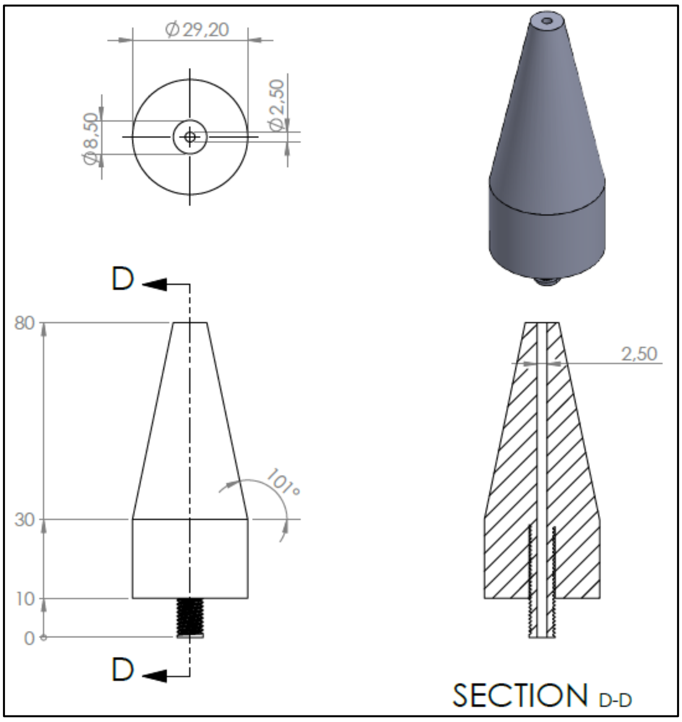


Figure 28 – Extruder Die Mandrel Design (Scale 1:1)

Figure 29 – Extruder die mandrel

3.3.4.4. Extruder Die

Extrudate Die head on Figure 30 and Figure 31 has a 11 mm internal diameter. The outside dimensions are determinate by the extruder characteristics. To guarantee that the tube will have an OD of 10mm, the die must have a larger diameter, because of the plastic flow deformation

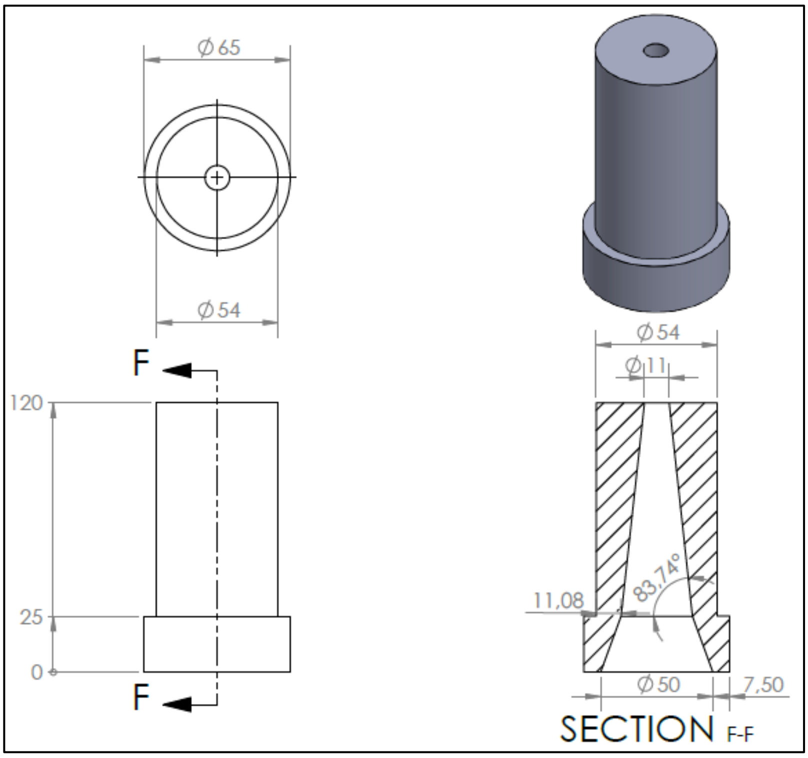


Figure 30 – Extruder Die Design (Scale 1:2)

Figure 31 – Extruder Die

On Figure 32 there is the entire extruder head connected with all the components. For adjust the die and mandrel, a threaded system it is used to hold up all the pressure form the screw extruder.

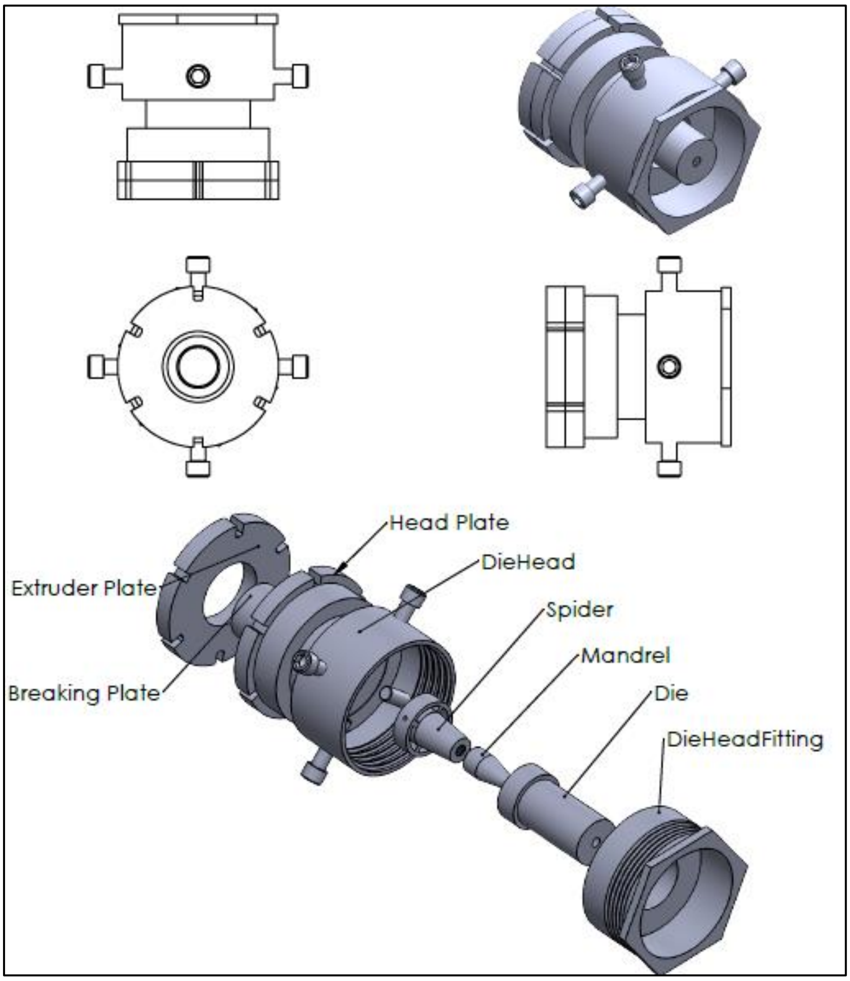


Figure 32 – Extruder mounted Tooling Design (Scale 1:5)

Figure 33 – Extruder head mounted

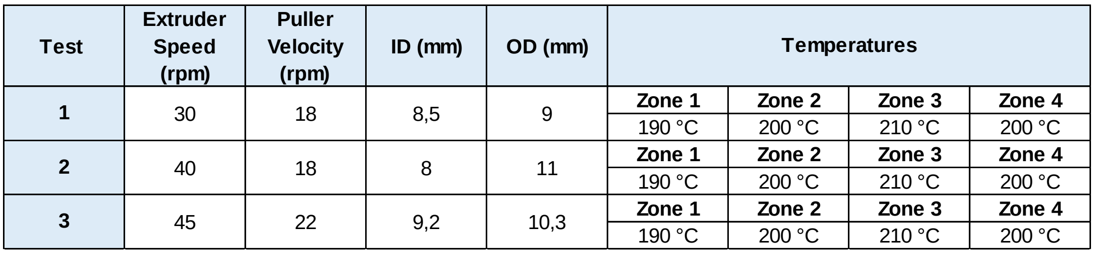
3.4. Test and evaluation

On this stage, will validate all previous design and determinate which parameters should be used to guarantee a stable process for the intended product.

With the whole tooling mounted on the extruder, as shown in Figure 34, and with the temperatures set according to fabricant recommendations, it was necessary to permit the plastic flow for 5 minutes at least before beginning the test, in order to allow the plastic to stabilize and achieved the optimum consistency. A 6-bar pressure air was connected to the mandrel to maintain the tube shape. The more air flow passing through the tube, the more this will inflate, which it is why an air regulator it is necessary to maintain the tube shape.

Figure 34 – Die head extruding PP

To analyse properly the results, three tests were performed under same temperatures conditions, as can be observed on Figure 35.



Test	Extruder Speed (rpm)	Puller Velocity (rpm)	ID (mm)	OD (mm)	Temperatures			
1	30	18	8,5	9	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
					190 °C	200 °C	210 °C	200 °C
2	40	18	8	11	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
					190 °C	200 °C	210 °C	200 °C
3	45	22	9,2	10,3	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
					190 °C	200 °C	210 °C	200 °C

Figure 35 – Product Test/Validation

The strength was measured by a durometer and the OD and ID where measured with a calliper.

In the first test the extruder speed was at 30 rpm and the puller on 18 rpm, but the ID and OD were out of specification. The OD needed to increase the dimension, which means that needed more material to achieve the 10mm OD or to reduce the pulling velocity. By reducing the pulling velocity, the nominal production velocity decreases as well. Which it is that on Test #2, only the Extruder speed was increased 10 rpm´s. Nonetheless, Test#2, has the ID and OD out of specification as well. On Test#3, the extruder speed was increased only 5 rpm, but the puller was also increased 3 rpm´s. With a 45rpm on extruder and 22 rpm on puller, the OD achieved 10,3mm and ID 9,2mm, values that are according to product specification. The tube has a 57 shore A. For further productions, these should be the values to utilize, nonetheless, might be possible to increase productivity by increasing the speed both on extruder and puller, however, this synchronous mode it is not available on this extruder, more efficient and modern extruder has this option. See extrusion test on Figures 36 and 37.

If both extruder speed and puller speed were changed and the product result do not achieve client specification, means that the die design will not guarantee the pretended dimension. The breaker plate and the screen pack act as a seal between the extruder barrel and the die adapter, thus preventing leakage of the melt.

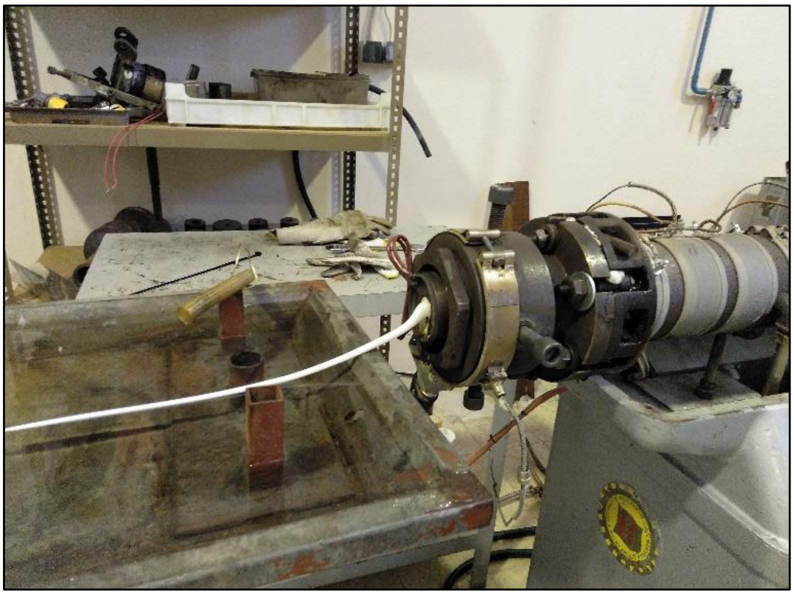


Figure 36 – Plastic Extrusion Production

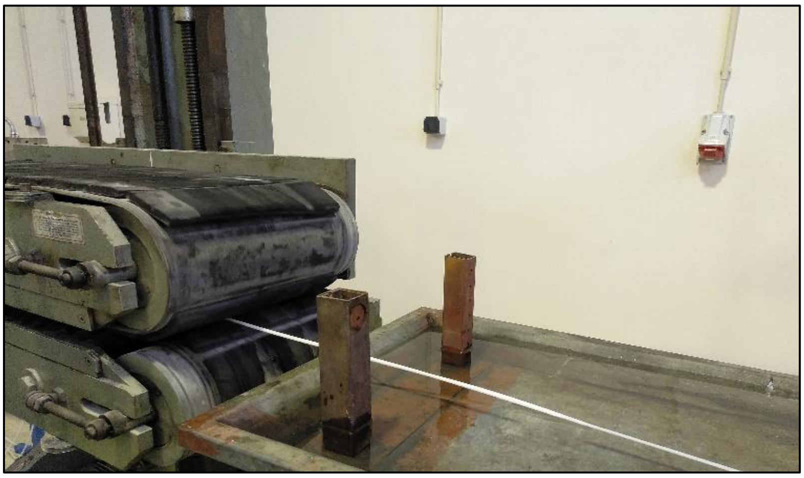


Figure 37 – Plastic Extrusion Production

In order to proceed with the proper length of the tube, it is necessary to implement a cutting system in the end of the line, the afore said equipment should be connected with an encoder on the motor of the puller to obtain this information and to proceed with the cutting. The cutting should follow the movement of the puller, to avoid stoppage on the line. Nonetheless this specification will be consider as achieved due to not being a critical requirement to obtain, see Figure 38.

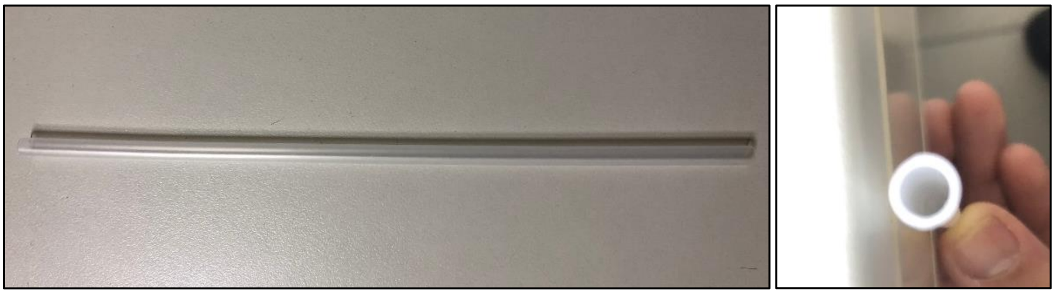


Figure 38 – Product Extruded

To validate the product specification, it is highly recommended to request parts where the product will be connected to. Like in this case of study, the final product dimensions were validated by inserting the tube on the pulveriser cup and filter, as observed in Figure 39. The fitting between the tube and the outlet of the pulveriser cup was on specification.

Figure 39 – Product Fitting validation

3.5. Manufacturing

The plastic extrusion process is very standardized, and there are few deviations between extrusion operation in terms of the basic principles of extrusion. Operating temperatures and output speeds may vary depending on the properties of the plastic material, but plastic extrusion processes resemble each other very closely aside from these differences

Start-up productions might be exhausted, nonetheless, when the extrusion lines stabilized, the productions it is continuous, obviously maintaining that the extrusion line has enough material and that the parameters has no external influences that might alter the product specifications.

A main advantage in extrusion it is the linear production. By avoiding extruder stoppage, will guarantee better production conditions and more reliable products.

Proper puller velocity maintains the product under client requirements, such as the temperatures stablished on the extruder.

3.6. Logistics, supply chain, and environment

The main purpose of the thesis it is to study the behaviour of extrusion process on tubes production, developing a new product.

Once the polymer or blend is properly dried and ingredients mixed, the formulation is fed to the extruder, where it is melted, mixed, and delivered to the die to shape the extrudate. After exiting the die, the product is cooled and solidified in the desired shape and pulled away from the extruder at constant velocity to attain the appropriate cross section. Secondary operations, like flame treatment, printing, cutting, annealing, etc., can be done in line after the puller. Finally, the product is inspected, packaged, and shipped.

Some company also focus on reduce the waste of material produced during the star-ups and stoppage, due to the main cost it is the thermoplastic itself, however, the aforesaid plastic might be reintroduced on the process using proper grinders on the end of the line. The grinded material it is mixed with the virgin material in a percentage that will not imply product quality, generally this mixture it is 80% raw material and 20% grinded material.

Product development has a particular vested interest in keeping the life-cycle cost for any product as low as possible, which it is why logistics makes a crucial phase to take account of.

4. Conclusions

- Product development process gives to the thermoplastic extrusion industry, successfully quality product by a methodologic team-work with specialized knowledge of various disciplines, prioritizing product requirements. During the entire design phase, all producibility, quality, and reliability design requirements are documented. Proper development process helps to assure future production and manufacturing quality
- Test # 3 with a speed of 45 rpm on extruder and 22 rpm on puller the OD dimension was 10,3 mm, ID 9,2 mm and length of 150 mm. The tolerances of these dimensions are 0,05 mm. The tube was ideal to accomplish the initial requirements that neither will be under stress or under pressure. Also guarantees an ideal seal on the cap junction. The tube has a rigid consistency (57 ShA). For further productions, these should be the values to utilize, nonetheless, might be possible to increase productivity by increasing the speed both on extruder and puller simultaneously.
- Extrusion start-up phase during production might be exhausted, nonetheless when the extrusion lines stabilized, the production remain continuous, if the extruder it is fed constantly by material and the parameters has no external influences, that might alter the product specifications.
- Takes 7,36 kW per hour to process 18 kg of PP resin at 235 °C. Since extrusion equipment is not 100% efficient, it actually takes more energy than calculated to process the PP, since some of the heat is lost to the surroundings and electric motors are not 100% efficient, nonetheless for the pretended experiment the extruder driver motor has a nominal power of 15HP, which means that a production on the aforesaid characteristics will guarantee a long-term efficient, avoiding over effort for the extruder.
- With the whole tooling mounted on the extruder and with the temperatures set according to fabricant recommendations, it was necessary to permit the plastic flow for 5 minutes before beginning the test, in order to allow the plastic to stabilize and achieved the optimum consistency. A 6-bar pressure air was connected to the mandrel to maintain the tube shape. The more air flow passing through the tube, the more this will inflate, which it is why an air regulator it is necessary to maintain the tube shape.

- The PP viscosity at 235°C in the die lip area was approximately 65 Pa-sec.
- The principal requirements of the product, that were translated on functional requirements and were achieved by thermoplastic’s performance and characteristics, has stablished that the most suitable thermoplastic was PP.
- The procedure to get the product in to specification it is required whether increase/decrease the extrudate “debit” or increase/decrease the puller velocity. This procedure must be tuned up according to the results of the product.
- The extruder has a L/D ratio of 3/1, ideal for processing PP thermoplastic.

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Appendices

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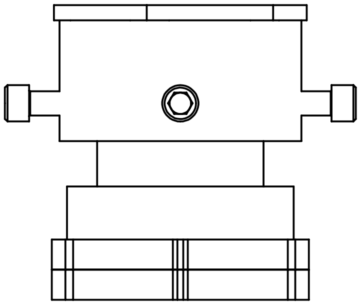

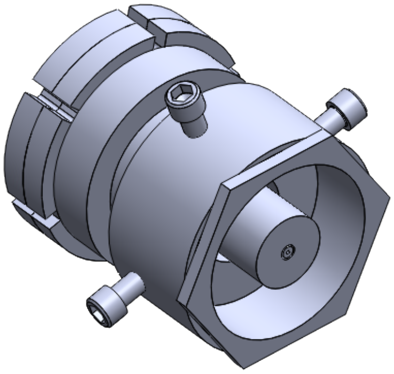

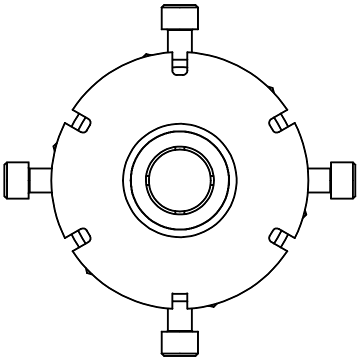

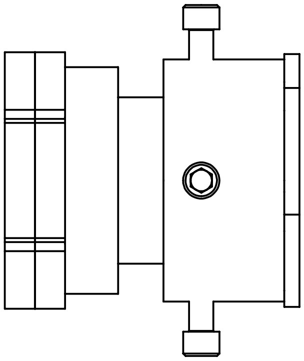

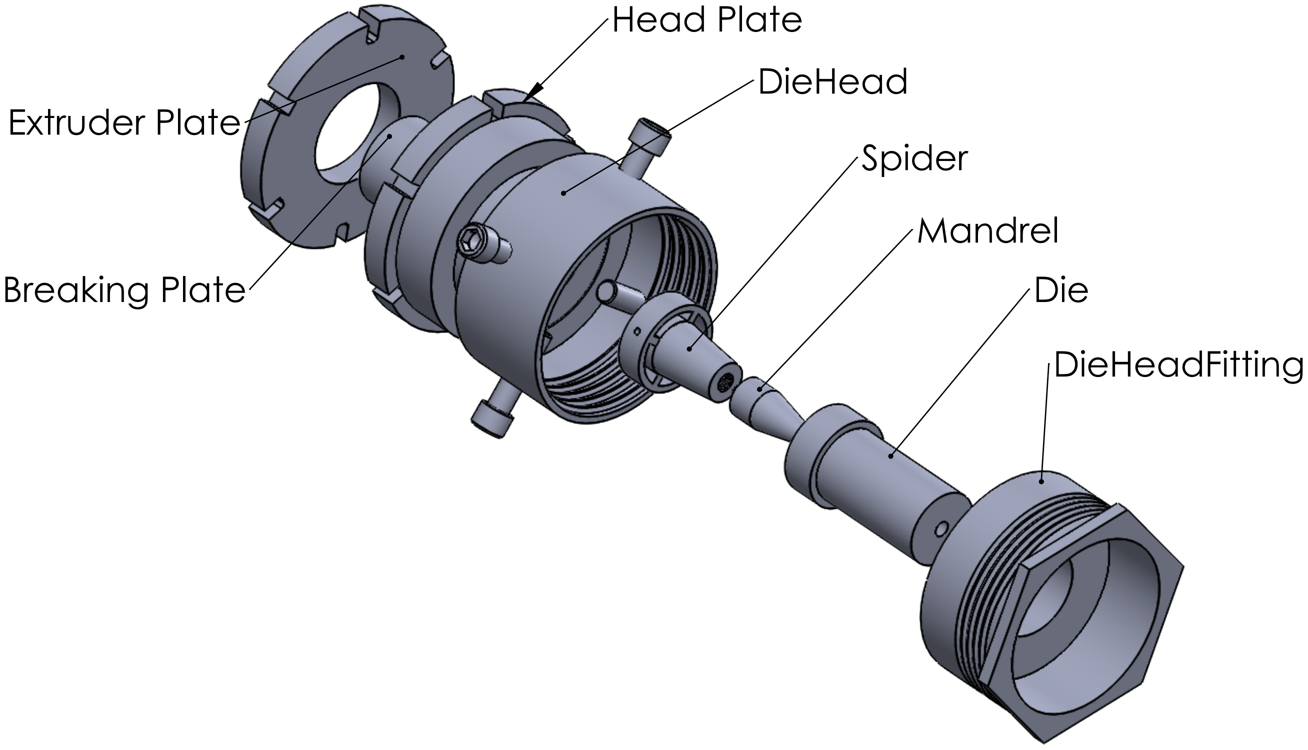

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	CHECKED		10mm_PP_Extruder_Die_Heac
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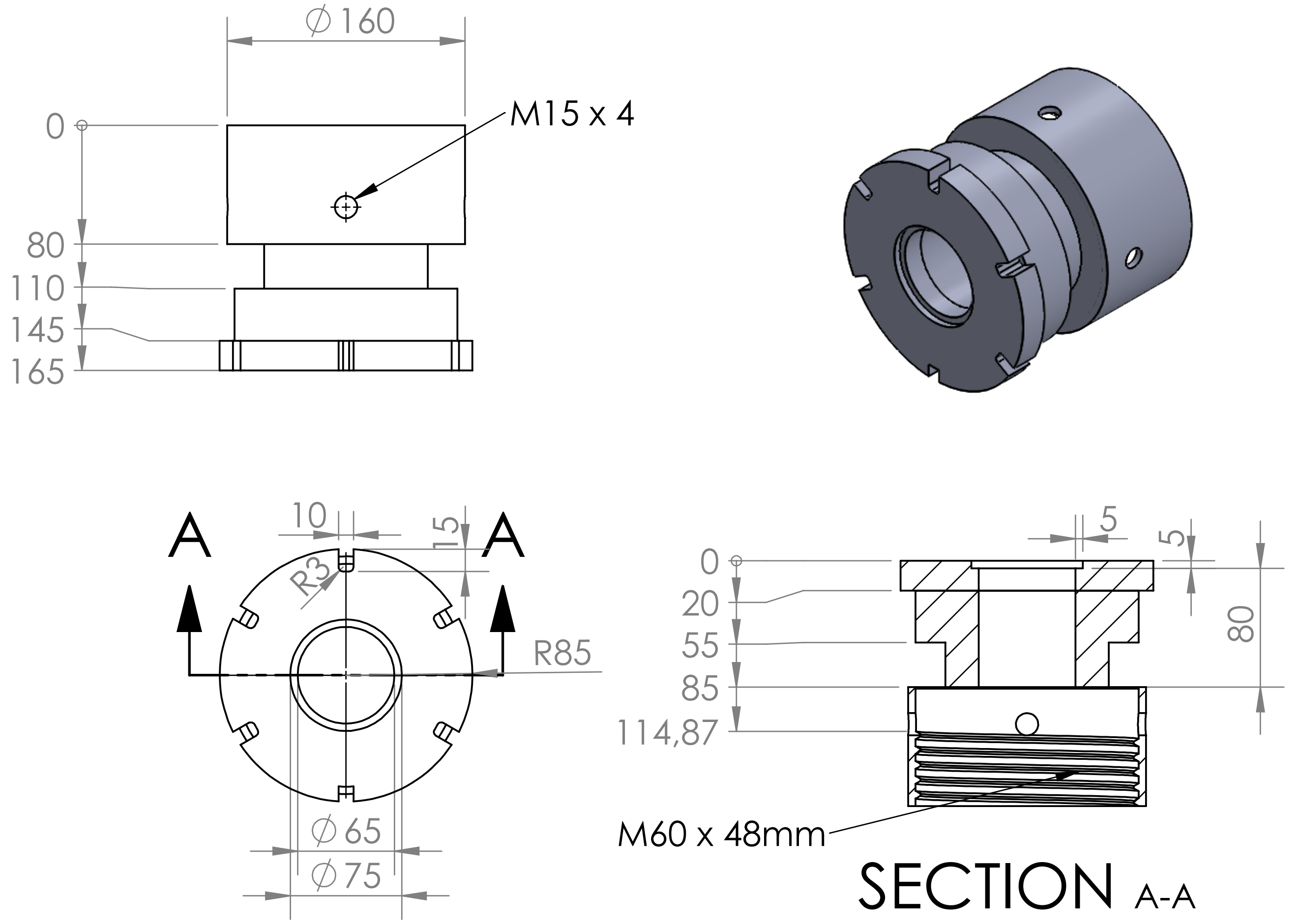


SECTION A-A

DIMENSIONS ARE IN MILIMITERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

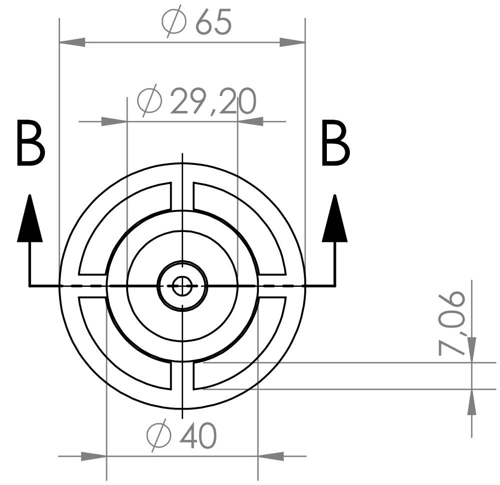
	NAME
DRAWN	Romeo Rivadeneira
CHECKED	
ENG APPR.	
MFG APPR.	
Q.A.	

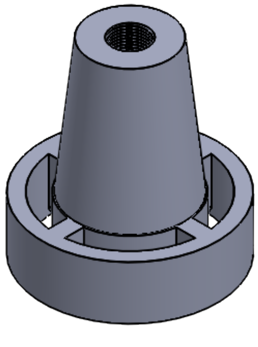
COMMENTS:

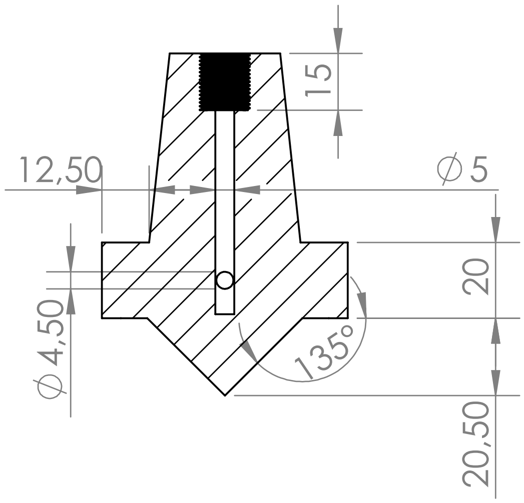
10mm_PP_Extruder_Die_Heac

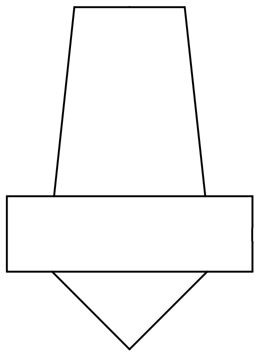
SIZE A
DWG. NO. Extruder DieHead
REV.

SCALE:1:5
WEIGHT:
SHEET 2 OF 7









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NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

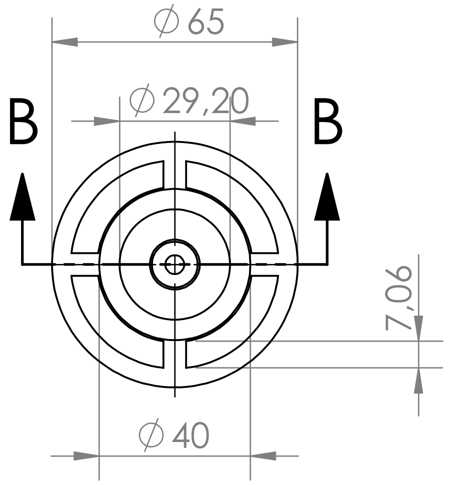
DO NOT SCALE DRAWING

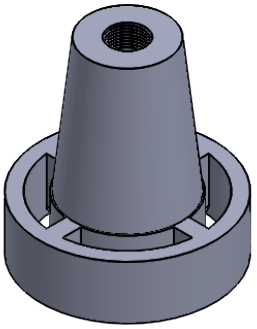
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

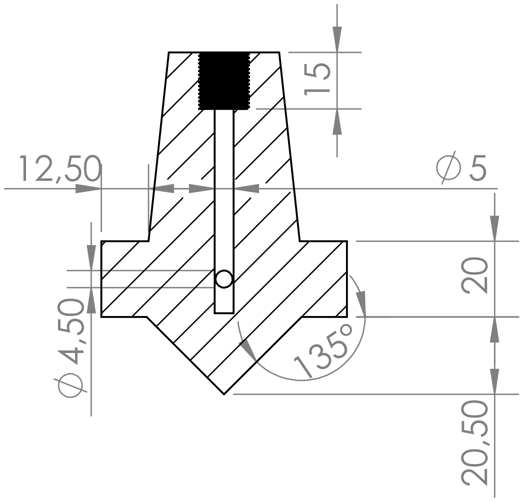
COMMENTS:

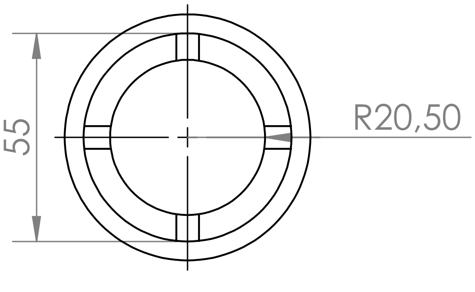
SIZE	DWG. NO.	REV.
A	10mm_PP_Extruder_Die_Head	

SCALE:1:2 WEIGHT: SHEET 3 OF 7

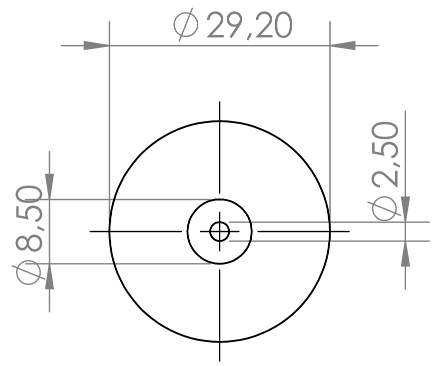


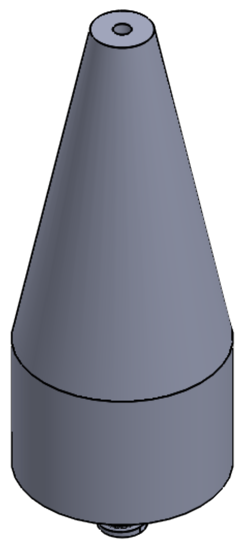


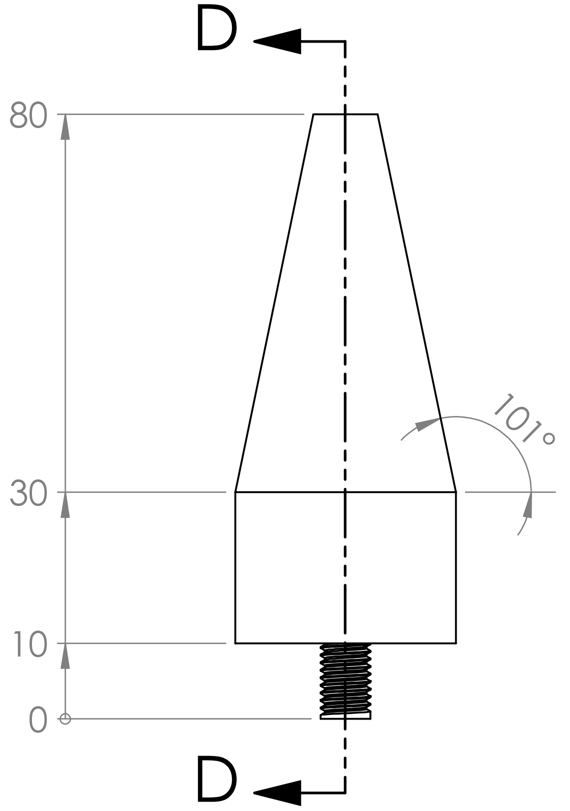


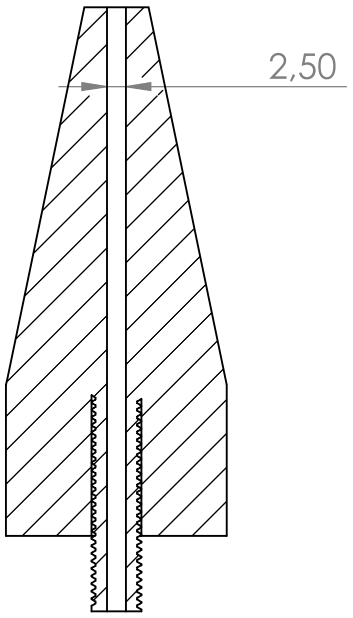


DIMENSIONS ARE IN MILIMITERS TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	
	DRAWN	Romeo Rivadeneira	
	CHECKED		10mm_PP_Extruder_Die_Heac
	ENG APPR.		
	MFG APPR.		
MATERIAL	Q.A.		
FINISH	COMMENTS:		SIZE A · DWG. NO. Spider · REV.
DO NOT SCALE DRAWING			SCALE:1:5 · WEIGHT: · SHEET 4 OF 7



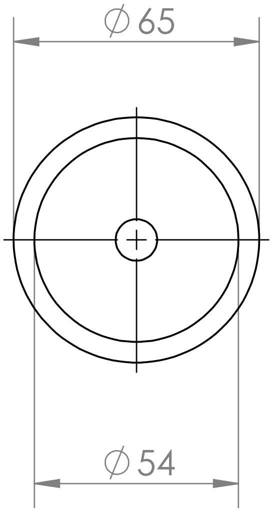


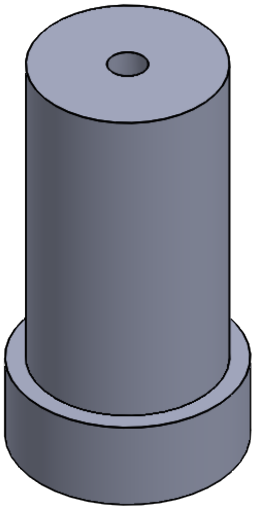


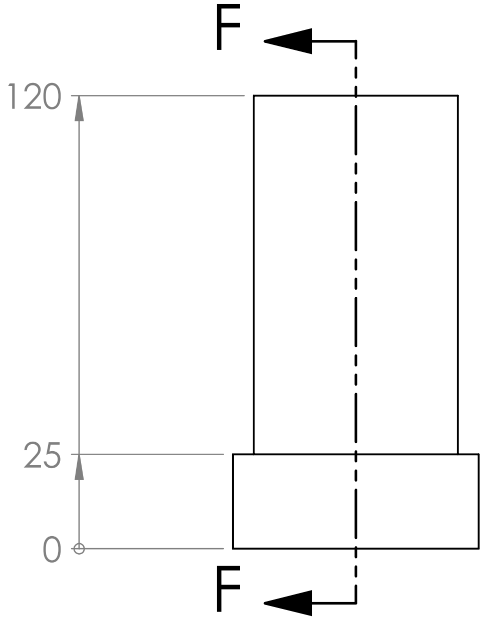


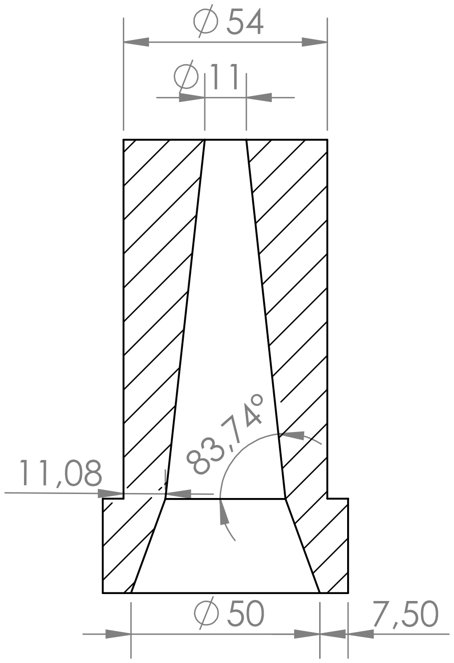
SECTION D-D

DIMENSIONS ARE IN MILIMITERS TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	
	DRAWN	Romeo Rivadeneira	
	CHECKED		10mm_PP_Extruder_Die_Heac
	ENG APPR.		
	MFG APPR.		
MATERIAL	Q.A.		
FINISH	COMMENTS:		SIZE A · DWG. NO. Mandrel · REV.
DO NOT SCALE DRAWING			SCALE:1:1 · WEIGHT: · SHEET 5 OF 7









SECTION F-F

DIMENSIONS ARE IN MILIMITERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

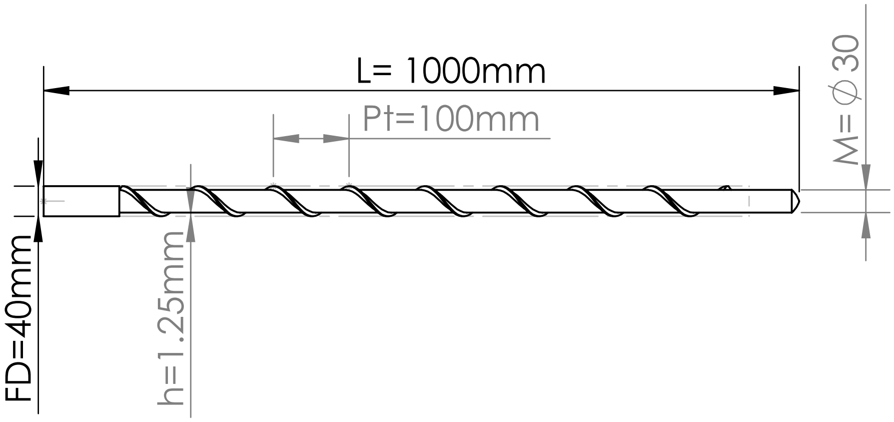
	NAME
DRAWN	Romeo Rivadeneira
CHECKED	
ENG APPR.	
MFG APPR.	
Q.A.	

COMMENTS:

10mm_PP_Extruder_Die_Heac

SIZE	DWG. NO.	REV.
A	Die	

SCALE:1:2 WEIGHT: SHEET 6 OF 7



DIMENSIONS ARE IN MILIMITERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME
DRAWN	Romeo Rivadeneira
CHECKED	
ENG APPR.	
MFG APPR.	
Q.A.	

COMMENTS:

10mm_PP_Extruder_Die_Heac

SIZE A
DWG. NO. Die
REV.
SCALE:1:10
WEIGHT:
SHEET 7 OF 7