Natural fibre composites for injection moulding

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Abstract:

Natural Fibre Composites are the hybrid materials made of a polymer resin reinforced by fibres. This combination provides high mechanical and physical properties to the composites. This thesis studies the possibility of producing dog-bone pieces in injection moulding machine using natural fibre composites as raw material and also optimizing the process parameters. In this thesis study, the drying time and cost variation between natural fibre composites and general thermoplastics are discussed. Furthermore, the tensile testing of those dog-bone pieces is done for the comparative analysis of strength between natural fibre composites and thermoplastics. Injection moulding machine is used for the production of dog-bone pieces whereas testometric machine is used to analyse the tensile strength and E-modulus of the produced pieces. The author concludes that even though the natural fibre composites are more expensive than thermoplastic polymers, they possess better ability to withstand higher stress than those thermoplastics. The fact that their environmental friendly nature and ease of production should be considered as possible replacement for thermoplastics.

Keywords:	Injection moulding of Natural fibre composites. Drying time. Price comparison. Tensile strength and Young`s modulus. Process Optimization.
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Glossary of abbreviations

IM	Injection Moulding
IMM	Injection moulding machine
PP	Polypropylene
PE-HD	Polyethylene high density
PE-LD	Polyethylene low density
PVC	Polyvinyl chloride
PS	Polystyrene
PLA	Polylactic acid
PPMS	Polypropylene metsäSellu (Finnish word for Pulp)
PLMS	Polylactic acid metsäSellu
T_m	Melting temperature
T_g	Glass transition temperature
°C	Degree Celsius, temperature measurement
NF	Natural fibre
GF	Glass fibre
NFC	Natural fibre composites
FRC	Fibre-reinforced composites
GFC	Glass fibre composites
GP	General purpose
HIPS	High-impact polystyrene
EPS	Expandable polystyrene

CO_2	Carbon dioxide
CO	Carbon monoxide
UV	Ultra violet
ECF	Elemental chlorine-free
CAD	Computer aided design
CAM	Computer aided manufacturing
FMD	Flexible modular dryer
DH	Drying hopper
NDT	Non-destructive testing

1 INTRODUCTION

The growing rate in use of non-biodegradable products and improper disposable methods has posed a serious threat not only to the human population but to the entire living population. Human activities are greatly responsible for all this issues and the present world we live in is constantly under threat of over pollution. If not acted fast and effectively on this issue, mankind will have to cope with a big challenge in coming future like climate changes. The huge reduction in the use of non-biodegradable products and the use of bio-degradable products prior to plastics can prove wiser in order to deal with this problem.

The Natural Fibre Composites are the hybrid materials made of a polymer resin reinforced by fibres. NFCs that are used for this thesis work are so called third generation natural fibre composites which have been combined in a new and innovative way. This combination provides high mechanical and physical properties to the composites. The availability of different manufacturing process and numerous design possibilities can result in their own characteristics products. These types of composite offer a new possibility to manufacture environmentally friendly injection moulding composite products that fulfil with environmental requirements. Kareline [1]

The use of natural fibres in the composite industry was practiced since a long time. There has been a decreased interest towards these natural fibre composites during the past 80 years because of the development of synthetic fibres such as glass and carbon fibres. The growing popularity of these synthetic fibres had virtually threatened the development of natural fibres. However, in recent years, the rise in awareness level in the human society that has provoked the use of natural fibre composites for environmental reasons has once again assured the interest towards natural fibres. This successful period has been influenced by a number of factors, including growing environmental and health concerns, more sustainable methods of manufacture and reduced energy consumption that is supporting the development of light weight structures. Thus natural fibre composites are getting the favour of environmentally alert population and are becoming popular nowadays and therefore its production is rising globally. Paul [2]

The term natural fibre in the composite industry refers to wood fibre and agro-based bast, leaf, seed and stem fibres, whose reinforcement provides a new material with great mechanical performance. Natural fibres reinforced polymer composites represents an emerging class of materials that combine the best properties of both fibres and polymers. The modern technology has contributed greatly towards the new and exciting development in this field. Sabu [3]

The automotive industry has shown the bigger interest towards the use of natural bio-composites. The European countries have emphasized towards the use of bio-degradable parts for the automobiles, especially cars. In the recent years, natural fibre-reinforced composites are being used by car-makers for door panels, seat backs, head-liners, dashboards and many more stuffs. Moreover, the natural fibres are getting more favour, mainly because of their many comparable properties to glass fibres within composites materials. Many properties such as light weight, strong, low cost and more importantly eco-friendly behaviour of these natural fibre composites are poised to replace glass fibre in numerous applications. Sabu [3]

The eco-friendly nature of natural fibre composites should be credited the most as it has played the important role towards increasing the social awareness to the general consumers about the environmental problems posed by the non-degradable synthetic fibre composite products. Europe has played a significant role in promoting environmental friendly composite products by issuing directives with regard to end-of-life vehicles. One such directive predetermined the deposition fraction of a vehicle to 15% from the year 2005, and gradually reducing it to 5% till 2015. Sabu [3]

Thus, the uses of natural fibre-reinforced polymer composites are gaining a rapid momentum worldwide. Figure 1 explains the increasing trend in consumption of natural fibre composites for the past 15 years. Within Europe, Germany dominates a market position and produces two-thirds of all natural fibre composites consumed in the automotive industry within Europe. Apart from automotive industry, natural fibre composites have penetrated the market daily application stuffs like cutleries, chair, desk, etc. Sabu [3]

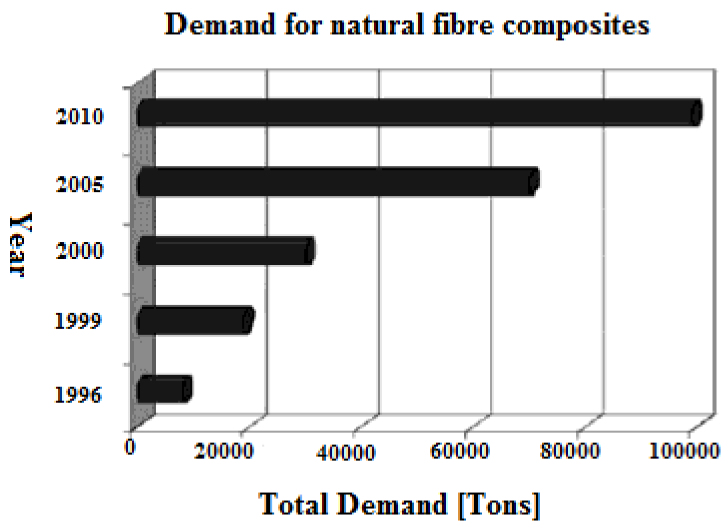


Figure 1 Total consumption of natural fibre composites in Europe [3]

Polymer composites can be considered as a great innovation which has unique advantages over more conventional materials. The present technology and scientific tools can play a vital role in contributing a steady growth regarding the consumption of these fibre composites. [2] Moreover, the environmental problem that the world has been suffering since a long time from non-biodegradable products can be reduced in greater volume by increased consumption of renewable fibre reinforced composites.

1.1 Objectives

This thesis work is to focus on comparison of tensile strength, cost and environmental benefits of natural fibre composites from that of common thermoplastics. The specific objectives of this research are set as follows:

1. To describe the manufacturing process of natural fibre composites
2. To analysis and optimize process parameters for injection of fibres
3. To compare the drying time of natural fibres and thermoplastics.
4. Comparative cost analysis of natural fibre composites to thermoplastics.

5. To calculate the tensile strength, stress and strain for natural fibres composites and to compare it with general thermoplastics like Polypropylene (PP), Polyethylene (PE) and Polystyrene (PS).

1.2 The methods and procedures

Practical methods as well as literature survey is used to get required data for the result. The research is performed in the laboratory of Arcada, with the use of Drying machine, Injection moulding machine and Testometric machine. The market and internet survey is made on cost analysis. The objective of the research is to produce several sets of test specimens with Fibre reinforced Polypropylene (PPMS), Fibre reinforced poly lactic acid (PLMS) and UPM ForMi GP as raw materials which were ordered from Kareline and UPM Companies respectively. The test specimens are produced through injection moulding method in a dog-bone mould. The test specimens are then subjected to stress and strain using Testometric Machine. The raw data obtained from machine is noted and average data is calculated from the whole range of data.

1.3 Scope and limitation

The thesis is mainly focused on finding the properties of injection moulded natural fibre composites and comparing those properties with common thermoplastics which are otherwise commonly used in injection moulding process. Since natural fibre composites is a combination of thermoplastics and natural based fibre, they are believed to be more environmental friendly with improved mechanical and physical properties compared to general thermoplastics. Also, knowing the availability of the machinery in the laboratory and limited fund from school, practical work is carried out only for three types of Composites, PPMS, PLMS and ForMi GP respectively.

Since the injection mould (Dog-bone mould) that is used for this thesis does not have good cooling channel, it could slightly alter mechanical properties of the final product. Granulates of PPMS and PLMS are of much larger diameter compared with granulates of general thermoplastics and this can hinder the smooth flow through the hopper because the injecting moulding machine in Arcada Laboratory consists of only one hopper with small inlet diameter. Also, there are different methods for testing the strength of the composites, among them are twist, bending and compression test. However, this thesis work will be focused on tensile test only using Testometric machine.

1.4 Significance of the research

The thesis is very practical as it is concerned with production of environmentally friendly plastic products through injection moulding. This is basically focused to Arcada students to help them enhance their knowledge in composite injection moulding. Also, the experimental result concerning the injection moulded part can be of greater importance to find the possibility of production of different types of product like Corr cup in Arcada. Moreover, the findings can help author to get deep knowledge on injection moulding of natural fibre composites.

2 LITERATURE REVIEW

2.1 Composites

Composites are hybrid materials that are made of a polymer resin reinforced by fibres. The properties of polymers combine with the properties of those fibres, resulting in greater performance materials which are called fibre-reinforced composites. In a fibre-reinforced composites (FRC), the high mechanical and physical performance of the fibre combines with the physical properties of the polymers along with appearance and bonding, providing a resultant material with greater performance ability. By this combination, the poor performance and drawbacks of the individual components disappears which results in a formation of a product with exceptional structural and physical properties. Natural Fibre Composites [4]

Composites have the ability to withstand high load and have good bending capacities because of the fibre reinforcement. The strength of the composites also depends on the fibre alignment. Natural Fibre-Reinforced Polymer Composites [5]

In ancient time, around 1500 BC, Egyptians used muds with bamboo shoots reinforcement to build houses. Fibre reinforced polymer composites were first introduced in 1908 when cellulose fibre was combined with phenolic. [6]. It was in mid-20th century when modern composites reinforced by glass fibres were used to build boats and aircrafts components. The composite industry widely gained a momentum in the late 20th century due to the development of new fibres such as carbon, boron and aramids. Looking back into last 100 years, a massive industry has been created which symbolizes the 20th century just as clearly as iron and steel characterized the 19th century. Hollaway [7]

In the year 1909, the world was introduced with first completely synthetic polymer when the American chemist Leo Baekeland was working in a laboratory to develop a material which flow and would be poured into moulds. Over the past 100 years, the synthetic industry has been growing so rapidly that it is now possible to create new types of polymers which can be designed for specific functions. Hollaway [7]

The use of polymers and composites gained rapid momentum during the Second World War, when these materials were used in a diverse range of applications. Composites are now used in aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and many more. There is also a potential for use of these materials in medical world and microelectronic devices. Hollaway [7]

The use and demand of glass fibre is increasing day by day because of their low cost and good mechanical properties. However, these fibres possess some serious disadvantages as indicated in table 1. These shortcomings can be overcome by the use of natural fibre reinforced composites. GFCs can be replaced by NFCs mostly in non-structural applications because of many good features it possesses compared to GFC as shown in table 1. Science Direct [8]

Table 1 Comparison between natural fibre and glass fibre [8]

Natural Fibre Vs. Glass Fibre		
Properties	**Natural fibre**	**Glass fibre**
Density	Low	Twice that of NF
Cost	Low	Higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
CO_2 Neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Non-biodegradable

Natural and wood fibres are environmental friendly as they are derived from renewable resources. The reinforcement of these renewable resources in plastics, either thermoplastics or thermosets provides greater environmental benefits compared to non-biodegradable plastics or glass fibre composites. Omar [6]

2.1.1 Constituents of Fibre-reinforced Composites

The fibres which are reinforced in the matrix play an important role in utilizing the plastic flow of the matrix under stress to transfer the load to the fibre, resulting in high strength composite. In general, there are different phases in the composite material and each of the individual phases together makes a high strength and high modulus composite. Each of the individual phases that makes up the whole composite are as follows: Hollaway [7]

2.1.1.1 Fibres

The microstructure and physical properties of the fibres constitute an important factor in determining the strength of the fibre reinforced composites. Since the matrix under stress transfers the load to the fibres, it is thus important that fibres should have a high modulus of elasticity for an efficient utilization of reinforcement. The fibres to be reinforced should also have high ultimate strength and the variation of strength between individual fibres should be low. More importantly, the fibres should retain their strength during handling and fabrication. Hollaway [7]

2.1.1.2 Matrix

The polymer matrix binds the fibres together and protects their surfaces from damage during handling, fabrication and service life of the composite. Not only this, it also transfers the stresses to the fibres efficiently when composite is under load. The polymer matrix used in the composite should also be chemically and thermally compatible with fibres over a long period of time. A matrix may be either thermoplastic or thermosetting plastics. Hollaway [7]

2.1.1.3 Interface

The interface is an anisotropic transition region between the fibre and the matrix. It is considered to be an important region because it provides chemically and physically stable bonding between the fibres and the matrix. If the composite material have weak interface than the whole composite will have low strength and stiffness but will possess high resistance to fracture. Similarly, a composite system with strong interface will have high strength and stiffness but are brittle. The properties of the interface region in the real composite system are as follows: Hollaway [7]

- the matrix and fibre behave as elastic materials
- there is a perfect bond between the fibre and the matrix and constituently there will be no strain discontinuity across the interface
- the material adjacent to the fibre has the same properties as the material in the bulk form
- the fibres are arranged in a regular pattern

2.2 Natural fibres

The fibres that are directly obtained from nature are termed as natural fibres. Polymer composites can be manufactured using fibres of different origins. Natural fibres are extracted out of plants, animals and mineral sources. Plant fibres are mostly used in the composite industry. Plant fibres are usually composed of cellulose in their structural formation and are also called as vegetable fibres. Generally plant fibres are only a few millimetres to couple of centimetres long. The properties of natural fibres are comparable to synthetic fibres like glass fibres, in some regard. Table 2 shows some properties comparison between GF and NF. Science Direct [8]

Table 2 Natural fibre properties in relation to E-glass [8]

Fibre Type	Density (g/cm^3)	E- Modulus (GPa)	Specific Modulus (GPa/g/cm^3)
Glass fibre	2.55	73	29
Hemp	1.48	70	47
Flax	1.4	60-80	43-57
Jute	1.46	10-30	7-21
Cotton	1.51	12	8
Coir	1.25	6	5
Ramie	1.5	44	29

2.2.1 Common natural fibres

Some of the common natural fibres that are used widely all over the world are described below.

2.2.1.1 Cotton

Cotton is a natural vegetable fibre mostly composed of cellulose. The cotton fibres are soft and ribbon-like, that grows in a protective capsule around the seeds of cotton plant. The cotton plant can grow up to 10 m high in the wild, has been domesticated to range between 1-2 metres, in order to facilitate picking. Cotton is rather weak in comparison to other natural fibres. The colour of the cotton fibre is generally white, but there is also reddish, tawny, grey, chamois, etc. coloured varieties. Considering length of the fibre, it is divided into long and short fibre cottons, where long fibre measures from 28-50 mm and short fibres measures about 18-28 mm. It is soft and can absorb moist up to 20% of its dry weight. The fibres show good resistant to alkalis and cold weak acids. It is a good conductor of heat and is extremely susceptible to any biological degradation. According to some statistical data, cotton accounts for 2.5% of the world’s arable land with an estimation of 25 million tonnes annually all over the world. Swicofil [9]

Cotton is one of the most important and widely used natural fibres all over the world for textile products that includes mostly all kinds of clothing like shirts, jeans, socks, underwear, towels etc. Its tensile properties and hydrophobic nature (shiny cotton) have made it possible to be used as fishing nets. In addition to this, the fibres are used to make paper coffee filters, tents etc. Swicofil [9]

2.2.1.2 Jute fibre

Jute is a long, soft and shiny plant fibre. It is a lingo-cellulosic fibre that is composed of partially plant fibre cellulose and partially wood fibre lignin. The fibres can be found in faded white or brown colour. The length if the fibre can differ according to the climate and soil condition available, ranging from 1-4 metres long. Jute is one of the strongest natural fibres with high tensile strength and low extensibility. The fibres are collected from bast or skin of the plant. Jute is one of the most important natural fibres after cotton with variety of uses. Jute fibre is used to make cloth for wrapping bales of raw cotton, sacs and coarse cloth. It is also used to make carpets, rugs, curtains, etc. Besides, the fibres are used to make pulp and paper and more importantly as a reinforced fibre material for composites. Lyscaleriskgrade [10]

2.2.1.3 Coir (coconut fibre)

Coir is a natural fibre extracted from the husk of the fruit of the coconut. The fibres are found between the internal hard shell and the outer coat of a coconut. The fibre is thick and strong, composed of cellulose and lignin. Depending on the nature and colour of the coconut, coir can be of two varieties, brown and white. The fibres that are harvested from fully ripened coconuts are brown in colour and are thick, strong and high abrasion resistance. Whereas, fibres extracted from the coconuts before they ripe are generally white or light brown in colour. These kinds of fibres are smoother and finer but weaker as compared to the brown fibres.

These fibres are largely used as rubberized coir by bonding rubber latex and coir fibre together to make upholstery padding for the automobile industry. Apart from this, it is also used for insulation and packaging. Wikipedia [11]

2.2.1.4 Flax

Flax is a natural fibre commonly known as linen. These fibres are among the oldest fibre crops in the world with its earliest traces dating back to prehistoric Georgia times, 30,000 years ago. Flax fibres are extracted from the stem of the plant that grows up to 80-120 cm high. It is soft, shiny and flexible, mainly composed of cellulose. In comparison to cotton, it is stronger but less elastic. It is good conductor of heat and is also durable compared to other natural fibres.

Flax plants are usually pulled from the ground rather than cut in order to obtain long fibres and prevent fibre discolouration. The long fibres are mostly used to make linen cloth, whereas the short fibres are used for the production of paper. High quality papers can be made out of these fibres. Apart from this, it is also used for decorative fabrics, kitchen towels, insulation, light aviation uses, reinforced plastics and composites, etc. Natural Fibres [12]

2.2.1.5 Ramie

Ramie fibre is a long, fine and white plant fibre that is mostly cellulosic in its composition. It is also amongst the oldest fibre dating back to 6000 years. The fibre is extracted from the bark of the vegetative stalk. It is amongst the strongest natural fibres. The fibre has the capacity to hold shape and is resistance to wrinkling. It is as fine as silk and provides a silky lustre to the fabric appearance. The disadvantage of this fibre is that it is not as durable like other natural fibres and because of which, it is usually used as a blend with other fibres like cotton, wool etc. that provides more strength and lightness. Ramie fibres are less used in textile industry as compared to other natural fibres because of its expensive fibre extraction process. Although it is used to make products like sewing thread, packing materials, fishing nets, table cloths, napkins, fire hoses, etc. Natural Fibres [12]

2.3 Polymers

Polymers are molecules which consist of a long, repeating chain of smaller units called monomers, joined together usually by covalent bond. Monomers are molecules of about 4-10 atoms, consisting of at least hydrogen (H) atom and carbon (C) atom usually bonded together by covalent bond. The examples of polymers include plastics such as polyethylene, polypropylene, polystyrene, etc. Polymers are produced by the process called polymerization. There are basically two types of polymers, synthetic and natural polymers. Examples of natural polymers are wood, fingernails, hair, etc. Synthetic polymers are usually known as plastics. Petroleum is the primary monomer that is used to produce polymers. Monomers and Polymers [13]

Polymer composite material consists of polymer matrix along with reinforced fibres. In order to add strength and improve flexibility, polymers are usually mixed with reinforcing fibres (Natural fibres or synthetic fibres). Matrix materials or resins in case of composites can be classified according to their chemical base i.e. thermoplastic or thermosets. Thermoplastics have excellent toughness, resilience and corrosion resistance properties but have fundamental disadvantage compared to thermosetting resins, in that they have to be moulded at elevated temperature. Introduction to Polymers [14]

Polymers are consumed in a huge amount all over the world. The total consumption of plastics globally in the year 2010 was estimated around 154 million tons. Europe alone consumed approximately 40 million tons of plastics in the same year. [15] The consumption of plastics in injection moulding industry within Europe in 2010 is shown in the figure 2.

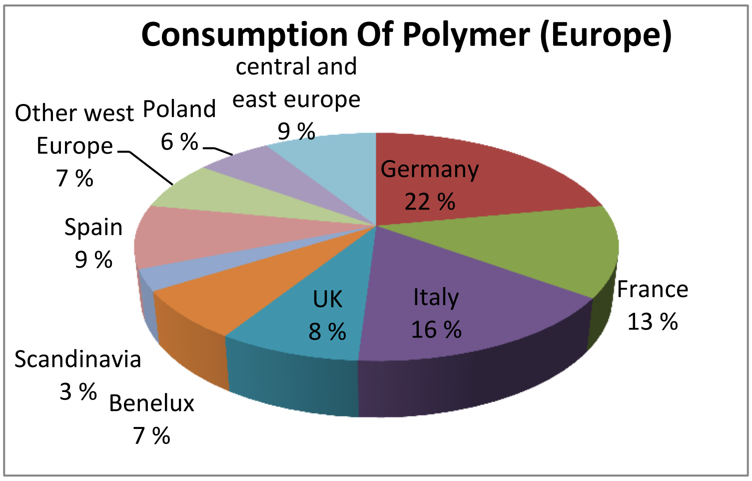


Figure 2 Polymer consumption distributions within Europe [16]

2.3.1 Different forms of polymer

The figure below shows different types of polymers along with their approximate production percentage worldwide.

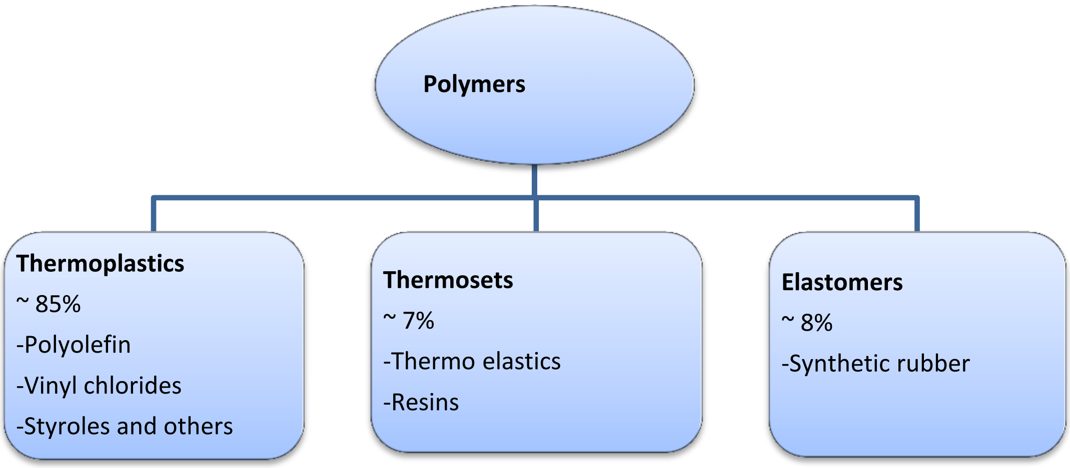


Figure 3 Classification of polymers [17]

2.3.1.1 *Thermoplastic polymers*

Thermoplastics refer to those kinds of plastics that can be fused repeatedly and are capable of dissolving in many solvents. Thermoplastics are the most common plastics and represent the largest fraction of plastics with respect to quantity (about 85% of the total volume of polymer production worldwide) [16]. These are linear and long chain polymers which has less heat resistance. When these types of polymers are heated the intermolecular forces are weakened and it becomes soft and flexible. At high temperatures, it is a viscous melt and the material solidifies again when it is allowed to cool. These properties make thermoplastics very suitable for injection moulding and extrusion moulding. Common examples are polyethylene (PE), polypropylene (PP), polystyrene (PS), etc. Crawford [18]

2.3.1.2 Thermosetting polymers

Thermosetting polymers have small share of about 7% in polymer industry. [16] These types of polymers have cross linking chain of monomers making it hard, rigid and brittle. Excessive cross linking between the chains is followed after heating, forming three dimensional networks, changing the polymer into hard and infusible. They are permanent setting polymers and cannot be softened once they have been solidified. Some examples are phenol formaldehyde, melamine formaldehyde, epoxies, polyesters etc. Crawford [18]

2.3.1.3 Elastomers

Elastomer consists of long chain of molecules which are coiled and twisted in a random manner and are capable to undergo large deformations. Elastomers describes those plastics which cannot be fused or dissolved, but can be swelled. Elastomers are also known as “rubber”. They have loose cross linked structure held up by weakest attractive forces which provides the polymer with high degree of elasticity. They have T_g below room temperature because of which it is soft and rubbery. They have generally low Young`s modulus and high yield strength compared to other polymers. Some examples of moulded parts made from elastomers are seals, bellows, tires, etc. Crawford [18]

2.3.2 Common thermoplastic polymers

The polymers which are discussed in this thesis work are mostly used as matrixes for composites material. Some of the commonly used polymer matrixes for manufacturing of composites are described below.

2.3.2.1 Polyethylene

Polyethylene (PE) is one of the most used thermoplastics all over the world. This polymer was introduced in England in 1933 by the Imperial Chemical Industries, Ltd. PE is the simplest hydrocarbon polymer produced by polymerization of ethylene monomer. Gupta [19]

There are many different ways to produce Polyethylene. It can be produced either by dehydration of ethanol or by the hydrogenation of acetylene. However, it can also be produced from crude oil by cracking process in which the saturated hydrocarbons such as ethane or propane undergo catalytic degradation and dehydrogenation to produce monomers of ethylene. Gupta [19]

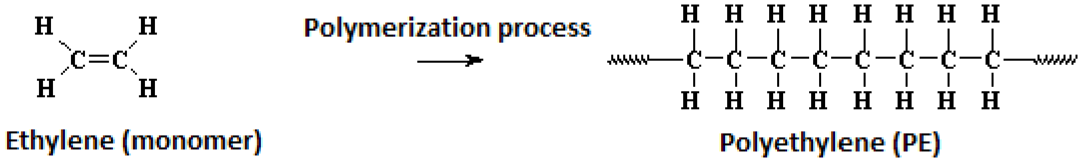


Figure 4 Polymerization process of polyethylene [20]

There are different varieties of polyethylene depending on the mode of manufacturing. Low-density polyethylene (LDPE) and high-density polyethylene (HDPE) are two main types of polyethylene which are commonly used all over the world.

Low-density polyethylene (LDPE)

Low-density polyethylene are the first commercial ethylene polymer. LDPE are produced by high pressure polymerization process, at about 1400 atm pressure (141855 kPa) and 180-250°C, with addition of oxygen as an initiator. It is partially crystalline solid and melts at the temperature of 110-125°C, with density in the range 918-935 kg/m^3. It is almost insoluble at room temperature, however dissolves in many solvents above 100°C. The properties of LDPE such as crystallinity, hardness, stiffness, chemical resistance increases with increase in density or decrease in amount of short-chain branching in the polymer. If the molecular weight of the LDPE increases, properties such as tensile strength, toughness, softening temperature and coefficient of friction decreases. However LDPE possesses good toughness and pliability over a wide range of temperature. It also has good electrical properties and can be used to make applications for high-frequency uses. Chemically PE is an inert compound with good resistance to acids and alkalis. Gupta [19]

High-density polyethylene (HDPE)

High-density polyethylene (HDPE) by its name has higher density than that of LDPE, in the range of 935-965 kg/m^3. HDPE is more crystalline than LDPE and is slightly more stronger, stiffer and expensive compared to LDPE. Since the development of metallocennes based catalysts for the production of HDPE, it has been a big advantages because the molecules which are produced tend to be all the same. An estimation of 1.7 kg of petroleum is consumed inorder to make 1 kg of HDPE. HDPE has stronger molecular forces and higher tensile strength compared to that of LDPE. Apart from this, it is more opaque and can withstand higher temperatures. HDPE can be used to make wide variety of products for e.g. bottle caps, containers, plastic bags, water pipes, milk bottles etc. [18], [11]

2.3.2.2 Polystyrene

Polystyrene is highly amorphous, glassy and brittle due to replacement of hydrogen by benzene ring with no steric order. It has T_g of 100 °C with high transparency, rigidity and easy workability. PS can be of various grades depending upon the mode of production such as, general purpose grade (GP) without any modification, high-impact polystyrene (HIPS), expandable polystyrene (EPS) and modified polystyrene for improved flow. General purpose polystyrene (GP) is rigid, brittle and possesses good optical and electrical properties, with excellent workability. It has a good chemical and water resistance, however it is sensitive to some oils (crude oil) and organic solvents. It has a boiling point of 145°C which limits the working temperatures of the polymer and tends to crack under stress. PS also appears as structural foam. An excellent grade of PS, called HIPS, has toughness of about eight times more than the normal polystyrene. Ram [21]

PS can be produced by the process called “free radical vinyl polymerization” and “Ziegler-Natta polymerization” from the monomer styrene. [20] Industrially it can be produced by different methods- bulk, solution, suspension and emulsion. In bulk polymerization process, a pure and transparent polymer is achieved with excellent electrical properties. Suspension and emulsion methods are applied usually in order to obtain the polymer with better temperature control. Ram [21]

Figure 5 Polymerization of styrene into polystyrene [20]

Polystyrene offers a wide range of applications. Polystyrene can be processed by injection moulding, extrusion, blow moulding and thermal forming. HIPS can be used as machine bodies, radio and television cabinets, food packaging, etc. The structural foam is used in furniture, containers and engineering structures as it provides rigidity and toughness to the materials. GP grades of polystyrene can be used for toys, household dishes and cheap packaging. Ram [21]

2.3.2.3 Polypropylene

Polypropylene is a semi crystalline thermoplastic which is widely used for injection moulding. PP was invented in 1959 as a result of development of stereospecific polymerization, which was basically performed to obtain polymers of a high degree of crystallinity. It is a versatile polymer that serves double duty, both as plastic and as a fibre. As a plastic, it is used to make dishwasher-safe food containers because this polymer does not melt below 160°C, and as a fibre, it is used to make indoor-outdoor carpeting because it does not absorb water. Ram [21] Polypropylene (PP) is structurally represented as shown in figure 6.

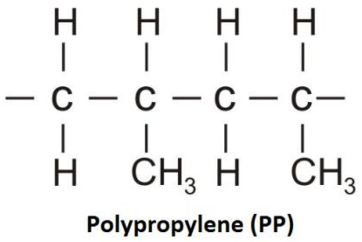


Figure 6 Chemical structure of Polypropylene [20]

Polypropylene was derived by Scientist named Natta in Italy by the process called Ziegler-Natta polymerization at pressure of 12 atmospheres (1216 kPa) and temperatures of 30-80 °C. Ziegler-Natta polymerization is a method of vinyl polymerization (from vinyl polymers). It can also be prepared by using metallocene catalysis polymerization. PSLC [20]

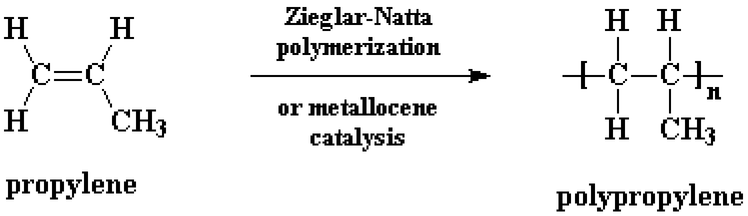


Figure 7 Ziegler-Natta polymerization of polypropylene [20]

It possesses good chemical resistance, fatigue resistance and heat resistance with internal hinge property. It does not possess stress-cracking problems because of its fatigue resistance nature. This polymer also offers excellent electrical and chemical resistance even at higher temperatures. Although polypropylene is very similar to polyethylene, they are specific differences between them. PP has better mechanical, chemical and thermal properties than HDPE. Polypropylene also possesses higher rigidity and hardness compared to polyethylene making it applicable to special packaging, containers and rigid films, fibres, piping, etc. Various kinds of reinforcement and fillers are added to PP mostly as glass fibres and wood fibres. Polypropylene can be of different type depending upon the synthesizing method. [21], [22]

Polypropylene offers a wide range of application as it serves double duty, both as plastic and as a fibre. Mostly it is used as a plastic lid because of its resistance to repetitive stress and fatigue. It is also used to make industrial moulds, rugged currency, car parts, etc. [22], [23]

2.4 Natural fibre composites

Natural fibre composites are a group of composite materials where at least the reinforcing fibres originate from renewable and CO_2 neutral resources either wood or plants. Natural fibres have been used as reinforcement in base materials long before the term “composite material” was ever coined. For example, in ancient times, straw and horsehair were commonly used to reinforce clay bricks. The research and development for NFCs began only in the mid 1960`s and ever since the use NFCs has been growing. Birgitha [24]

Natural fibre reinforced composites is an emerging area in polymer science. These natural fibres are low cost fibres with low density and high specific properties. These are biodegradable and non-abrasive. The natural fibre composites offer specific properties comparable to those of conventional fibre composites. However, in development of these composites, the incompatibility of the fibres and poor resistance to moisture often reduce the potential of natural fibres and these draw backs become critical issue. Birgitha [24]

Many researches have been completed and much more still to come on the potential of cellulose based fibres as reinforcement for plastics in order to replace wide use of non-biodegradable GFCs. While manufacturing NFCs, fibre-matrix adhesion plays an important role. Since the matrix in the NFC transfers the load to the stiff fibres through shear stresses at the interface, it requires good bonding between the polymeric matrix and the fibres. The poor adhesion can impair the mechanical properties and can also make it vulnerable to environmental attacks, which can reduce its life span. The properties of NFCs also depend on the natural fibre properties. Since natural fibre properties depends on weather conditions of growth, it is almost impossible to get the fibres with same mechanical properties. Birgitha [24]

2.4.1 The manufacture of natural fibre polymer composites

Natural fibre composites are manufactured largely based on the existing techniques for processing plastics or composite materials. There are many different methods to produce NFC. Some of the techniques include press moulding, extrusion, injection moulding, compression moulding and resin transfer moulding. Extrusion is widely practiced processing method and majority of the current bio-composite materials based on thermoplastic polymers are processed by this method. Here are two main methods practiced in order to manufacture the natural fibre composites using thermoplastic polymer and natural fibres. Paul [2]

2.4.1.1 Compounding and extrusion of thermoplastic polymers and natural fibres

During compounding, the thermoplastic polymer is heated to an appropriate temperature so that it does not undergo thermal degradation. The polymer is heated either by external heat source or mechanical shearing of the extruder that causes the polymer to melt. As the polymer melts, wood fibre is added along with other additives. Wood fibres to be added in the molten polymer are usually in the form of flour and these wood fibres are added along with additives in order to improve the characteristics of the material. Once the constituents have been thoroughly mixed, the mixture can be either extruded directly in the final product or pelletized for further injection moulding processes. One of the drawbacks of this compounding and extrusion process is that only relatively short fibres (wood fibres) can be used. Paul [2]

2.4.1.2 Co-mingling of thermoplastic and natural fibres

This type of manufacturing method is generally used to make composites from relatively longer fibres such as flax, hemp, cotton, jute, etc. In this method, the natural fibres are mingled together with the thermoplastic polymer to form a non-wooven “fleece” which is subsequently hot pressed to melt the thermoplastic fibre to form the composite. The advantage of this method is that longer fibres can be used to form the composite material which basically cannot be manufactured using previous compounding and extrusion method. Paul [2]

2.4.2 Natural fibre composites for injecting moulding

2.4.2.1 PLMS composites

PLMS is natural fibre reinforced polylactic acid composite. It consists of polylactic acid as the polymer matrix and Nordic soft wood pulp as a reinforced fibre material. PLMS composites possess good mechanical and thermal properties compared to the polymer matrix polylactic acid. It offers good abrasion resistance and has small coefficient of friction with smooth surface finishing. It hardly leaves any sink marks in moulded parts. PLMS composite can be used under temperature conditions ranging from -20 °C - +70 °C, which means the product are not microwave oven and dishwasher safe. It has very small linear thermal expansion. The composite is non-transparent with slightly brownish colour. The products made out of PLMS composite offers good UV radiation and weather resistance. It is a flammable material and generates smoke when it catches fire. PLMS is a good insulator with thermal conductivity lower than that of polymer matrix. Data Sheet [25]

PLMS composites have various applications. Different kinds of products can be made from PLMS composites, like compostable products, products used in cemeteries, disposables and packaging. PLMS composite products are completely biodegradable in nature under suitable conditions. Although it is not listed as dangerous material, special attention should be given concerning the possible health hazards as there is risk of formation of toxic fumes whenever this composite catches fire, producing dangerous gases like carbon monoxide (CO). Dust and fumes generated from machining may also cause temporary breathing difficulties along with irritation in eyes. At the end of their life cycle, the end product can be destroyed either by burning or recycling them into production. Availing to the fact that PLMS composite is biodegradable in nature, the properly disposed waste possesses no ecological hazards. Data Sheet [25]

The PLMS composite can be injection moulded in all thermoplastic injection moulding machines and moulds. However it is recommended to use specific parameters provided by the company. Data Sheet [25]

The pre-conditions for injection moulding of PLMS composite are as follows:

Pre-drying	+75 °C / 8 h, dehumidifying dryer
Temperature profile	+ 200 / 185 / 185 / 180 °C
Injection pressure	< 1000 bar

- Mould temperature +5…20 °C
- Recommended nozzle diameter > 2 mm (not mandatory)
- Minimal back-pressure

The four different temperatures in temperature profile represents temperature at three different sections of the cylinders and the nozzle respectively.

2.4.2.2 PPMS composite

PPMS composites are injection mouldable natural fibre reinforced polypropylene composites which gives very natural appearance to the moulded products with earth-colours. PPMS consists of polypropylene (PP) as polymer matrix and ECF bleached long fibre Nordic soft wood pulp as reinforced fibre. The fibre content of the composite is 10 – 55 weight %. Data Sheet [25]

PPMS composites possess a wide range of good properties. It possesses a good dimensional stability with very small thermal expansion. PPMS composites are brownish in colour and are non-transparent. However, it can be coloured with normal pigments and colouring agents. It has a high rigidity, good thermal, mechanical and chemical properties, along with very fine and smooth surface. The composite possesses better thermal properties than pure PP, making it usable from temperature ranging between -25°C - +120°C. It has good electrical insulation properties, whereas, thermal conductivity is lower than that of pure plastics. It also has good chemical resistance to dilute and concentrated acids, alcohols, mineral and vegetables oils, aldehydes, esters, aliphatic hydrocarbons and ketones. However, it is not recommended to use this product with strongly oxidizing chemicals. The PPMS composite products can be used in food contact applications as it possesses no health hazards. It also has good weather resistance properties as the reinforced fibre acts as UV-stabilizers. Like other composites, PPMS is also flammable and generates smoke when catches fire. Nowadays, there are PPMS composites manufactured with addition of special additives that are fire retardant. Data Sheet [25]

The material possesses hardly any health hazards as the final products are approved as food safe. However, special attention should be given if the composite catches fire because of risk of formation of toxic fumes, e.g.CO. Also care should be taken during machining, as fumes from thermal decomposition and dust generated may cause temporary breathing difficulties and irritation in eyes. Data Sheet [25]

PPMS composites products can be used for wide variety of applications. For e.g. furniture, decorations, cutlery items, garden furniture and tools, interior design, technical applications, household applications, in sauna and bathroom, etc. Since all the PPMS products are recyclable, at the end of its life-span the product can be grinded and casted again into new products. Data Sheet [25]

The composites can be used in injection moulding and extrusion moulding; however the parameters depend on the injection moulding machine and mould used. The material has very small shrinkages in injection moulding. There is hardly any sink marks in moulded parts, even in very think walls products. Data Sheet [25]

The pre-conditions for injection moulding of PLMS composite are as follows:

Pre drying	+100°C / 4h or +80°C / 8 h, dehumidifying dryer
Temperature profile	+ 200 / 195 / 190 / 180°C
Injection pressure	< 1000 bar
Mould temperature	+20…40°C
Recommended nozzle diameter > 4mm (not mandatory)	

2.4.2.3 UPM ForMi GP 40

UPM ForMi is a natural fibre (wood) reinforced plastic composite. It is high quality and durable natural fibre for injection moulding. Since the fibre reinforced is wood fibre (cellulose), it is recyclable and odourless bio composites. UPM [26]

UPM ForMi 40 is made up of 40% pulp fibre content by weight and 60% pure polypropylene. The source of the fibres is Nordic wood pulp. The reinforced fibre significantly increases stiffness and strength of the polypropylene, making composite more stronger and tougher than the plastic. It can be used in injection moulding applications instead of polypropylene as it possesses better properties and offers environmental friendly applicability. It also offers unlimited dyeing possibilities. UPM [26]

UPM ForMi composite granulates offer smooth and reliable process ability. These renewable and environmental friendly composite granulates offer clean and odourless composite products due to high pulp quality. It should be protected from UV-light and it is recommended to store in closed packages in dry conditions at temperatures below 50°C. The composite can absorb moisture if exposed to humid air for long time. UPM [26]

UPM ForMi composite offers a wide range of good properties. It possesses a good dimensional stability. UPM ForMi composites are brownish in colour and are non-transparent. However, it can be coloured with normal pigments and colouring agents. It has a high rigidity, good thermal, mechanical and chemical properties. It also has good chemical resistance to dilute and concentrated acids, alcohols, mineral and vegetables oils, aldehydes, esters, aliphatic hydrocarbons and ketones. UPM ForMi composite products can be used in food contact applications as it possesses no health hazards. UPM ForMi composite is flammable and generates smoke when catches fire. UPM [26]

UPM ForMi composite, like other composites, possesses hardly any health hazards as it is environmental friendly. There is risk of formation of toxic fumes in case the composite catches fire, e.g.CO. Also care should be taken during machining, as fumes from thermal decomposition and dust generated may cause temporary breathing difficulties and irritation in eyes. UPM [26]

UPM ForMi composite products can be used for wide variety of applications. For e.g. furniture, decorations, cutlery items, interior design, technical applications, household applications, etc. Since all the UPM ForMi products are recyclable, the used product can be grinded and casted again into new products. UPM [26]

The composites are especially manufactured for injection moulding. Granulates of the composite should be dried before injection moulding. The recommended processing parameters from the company have to be reviewed before injection moulding.

The pre-conditions for injection moulding of PLMS composite are as follows:

• Pre drying	+110°C / 3h or +115°C / 4 h, dehumidifying dryer
• Temperature profile	+ 195 / 190 / 185 / 180 °C
• Injection pressure	< 1200 bar
• Mould temperature	+60…80°C
• Injection speed	As high as possible

Table 3 Comparison of properties between fibre composites [25], [26]

Properties	PPMS	PLMS	ForMi GP
	PP + wood fibre	PLA + wood fibre	PP + wood fibre
Physical properties	Brown with mild wood odour	Brown with mild wood odour	Light brown with mild wood odour
Mechanical properties	Good resistance to abrasion, small coefficient of friction, very small shrinkage in injection moulding	Good resistance to abrasion, small coefficient of friction, small shrinkage in injection moulding	Good resistance to abrasion, small coefficient of friction, small shrinkage in injection moulding
Thermal properties	Good insulator, very small thermal expansion, applicable temp. range -25- + 120	Good insulator, very small thermal expansion, applicable temp. range -20- + 95	Good insulator, very small thermal expansion, applicable temp. range -25- + 115
Chemical properties	Resistant to acids, alcohols, oils. Etc. expect strongly oxidizing chemicals	Resistant to acids, alcohols, oils. Etc. expect strongly oxidizing chemicals	Resistant to acids, alcohols, oils. Etc. expect strongly oxidizing chemicals
Optical properties	Non transparent	Non transparent	Non transparent
Physiological properties	Are not microwave and dishwasher safe	Are not microwave and dishwasher safe	Are not microwave and dishwasher safe
Biodegradable	Partially	Completely	Partially
Storage	In dry conditions below +35	In dry conditions below +30	In dry conditions below +50
Applications	Furniture, interior design, technical applications, household applications, etc.	Cemeteries, disposables and packaging	Automotive and electronic industries, packaging and furniture

2.5 Injection moulding

Injection moulding is one of the most important processes to manufacture plastic and composite products. A wide variety of products can be manufactured using injection moulding process ranging from simpler products like cups, combs, one-piece chairs, small tables, storage containers to complex products like mechanical parts of automobiles, ships, aircrafts, etc. Michaeli [27]

Injection moulding is a primary processing method which is well suited for mass production of goods, because the raw material is converted to finished part usually in one operation. A composite material in the form of granules is put into the hopper which transfers into the barrel. In the barrel the composite material gets heated and melts as a result of the friction and heat from the heater. The melt is than conveyed into the mould through the nozzle where the molten plastic gets the shape of the desired part. After sufficient cooling, the part is ejected out of the mould with the help of ejection pins. Thus it is a cyclic process which includes the injection of heated molten plastic into the mould, and upon cooling and solidification, the part is ejected out of the mould and the process continuous. Injection moulding is best suited to produce products with complicated shapes requiring precise dimensions in a single operation. Injection moulding technique has the ability to produce light weight parts of specific colour with built in surface texturing. Michaeli [27]

The materials which are injection moulded are basically polymer compounds. However due the advancement in technology, fibre reinforced polymer composites materials are also in growing favour as a feedstock for injection moulding because of their many better properties than polymers.

2.5.1 Injection moulding machine

Injection moulding machine was first designed and patented in 1872 by John Hyatt and Isaiah Hyatt. Over more than 100 years of time, injection moulding machine has made a huge progress from its design to its capability to produce complicated parts. There are basically three types of injection moulding machines; Plastics Wiki [28]

1. Hydraulic IMMs

2. Electric IMMs
3. Hybrid IMMs

The first injection moulding machines were single-action hydraulic injection machine. Later, plunger machines were developed in which plastic material was melted in a heated cylinder and injected into the mould by means of the plunger. These types of machines are found only in museum nowadays. [27] The first electric moulding machine was introduced in the year 1983 which was capable to reduce operation costs by using less energy. Electric injection moulding machines and Hybrid injection moulding machine both operate on the screw principle in which polymer is melted by means of band heaters and the frictional heat from the rotating screw. However, hybrid injection moulding machines captures the best features of both hydraulic and electric systems. Plastics Wiki [28]

When considering modern IMMs, it can be said that the size of the machine and the size of the moulded part are directly related, i.e. larger the moulded part, larger the machine required. An injection moulding machine can produce thousands of parts in a day depending on the size and it is considered more economical to manufacture many moulded parts simultaneously on a large machine than to manufacture one part at a time on a small machine. SFSU [29]

Injection moulding machines are generally rated by their capacity to inject plastic/composite material in one shot and the force (in tonnes) that holds the closed mould. The maximum amount of force that holds the closed mould is counted as clamp capacity of the IMM. SFSU [29]

IMMs are considered as one of the most significant and rational forming methods to produce plastics products. The present day’s all-electric injection moulding machines are able to produce moulded part with the shortest cycle times and highest injection speeds. The integration of multi-axis robot in present day injection moulding machine has lead the technology that is capable for high-precision manufacturing. Engel [30]

The Injection moulding machine used for this thesis work is Engel 90 CC which is located in plastic laboratory at Arcada University of Applied Sciences.

2.5.2 Components of injection moulding machine

The major components of an injection moulding machine are: [27]

1. Injection unit
2. Clamping unit
3. Machine control systems

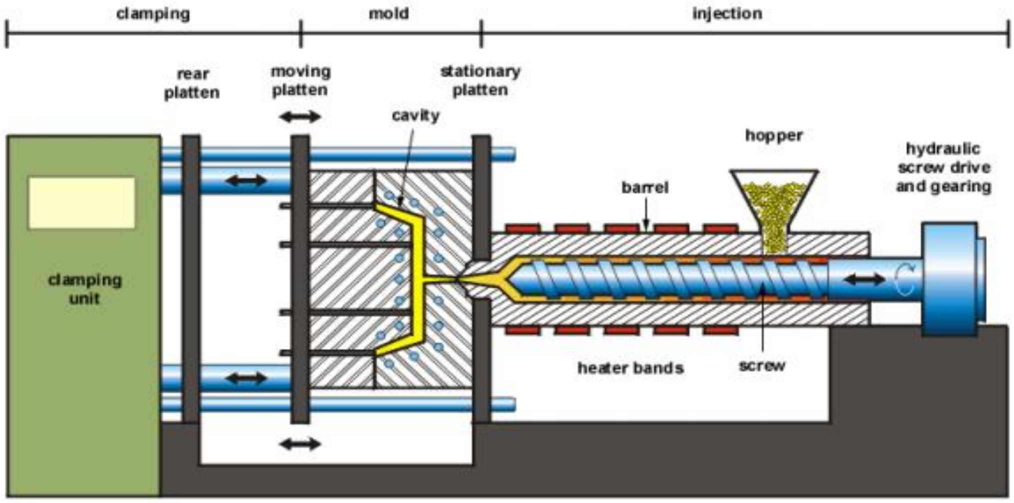


Figure 8 Detail structure of Injection Moulding Machine [31]

2.5.2.1 Injection unit

The injection unit melts the composite material, accumulates and conveys the melted material and finally injects the material into the mould. It also builds up required back pressure needed to hold the material from moving forward over the rotational movement of the screw. In order to perform the smooth operation, the injection unit in turn consists of many sub units which are explained below. Michaeli [27]

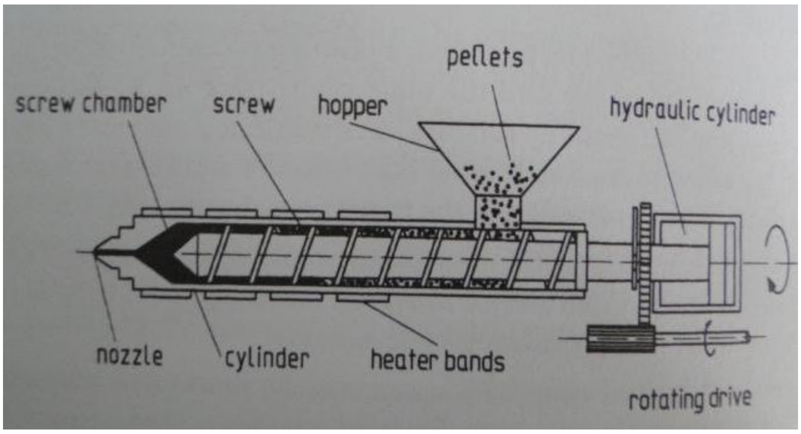


Figure 9 The Injection Unit [32]

2.5.2.2 Hopper

Hopper is the first unit of the injection system which consists of a small/large container depending upon the machine, into which the raw material is poured. It stores material which is conveyed to the barrel of an injection moulding machine. The hopper also consists of the holding area for the material as it is fed from its bulk storage and awaits any preconditioning of the material that may be needed, such as drying. Charles [33]

2.5.2.3 Barrels and Heaters

Barrel is a chamber in which the reciprocating screw is located. It is defined as an open-ended cylinder that controls the linear direction of the melt-conveying process, from the hopper to the mould. [33] It also contains electric heater bands that heat the chamber so as to melt the composite material in the screw and the cooling water channel that always maintains low temperatures outside barrel. The composite material enters into the barrel through the hopper due to the reciprocating action of the screw. The time taken by the material to travel from the feed zone to the nozzle is called residence time. [18] The material from which the barrel is made determines the properties of the barrel. Normally steel with a bimetallic liner is used as a material for the barrel. There are several types of barrel liner such as, abrasion-resistant liner and corrosion-resistant barrel, which are used for the barrels. [18]

2.5.2.4 Reciprocating screw

Granulates of the composite material is fed into the hopper which then enters the feed zone of the screw. The screw rotates continuously which helps the material to flow towards the hot cylinder. The cylinder is equipped with heater bands that heat the composite material to a temperature of 180-300°C. The hydraulic plunger generates back pressure which is applied to the screw to hold the compound from moving forward due to the rotation of the screw. The screw allows the material to be plasticated quickly and uniformly. The screw can be further divided into three zones respectively, the feed zone, compression zone and the metering zone, on the basis of depth of the screw channel along the screw length and also the changes the material acquires along the length of the screw.

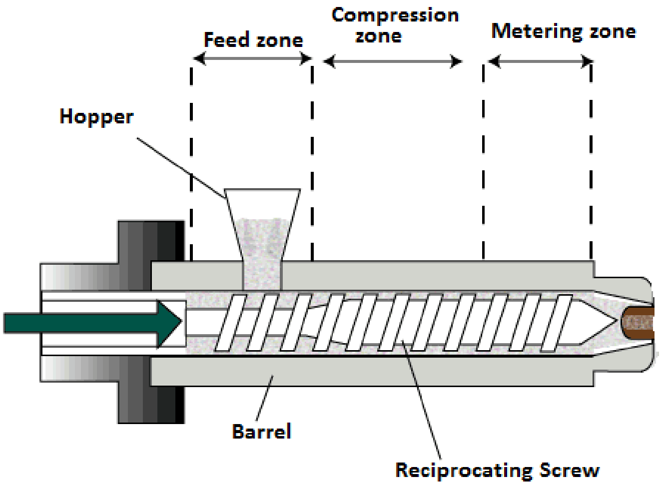


Figure 10 Different sections of the screw [34]

In the feed zone, the material from the hopper is transferred in the direction of the nozzle. The depth of the screw channel decreases in the compression zone and as a result the material is further compressed and melted. Temperature is more in this region compared to the feed zone and further increases towards the metering zone. Additional homogenization of the material takes place in the metering zone. Michaeli [27]

The plasticated material gets accumulated in the screw before it is injected into the direction of the nozzle. When the screw travels the specified distance as predetermined by the machine operator and enough material gets accumulated in the screw, the rotation movement of the screw stops which also blocks more material into the screw from the hopper. Michaeli [27]

Thus, the screw rotates in a start/stop cycle which controls the right amount of the plastic/composite material to be melted inside the screw. The screw backs up a certain distance to control the right amount of material to be deposited in the melt pool. Controlling the backing distance allows the reciprocating screw control the right amount of material. Michaeli [27]

L/D Ratio

The L/D (length/diameter) ratio is an important role for determining the sizing of an injection unit. It is determined by dividing the length of the overall flight of the screw by its nominal diameter as shown in equation 1.

$$\frac{L}{D} = \frac{L_S}{D_S} \tag{2.1}$$

Where L_s is the overall flight length and D_s is the nominal diameter of the screw. The most common L/D ratio of 18:1 and 20:1 are used in the injection moulding process. [33] If the ratio is larger, more shear heat can be uniformly generated in the plastic without degradation and also greater is the opportunity for mixing which results in the homogeneity of the melt. Crawford [18]

Compression Ratio

It is important to know how much the screw compresses and squeezes the molten material in the screw. This compression of the material is defined as a compression ratio. It is determined by dividing the depth of the screw channel in the feed section (D_f) by the depth of the channels in the metering section (D_m). Charles [33]

$$CR = \frac{D_f}{D_m} \tag{2.2}$$

The compression ratios are normally in the range of 2.5:1 to 4:1 for various thermoplastics. Low compression ratio means less mechanical action is added during melting process. Crawford [18]

2.5.2.5 Nozzle

The nozzle represents the connection between the barrel and the sprue bushing of the mould and also forms the seal between the barrel and the mould. The temperature of the nozzle should usually be set near to the materials melt temperature or just below it depending upon the processing parameters of the material. The nozzle is designed in a way to fit exactly into the mould´s sprue bushing radius with the help of a locating ring. [34]

The nozzle is designed in such a way so as to make sure that no material escapes from the nozzle at any time other than during the injection phase. There are basically two different types of nozzles, shutoff nozzles and open nozzles. In shutoff nozzles, the nozzle is held closed by the force of a spring that stops the molten material out of the screw. Whereas open nozzles are used normally in the moulding process so as to minimize the cost of machinery in general. In an open nozzle system, it is impossible to prevent completely the leakage of the material through an open nozzle. [27] The nozzle and the mould should not be kept in contact for a long time because the cooled mould if comes in contact can cool the nozzle and if the nozzle cools down too much, the material being injected can solidify upon entering the nozzle which can block the remaining material into the mould. Gerd [35]

When sufficient amount of the material has accumulated in the injection chamber, the machine is ready for injection of the material into the mould. [27] The screw functions as a piston moving axially forward due to the application of high hydraulic pressure at the hydraulic cylinder. At the same time, the screw pushes the melted material from the screw chamber to the nozzle and finally into the mould. Gerd [35]

2.5.2.6 Clamping unit

It is important that two half of the mould must be closed by the clamping unit before injecting the material into the mould system. The mould must close tightly so that the moulding material only flows into the cavity without getting deviated into the parting line. And when the moulded part is cooled sufficiently, it should be possible to eject the part out of the mould system. Thus, the clamping unit is responsible for opening and closing the mould tightly and moving rapidly and precisely. Michaeli [27]

The clamping unit of the injection moulding machine can be compared to the horizontal press which comprises of:

- a fixed support plate,
- a movable mould carrier plate (clamping side)
- a fixed mould carrier plate (nozzle side), and
- a drive for moving the mould plate (clamping side)

In an injection mould system, which is comprised of two parts, one half of the mould is attached to the carrier plate on the injection side and other half to the mould plate on the clamping side. These types of two-sectioned mould system moves axially with an application of hydraulic force. The work of a clamping system is to tightly close the mould with an adequate force so as to prevent the possible melt flow into the gap between the mould halves. [27] Two common clamping systems that have been used in injection moulding machine are:

2.5.2.7 Hydraulic clamp system

The hydraulic clamping system is the most common clamping system used nowadays in injection moulding machine. It uses hydraulic fluid for its operation. In this type of clamping system, the axial movement of the screw is generated by the application of pressure to the hydraulic cylinder. The hydraulic pressure that is produced in the injection cylinder can be measured by means of pressure sensor. The hydraulic clamp system consists of three platens: cylinder, movable and stationary. The large main cylinder is located at the rear end of the machine. The central cylinder and the transverse cylinders control the motion of the mould tool without mechanical linkages or connections. The system utilizes a larger clamp cylinder to build the required clamp tonnage for the injection moulding machine. The main idea of this clamping system is to apply a pressure on the hydraulic fluid which in turn moves the clamp forward. The large cylinder of the hydraulic system is filled with hydraulic oil. As the pressure is applied to the cylinder, the oil flows from the reservoir to the area behind the cylinder. When the clamp is closed, the fluid is trapped behind the cylinder due to closing of the prefill valve, which eventually increases the pressure in this area to the level assigned by the operator, for holding the mould closed during injection and cooling operation. The hydraulic fluid moves away from behind the cylinder when the mould is opened. The fluid moves back to the reservoir after the prefill valve opens. Charles [33]

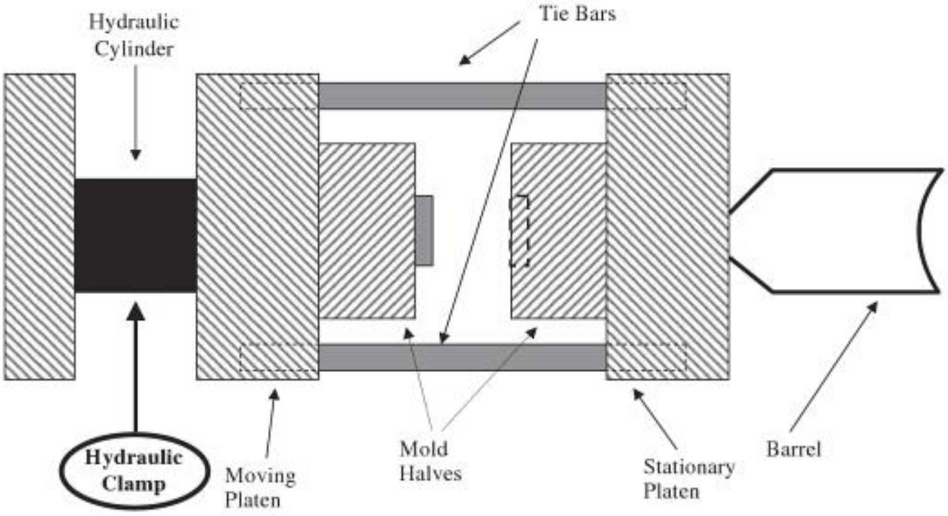


Figure 11 Hydraulic clamp system [Charles (33, p.36)]

The hydraulic pressure depends on the type and shape of the screw diameter. Approximately 70% of the pressure in the space in front of the tip is effective in the injection system because of flow and pressure losses in the nozzle and the gating system. Charles [33]

2.5.2.8 Mechanical clamp system

The mechanical clamping systems are old type of clamping system and were used commonly before the development of hydraulic clamp. This system utilizes mechanical linkage, commonly called as toggle, which develops the required clamping force to hold the mould during injection moulding operation. It consists of three platens, four tie bars and a toggle system that is activated by a hydraulic cylinder. In this clamping system two types of mechanical toggle are used: the single toggle lever and the double-toggle lever, which are used depending upon the clamping forces of the injection moulding machine. The hydraulic cylinder controls the toggle mechanism in the similar way as the human elbow extends or contracts the human arm. The mould is fully closed when the toggle is stretched and is locked in that position. The overstretching of the toggle system can open the mould slightly and therefore are equipped with a limit switch mechanism that will switch off the hydraulic valves operating the linkages in those cases. Charles [33]

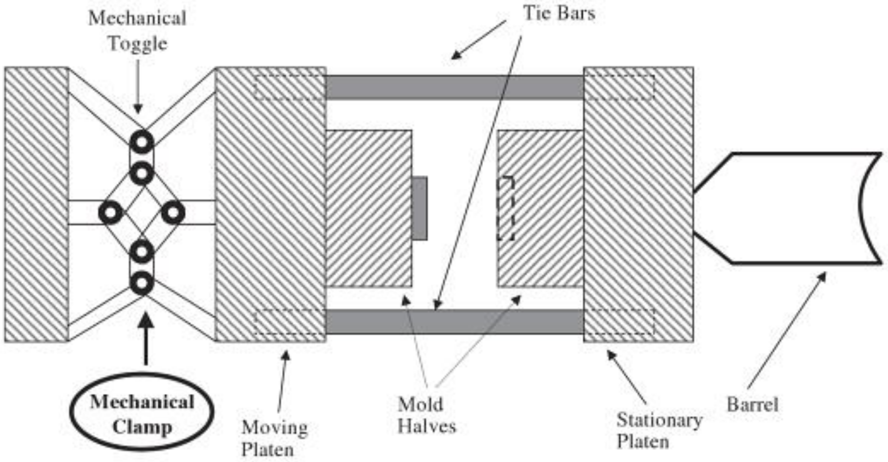


Figure 12 Mechanical clamping systems [Charles (33, p.37)]

2.5.3 Clamping force

The force which keeps the mould tightly closed during injection of the molten plastic is termed as clamping force. A machine with enough clamping force can prevent the material escape out of the mould cavity at the parting line, also called “flashing”. Before starting the injection moulding cycle, it is always worthwhile to check that there is sufficient clamping force available on the machine. It is also important not to apply too much clamping force to the mould. [18]

The clamping force for a material depends upon many factors like shape, thickness, and type of material. The projected area determines the clamping force required. The flow ratio (flow length/channel lateral dimension) is also important when calculating the clamping force. Clamping force of the material is calculated as:

$$\text{Clamping Force} = \text{Projected Area} \times \text{Mean Effective pressure} \tag{2.3}$$

2.5.3.1 Mechanical control systems

The control unit of the machine is located in a separate control cabinet alongside the machine. It consists of display monitor along with electrical and electronic circuit elements and controls. In older days, injecting moulding machines were equipped with limit switches located directly on the major components. The modern days injection moulding machines are equipped with extensive control devices to provide consistency during machine operation. It monitors and maintains the correct operating parameters, including the temperature of the plasticizing unit, pressure, injection speed, screw velocity and clamping system for the correct clamping force. The availability of keyboard and screen in modern injection moulding machines has made it easy to enter desired parameters and also to monitor them. In other words, microcomputer has become the necessity part of the modern injection moulding machines. Microcomputers not only control and regulate the sequence of events but also monitor the production data and store the information. The machine control system not only controls and monitors these parameters, but also coordinates the full injection moulding cycle. The control tasks performed can range from a simple relay on/off control to a sophisticated computer based systems. Michaeli [27]

2.5.3.2 ENGEL CC 90 specification

For this thesis, most of the practical work has been carried out in the ENGEL 90 CC injection moulding machine located in Arcada Plastic Lab, shown in figure. ENGEL 90 CC is a simple modern injection moulding machine that is able to mould different small and medium sized products.

Figure 13 Engel 90 CC [36]

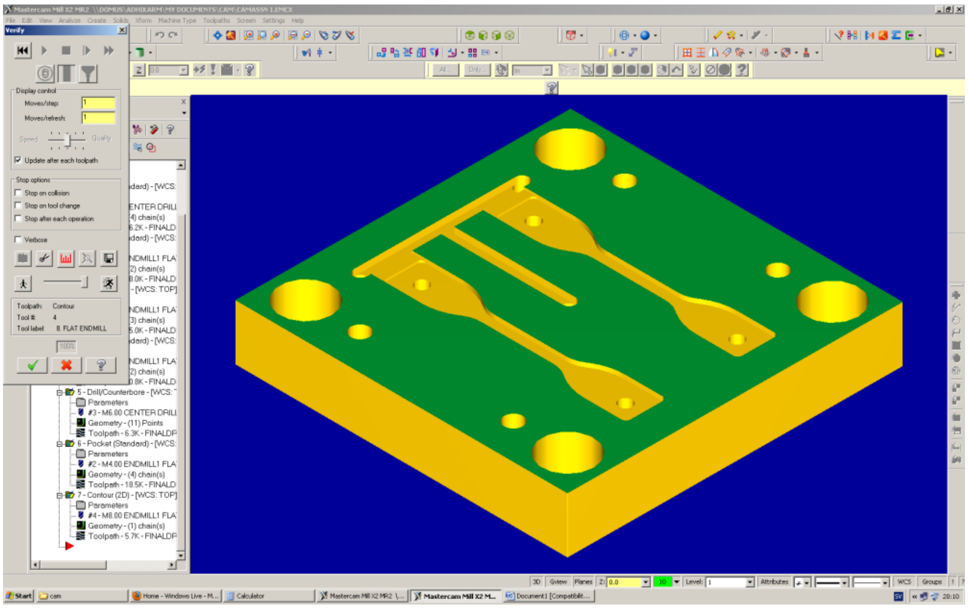
The technical data for the injection unit and the clamping unit of ENGEL 90 CC injection moulding machine used for the practical work for this thesis is shown in table 4.

Table 4 Specifications for Engel 90 CC [36]

ENGEL 90 CC SPECIFICATION			
Injection Unit		Clamping Unit	
Screw diameter	30 mm	Clamping force	500 kN
Metering Stroke	140 mm	Opening stroke	330 mm
Screw speed	20-480 rpm	Ejection force	25.4 kN
Flow rate	20 g/sec	Ejection distance	100 mm
injection rate	82 g/sec	Min tool height	110 mm
Maximum shot volume	98 cm^3	Stationary platen (dimensions)	460*310
Maximum shot weight	88 g	Dry run	1.5 sec
Specific injection pressure	2200 bar/220 MPa		
Nozzle stroke	200 mm		
Nozzle contact force	28 kN		
Heating capacity	4.4 kW		
No. Of heating zones	3+ opt. nozzle heating		

2.5.4 The injection mould

The injection mould is considered as the heart of the injection moulding machine. The technology has always inspired to develop a kind of mould that can produce complicated part more accurately and precisely. There are various kinds of moulds available in the market nowadays. The simplest injection moulding machine consists of two halves. The mating surfaces of the mould halves should be accurately machined in order to make sure that there is no leakage of the material at the split line. Crawford [18]. Injection moulds are usually classified on the basis of design of the mould. A two plate mould opens in one direction, and the part is demoulded by gravity, ejector pins. A different type of two-plate mould, also called a stripper plate mould, contains of both core and ejector plates combined into a stripper plate. A modern three-plate mould contains two parting lines that provide automatic separation of the parts and the runner system. [37] However, the main work of all those kinds of injection mould is to receive and distribute the melt, form the melt into the final part geometry, cool the melt and finally to eject the moulded part. To perform these tasks, the injection mould comprises of various functional elements that are fitted together to make a fully functional injection mould which are as follows:



Display control
Moves/step: 1
Moves/refresh: 1
☑ Update after each toolpath
Stop options
☐ Stop on collision
☐ Stop on tool change
☐ Stop after each operation
☐ Verbose
Toolpath: Contour
Tool #: 4
Tool label: 8. FLAT ENDMILL

5 - Drill/Counterbore - [WCS:
Parameters
#3 - M6.00 CENTER DRILL
Geometry - (11) Points
Toolpath - 6.3K - FINALDP
6 - Pocket (Standard) - [WCS:
Parameters
#2 - M4.00 ENDMILL1 FLA
Geometry - (4) chain(s)
Toolpath - 18.5K - FINALD
7 - Contour (2D) - [WCS: TOP]
Parameters
#4 - M8.00 ENDMILL1 FLA
Geometry - (1) chain(s)
Toolpath - 5.7K - FINALDP

Figure 14 Sample of one half of Injection Mould

2.5.4.1 Sprue

The sprue is the channel that is located in the stationary platen, which receives the melt from the nozzle of the injection unit and transports it to the runner system or direct through the sprue to the cavity. The sprue should be designed in such a way that the pressure drop is minimum and its ability to transport material to the runner is not affected. The runner system determines the required size of the sprue and the outlet of the sprue should not be smaller than the runner diameter, at the point where it meets the runner. Rosato [38]

The sprue enters directly into the cavity in single cavity moulds and in such moulds, the sprue diameter at the point where it meets the cavity should be approximately twice the thickness of the moulded part. In multi-cavity moulds, the smaller sprue that transport the molten material from the runner to the cavities are tapered in design. Rosato [38]

2.5.4.2 Runner system

Runner system comprises of those parts in the mould that receives the hot melt coming from the sprue and transport the melt to the cavity or distribute it to many cavities. [35] In order to avoid runner freezing of during injection, the surface area should be small to minimize heat transfer to the mould. However, it should not be so small that it prevents the smooth flow of molten material. The ratio of its cross-sectional area to its surface area determines the efficiency of a runner system. [18]

Good runner systems are those that are short and free of bends, so that the supply of material to each cavity is balanced. Runners must be practically identical in both shape and size which is important for precision parts. It is better to use same grade of steel as the cavities to the runner system. A good surface finish is highly required for the runner system to keep the pressure drop low which prevents the tendency of the runner to stick to either half of the mould. For a multi cavity moulds, the runner systems must be large enough to transport the material rapidly to the gates without excessive cooling by the cooler mould. However, large runners should be avoided as it produces more scrap that must be grounded and reprocessed, resulting in higher operating cost and possibility of contamination. There are basically two types of runner systems, hot runner system and cold runner system. Rosato [38]

Hot runner systems are normally used in processing of thermoplastics. It is characterized by internally heated flow passage. It is designed in such a way that it prevents heat transfer to the mould and avoids thermal expansion of the various mould components. A major advantage of hot runner system is that it reduces or eliminates scrap as plastic material remains melted in the heated runner, ready for the next injection cycle. Rosato [38]

However, processing of elastomers generally involves cold runner system as it prevents the elastomer from cross-linking prematurely in the gating and manifold system. [19] In cold runner system, melted material solidifies in the runner and is ejected with the part. Rosato [38]

2.5.4.3 Gates

The gate is the connection with a very small cross section between the runner and the cavity. [35] Gates in the injection mould plays an important role as it has many functions. It provides a weak link by which the moulding can be broken off easily from the runner system. In some moulds the degating may be automatic at the time of the mould opening. Similarly, it also acts like a valve that allows the melted material to fill the mould. The gate usually freezes off first because of the small cross-section area which in turn prevents the material being sucked out of the cavity during screw-back. Therefore gate with small cross section than the runner is preferred more as the moulding can be easily degatad. [18]

The type of material used for injection also determines the gating style. The positioning and dimensioning of the gates should be given special consideration. Improper gating system can result in sink marks or shorts in the outer cavities. These sink marks can be corrected by increasing the size of some gates so that the material fills simultaneously to all cavities of the mould. Similarly, the location of the gate also affects the mould construction. Therefore the gate must be located in such a way that the material is filled rapidly and uniformly in the mould. [38]. When performing the injection moulding with high viscous material like fibre-reinforced composites, gate size is usually the critical factor that indicated the final mould-filling speed. When the temperature of the melt is increased, it reduces the viscosity of the material which in turn reduces the pressure drop across the gate. A proper gating system will ensure good flow of the material and uniform mould filling which will prevent formation of layers as shown in figure.

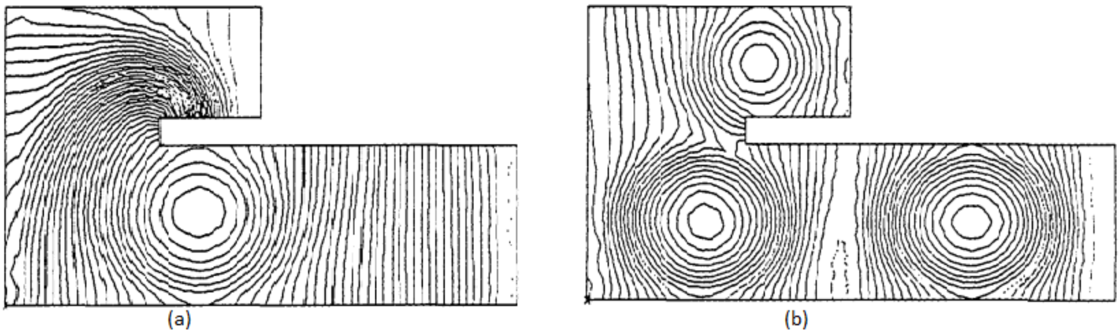

(a) (b)

Figure 15 Single-gate flow pattern and (b) Multiple-gate flow pattern [38]

2.5.4.4 Venting

The mould cavity is usually filled with air before injection procedure. The air present in the cavity can affect the mould part if it cannot escape the cavity at the time of material injection. At the time of material injection, if the air cannot escape, it become compressed, which at worst can affect the mould filling. In other cases, the sudden compression of the air can cause considerable heating in the cavity which can burn the composite. Vents are especially designed to overcome all these problems. Vents are designed especially at the mating surfaces of the mould to allow the air to escape. The vent diameter should be considerably small of approximately 0.025 mm deep and several millimetres wide. However, the depth of the vent can be increased considering that it would not disturb the final part, designing it little away from the cavity so that there is minimum resistance to the flow of the gases out of the mould. Crawford [18]

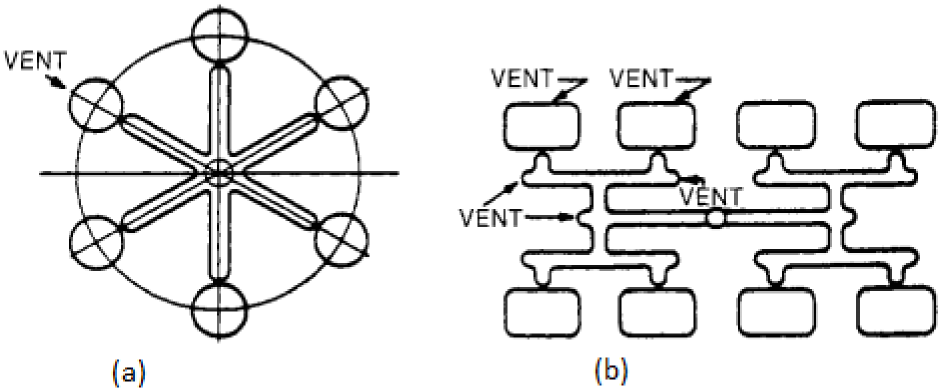


Figure 16 Vents occurring in (a) balanced spoke-runner (b) H-runner layout [38]

2.5.4.5 Cavity

Cavity is the space in the mould which is occupied by the melted material coming from the runner through gate system that forms the moulded part by solidification of the moulding compound. A mould cavity represents the negative shape of the moulded part to be manufactured. The cavity in any injection mould should be designed larger than the moulded part, taking in consideration that the excess volume equals the amount of the volume lost in shrinkage. Michaeli [27]

There are different types of mould depending on the number of cavities they consist of, from single cavity mould to multiple cavity mould. Single cavity moulds have simple and compact construction which makes it cheaper and quicker construction compared to multi-cavity moulds. The multiple-cavity moulds are not only expensive but also increases risk of faults in fully automatic operation. However, for longer production runs, multiple-cavity moulds are more profitable than single cavity moulds. Rosato [38]

2.5.4.6 Cooling system

Cooling system consists of those designs in the mould which helps to solidify and cool the moulded part in the cavity making it ready for ejection. Cooling channels are located below the cavity in the mould and also within the body of the mould. In order to obtain the final moulded part out of the mould, the melted material in the cavity should be well cooled. For this reason, the temperature of the mould should be controlled and this is done by passing a fluid through the channel in the mould. Rosato [38]

In order to cool the mould faster, the cooling medium should be in turbulent flow, rather than laminar flow. With laminar flow, the hot fluid can accumulate on the wall and act as an insulator, whereas turbulent flow of coolant avoids such process and can ensure more heat removal. The coolant used is mostly water but any liquids or gas can be used to absorb and transfer the heat out of the mould. Rapid cooling of the mould economizes the whole moulding process. Whereas, uniform cooling improves the quality of the final product preventing shrinkage, internal stress and mould release problems. The location of the cooling channel should be consistent with the shape of the mould and the depth and pitch of the cooling lines from the moulding surface should be carefully maintained (see figure below). Increasing the depth of the cooling lines means reducing the heat transfer efficiency, whereas too wide pitch gives non uniform mould surface temperature. Rosato [38]

Recommended depth and pitch of the cooling channel for steel

D = Diameter of water line = 1cm-1,5cm

D = Depth of water line = d to 2d

P = Pitch = 3d to 5d

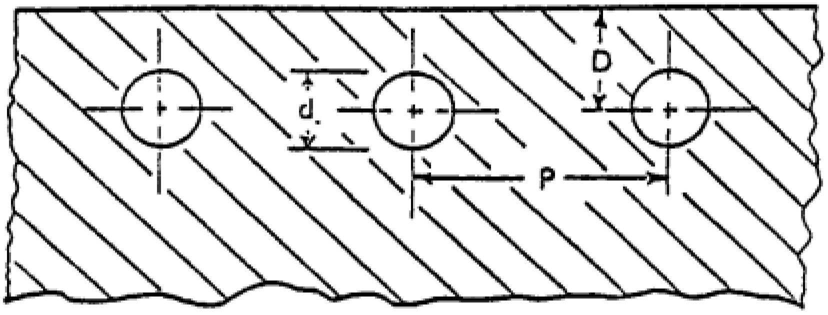


Figure 17 Mould Cooling channels [38]

2.5.4.7 Ejector system

Ejector system consists of those parts in the injection mould that helps to push the moulded part outside of the mould. Depending upon the geometry of the part, ejector system may consist of pins or rings which are embedded in the mould system. These pins or rings help to push the moulded material out of the mould when the mould opens. The ejector pins must be located specifically so that they do not disturb the cooling channel of the mould system. Similarly, the ejectors should not be designed in such a way that it leaves remarkably big marks on the moulded part. Also, it should be taken into consideration that the ejectors do not bend the moulded material when it is ejected out of the mould. Therefore the ejector system should be carefully designed in order to obtain the good moulded part. Gerd [35]

2.5.5 The Injection moulding process

In order to manufacture a plastic part, all the components of the injection moulding machine must be placed in their respective starting conditions and it must work together in a practical manner. The moulding process starts when the material is fed into the hopper. The material is then transported to the barrel which is then conveyed to the nozzle by the rotating action of the screw. The material is molten and thoroughly mixed in the screw. The temperature in the screw channel can be set according to the material used, ranging from 200-300 °C. The machine can be turned on in semi-automatic mode or fully automatic mode, which fully depends on the operator. Once the required temperature is reached and the molten material fills the screw chamber, the machine works in following sequence, as in figure, when the semi-automatic mode is turned on. Michaeli [27]

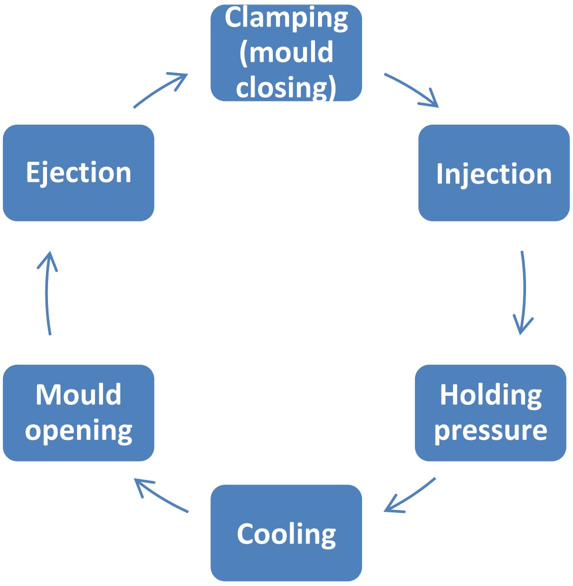


Figure 18 Injection Moulding Cycle [27]

The clamping unit moves the two halves of the mould slowly and closes the mould. After closing the mould together, the clamping force is built up which locks the mould tightly. As the mould closes tightly, the hydraulic system exerts pressure upon the screw forcing the screw to move forward, injecting the material located in front of the screw into the mould cavity through the nozzle. The clamping unit holds the mould tightly shut in opposition during this process. The non-return valve present in front of the screw prevents the shot from flowing back into the screw sections. Michaeli [27]

When the material gets injected into the cavity with appropriate injection pressure and time, the material fills the cavity. Injection speed affects on surface pattern so it should be adjusted according to the end product specifications. As soon as the material fills the mould, it begins to cool and solidify because of the transfer of the heat due to the cooling channel present in the mould. The cooling begins at the mould wall and proceeds inward. The holding pressure is applied at the same time to make sure that there is no shrinkage by supplemental injection of the material. If the holding pressure is low, it can result in the production of the defective moulded part. Michaeli [27]

When the cooling time expires, the mould is opened by moving of the platen on the clamping side. The mould is opened at the parting line. Finally the moulded part that remains stuck on the platen on the clamping side is ejected out of the mould by the pushing action of the ejector pins. After ejection of the moulded part, the ejectors are retracted and the clamping unit and the mould move to its original position signalling the end of the cycle. The control unit of the machine fully controls and monitors the entire injection moulding process. Michaeli [27]

As soon as the moulded part is ejected out of the mould, one cycle ends and the machine is ready for another cycle.

2.6 Drying machine

The Flexible Module Dryer (FMD) is a drying machine that is located in Arcada plastic laboratory room. The FMD is a combined air dryer i.e. material drier and conveyor of dried material into the machine. The FMD has been specifically designed for satisfactory drying of plastic and plastic embedded composites of very low humidity content. The material is dried by means of dry, recirculated air which is fed into the drying hopper. The main functions of a FMD machine are:

- Drying of the raw material using preheated air
- Regeneration of the desiccant (drying agent)
- Conveying of granular material to the hopper

The FMD is supplied with a DH drying hopper mounted on the top of the machine. The machine drying hopper assembly is supplied with many different sizes as an option of connecting up to five different sizes of drying hoppers. Whereas the machine unit is available with two different conveying systems for conveying either by compressed air or by vacuum. The FMD machine usually consists of wheel to make it easy to place next to the individual processing machines. It can be used to dry the hygroscopic raw materials and non-hygroscopic raw materials in the temperature range of 60-140°C. However, it can also be used for higher or lower drying applications with the use external heating element. The raw material is conveyed by the means of atmospheric air. The FMD machine is provided with one of the three conveying systems depending upon the material machine usability i.e. combined pressure/vacuum, vacuum and compressed air. Arcada [39]

Figure 19 Flexible Modular Dryer (FMD) [39]

2.6.1 Drying material

Most of the composite materials have to be dried before being used for injection moulding process. Almost all plastics when exposed to atmosphere absorb moisture to a certain degree depending upon the humidity and the type of polymer. The chemical structure of a polymer used in a composite and the particular fibre used determines whether the composite material will absorb moisture or not. Polymers which have nonpolar chemical structure are non-hygroscopic and do not absorb moisture. However certain polymers which have complex chemical structure such as polycarbonate, polyesters, acrylonitrile-butadiene-styrene (ABS), thermoplastic polyurethanes and nylon are hygroscopic in nature and absorb moisture. The moisture in the polymer can be either external (surface of the pellet) or internal (inside the pellet). Charles [33]

Table 5 Figure showing hygroscopic and non-hygroscopic materials [33]

Materials	Hygroscopic	Non-Hygroscopic
Polyethylene	No	Yes
Polypropylene	No	Yes
Polystyrene	No	Yes
PLMS	Yes	No
PPMS	Yes	No
UPM ForMi GP	Yes	No

A moisture remains in the form of water in the polymer. And the level of moisture contained in the polymer can cause problem when the polymer processing temperatures exceed 200°C because at this temperature (100°C), the water boil off in the polymer. When the water boils, the vapours in the form of bubbles get trapped inside the moulded part. As the moulded part cools and solidifies in the mould, splay marks are created in the finished part. Polymer degradation can occur in some polymers like polycarbonate and nylon, reducing the physical and mechanical properties when water reacts with these polymers in high temperature. Charles [33]

The figure below illustrates the effects of moisture in the moulded part.

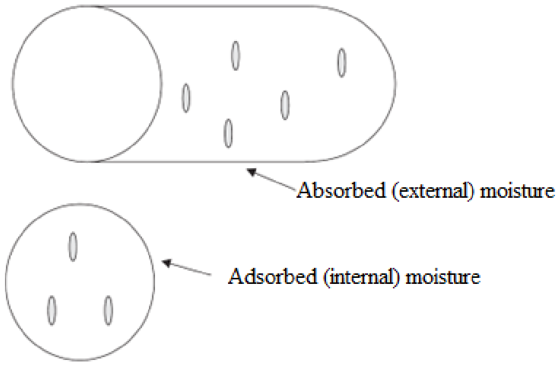


Figure 20 Effects of moisture in the moulded part [Charles (33, Pg. 14)]

It is very essential for the composite materials to be dried up before they can be used for injecting moulding process. A drying machine which is located in Arcada is used to dry the composite material before it is fed into the hopper of the IMM. The moisture has to be removed from both the external as well as internal surface of the pellets because pellets easily reach the moisture balance point in normal environment. There are four necessary conditions for removal of the moisture from the surface of the pellet using the drier machine which are as follows:

- Heat
- Airflow
- Dry air
- Time for drying effects to take place

Heat is responsible to drive the moisture out from the surface of the pellets. The dry air helps to absorb the moisture from the pellets. Whereas the dry airflow acts as a transporting factor to the remove the moist air from the pellets which is then collected to the desiccant dryer for reconditioning. The drier the air, the more effective it will be in extracting moisture from the composite. Charles [33] Table 6 shows particular drying conditions for each thermoplastics and composites.

Table 6 Drying conditions for thermoplastics and composites [1], [42]

Typical drying conditions for Polymers and Composites		
Material	Time (hr.)	Temperature (°C)
Polyethylene (PE)	1-2	50-60
Polypropylene (PP)	1-2	50-60
Polystyrene (PS)	1-2	65-80
PPMS (composite)	4-8	80-100
PLMS (composite)	4-8	75-80
UPM ForMi GP 40	3-4	100-110

2.7 Hopper sizing and mass flow

Hopper size is plays an important role in determining the efficiency of the injection moulding process. The composite material that is supplied in the form of small pellets into the hopper should pass easily and smoothly into the barrel so that required amount of material can be melted and the machine can prepare enough shot size required for the process. The hopper should hold enough material for smooth production. There are different methods used in order to feed the material to the hopper which range from manual to sophisticated automatic material handling systems. The type of method used also depends on many factors such as space available, type of material (shape, form), blending requirements, amount to be processed, and delivery rate into the machine. Material particles can also be reduced in size and made more uniformity for smooth flow of the material from the hopper. Charles [33]

A properly designed hopper system delivers materials smoothly without any interference in its movement. A simple test that determines if the material is going to be difficult to convey is to take a handful of the material and squeeze it firmly, and upon opening the hand, if the lines in the hand are filled with powders, conveyance will be difficult. This is the case for composite materials as they contain much of fibres embedded in it and leaves lot of dust particles (fibres) in the hopper during conveyance which can interfere with the movement of the material. Charles [33]

Material mass flow and bulk density are two important factors that provide information on how to choose the correct-size hopper.

2.7.1 Bulk density

Bulk density is an important material property as it determines the smoothness and ease of the material flow and the required size of the hopper required for the injection moulding process. It is defined as the weight per unit volume of the bulk material, including the air voids. Whereas, material density is defined as the weight of the unit volume of the plastic, excluding air voids. Rosato [38]

The bulk densities of the composites used during the thesis work are shown in table 7.

Table 7 Densities and Bulk Densities of Composites

Material	Average Diameter (mm)	Density (g/cm^3)	Bulk Density (g/cm^3)
PLMS	4,4	1,36	0,4
PPMS	4,5	1,05	0,57
UPM ForMi GP	2,8	1,07	0,645

The bulk densities of Kareline composites, PPMS and PLMS respectively, are lower compared to UPM ForMi, mainly because of their granulate size. PPMS and PLMS have granulates with larger diameter and when considering their bulk weight, these materials contain more air voids and the space between granulates is larger, which makes it lighter than those compared to UPM ForMi.

2.7.2 Hopper sizing for material mass flow

There are basically two types of flow modes of materials in hoppers depending on the way in which the solids move in the hoppers, mass flow and funnel flow. In mass flow, all of the material in the hopper is in motion with different velocities depending upon the location of the material inside the hopper. Whereas, in funnel flow only a core of material in the centre above the hopper outlet is in motion with rest of the other material next to the walls as stationary.

In this thesis work, the author is more focused in determining the mass flow as most of the problems associated with hopper design can be avoided by designing the hopper to operate in mass flow mode. There are variety of shapes and designs for hopper in the market. Figure 21 shows some of the common designs for mass flow hoppers.

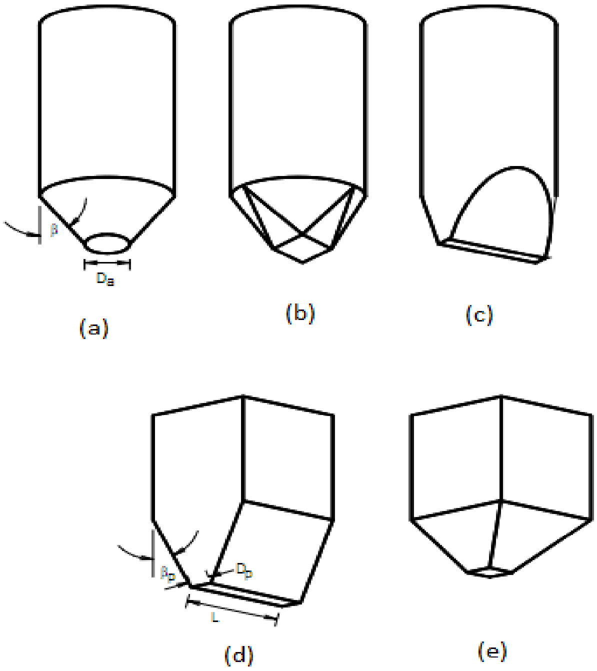


Figure 21 Common type of hopper designs. (a) Conical, (b) Square, (c) Chisel, (d) Wedge and (e) Pyramid [40]

2.7.3 Hopper angle for mass flow hoppers

Hopper sizing plays an important and critical role during injection moulding procedure for natural fibre composites. Proper hopper sizing depends on the mass flow of the material. A composite material moves downward due to gravity when placed inside a hopper. [33] The velocity with which the material flows from the hopper depends on the hopper angle (θ) as shown in figure 22. The recommended cone angle for the hopper from the vertical axis ranges from 40°- 0°. George [40]. The cone angle of the hopper which is used for this thesis work is 40°.

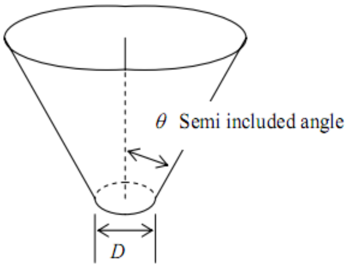


Figure 22 Conical Hopper [16]

2.7.4 Hopper outlet size for mass flow hoppers

For materials with large granulates, the diameter of the hopper outlet should be big enough to allow the smooth flow of the material. If the diameter is too small, the stress in the outlet of the hopper can be very small which can hinder the flow of the material. George [40]. The diameter of the hopper outlet for Engel 90 CC is 30mm.

When the material in the granulate form is stored in the hopper, there is a force acting on the material that tend to compact the granulate reducing its bulk density and also the shear stresses are developed which tend to make it flow. According to Jenike [40], for an element at any position inside of a mass flow hopper, the ratio of the compacting stress to the shear stress has a constant value which he called the “flow factor”. [40]

$$\text{Flow factor, } ff = \frac{compacting\ stress}{applied\ shear\ stress} = \frac{\sigma_1}{AS} \tag{2.4}$$

2.7.5 Mass flow rate from hopper

There are different methods for calculating the mass flow or discharge rates from the hopper. The mass flow of the coarse particles whose diameter is greater than 500 microns is given by [40];

$$\dot{m} = \rho A \sqrt{\frac{Bg}{2(1+m)Tan(\theta)}} \tag{2.5}$$

Where, θ = semi included angle of the hopper
$\dot{m}$= discharge rate (kg/sec)
ρ =bulk density (kg/m^3)
g =gravity acceleration (9.80 m/s^2)

For conical hopper,

B = D, outlet diameter

$A =(\frac{\pi}{4}) * D^2$ and

m = 1

2.8 Testing the mechanical properties of composites

Testing of a material normally means determination of properties and performance of materials by technical means. It gives basic information about composite, its properties relative to another material (plastics), and its quality with reference to standards. There are different test methods that are carried out in order to explain different specifications and standards of those materials being tested. These tests can be categorized as: destructive and non-destructive tests. [33]

In destructive testing, the original composite test specimen is changed, distorted or even destroyed. This kind of test is usually done in order to get information such as amount of force that the specimen can withstand before it exceeds its elastic limit and permanently distorts (usually called yield strength) or the amount of force required to break it (the tensile strength). [33]

In non-destructive testing (NDT), a test specimen is subjected to such test methods in order to obtain useful information about the test specimen without impairing its ultimate usefulness. The method used does not distort the specimen and at the same time provides necessary information about the shape, severity, extent, distribution and location of such internal and subsurface defects as voids, shrinkage, cracks, etc. [33]

In this particular thesis work, destructive testing (tensile testing) method is used to obtain basic information about the properties of the composite materials and to compare it to other materials, especially with common thermoplastics. [33]

2.8.1 Dog-bone piece

The tensile test piece which will be produced in order to test the tensile strength of the composite has the shape of a dog-bone. This dog-bone test piece, in a way it is made, makes it easy for measurement of tensile strength. This type of test piece as shown in figure 23 is produced from three different composite materials.

Figure 23 Dog-bone piece for tensile testing

2.8.2 Tensile testing

The tensile testing is commonly used method to test the mechanical properties of materials (plastics, metal, composites, etc.). The information obtained includes various material properties like yield, strength, elastic property, toughness based on the stress-strain data, etc. The most important mechanical property of a composite material is its stress-strain curve which is obtained by stretching a sample in a tensile testing machine and measuring the sample`s extension and the load required to reach this extension (see figure 24). [33]

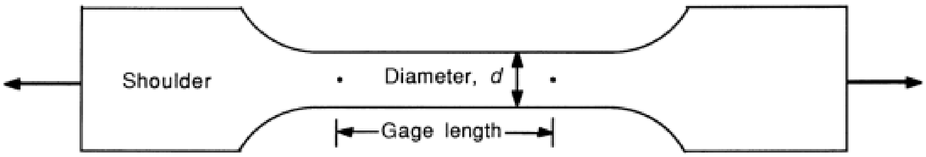


Figure 24 Tensile specimen [Davis (41.Pg. 7)]

A tensile specimen as shown in the figure 24 has enlarged ends or shoulders for gripping. Gage section of the specimen plays an important part in the tensile testing procedure as the cross-sectional area of the gage undergoes continuous stretching until it fails or breaks. The gage length must be greater than its diameter because in reduced gage length, the stress state will be more complex than simple tension. During tensile testing, the specimen should be well gripped so as to make sure that there is no slippage or failure due to maximum load. Davis [41]

2.8.3 Tensile strength

Tensile strength is the maximum tensile stress that a sample material can hold in a test carried out without undergoing failure or breakage. The tensile strength is also called ultimate tensile strength or tensile strength at break. The maximum stress at which the specimen breaks can be measured using tensile testing. Failure normally relates to materials viscoelastic behaviour, explained as the ability of the material to endure tensile stretching stress. [38] The properties of the short-fibre composites depend pretty much on the aspect ratio (length/diameter). If the aspect ratio is greater, then the strength and stiffness of the material will be greater. Crawford [18]

$$\text{Tensile strength } (\sigma) = \frac{Force}{Area} = \frac{F}{A} \qquad (2.6)$$

Where,

Tensile strength (σ) is calculated in N/mm^2, force in Newton (N) and area (cross-sectional area) in mm^2.

2.8.4 Stress, Strain and Young`s modulus

The force per unit area (F/A) acting on a plane in the material is called stress. It is the force related to the original cross-section of the specimen prior to its usual neck-down reduction. Whereas tensile strain is the amount of deformation that occurs in the specimen compared to its original length upon application of force. [38] Stress and strain are mathematically represented as follows:

$$\text{Stress} = \frac{Force}{Area} = \frac{F}{A} \qquad (2.7)$$

$$\text{Strain} = \frac{Deformed\ Length}{Original\ Length} = \frac{\Delta L}{L} \qquad (2.8)$$

The initial section of the curve is linear for most of the material. The slope of this linear region is called the elastic modulus or Young`s modulus [38], which is represented as;

$$\text{Young`s modulus} = \frac{Stress}{Strain} \qquad (2.9)$$

2.8.5 Percentage difference

Percentage difference explains the variation which exists between the standard values (as provided by the companies) and the average experimental value (as obtained from several trails). In this particular thesis, the author has referred to percentage difference as follows:

Difference percentage

$$= \frac{difference\ between\ the\ standard\ value\ and\ the\ experimental\ value}{standard\ value} \times 100 \qquad (2.10)$$

2.8.6 Standard deviation

Standard deviation is a measure of the dispersion of a set of data from its average value. If the dispersion of data is close to its mean or average value than the standard deviation is said to be low, whereas more spread of data indicates higher standard deviation. Standard deviation is calculated using the formula as shown below: [11]

$$\text{Standard deviation(S)} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (2.11)$$

Where, $\overline{x}$ = mean or average value

N = total number of samples

x_i = Sample data

2.8.7 Tensile stress-strain curves

A specimen is mounted in the machine and is subjected to tensile force. As the force increases, the gage length also increases and this elongation continues until the specimen fails or breaks. A typical curve known as "Stress-Strain curve" for the ductile material is recorded. The stress-strain curve provides important information about the mechanical properties of the material tested. It gives the information regarding the energy required to break the composite; larger the area, the more the energy required. Elastic strains for the composite materials are usually small in compared to plastic materials. [42]. The stress-strain curves for brittle materials are usually linear over the full range of strain and terminate with a fracture which is caused due to poor plastic flow in the material. David [41]

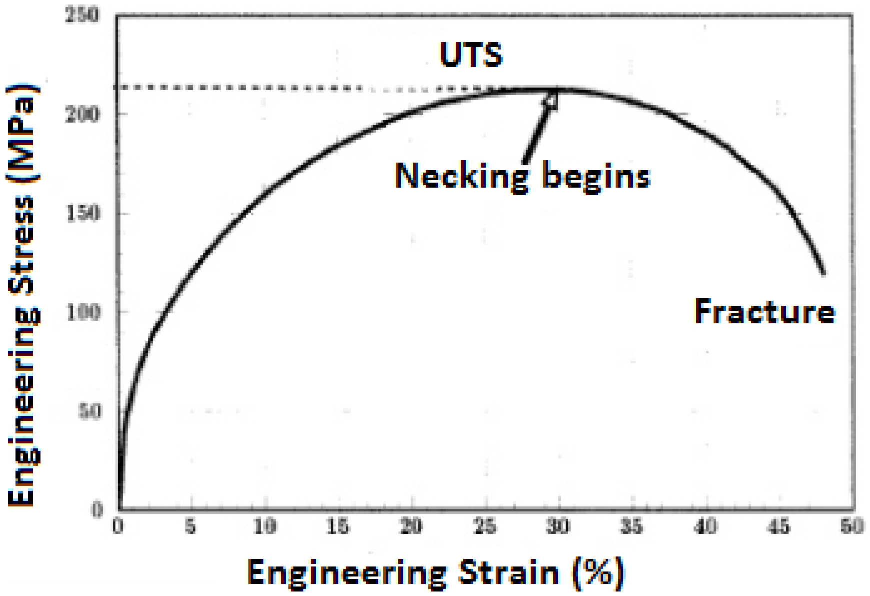


Figure 25 Stress-Strain curve [21]

3 METHOD

The experimental works required for the thesis are carried out in the plastic laboratory of Arcada University of Applied Sciences. The injecting moulding machine, Engel 90 CC was used to produce several sets of dog-bone pieces out three of different composite materials, PPMS, PLMS and ForMi. These dog-bone structure pieces were subjected to tensile testing machine, i.e. Testometric Machine. The whole procedures of laboratory works carried out for the thesis are explained in this topic.

3.1 Calculating the clamping force

This calculated value can have small variation from that of practical value. Hence, as mentioned by Crawford [18], this final value is increased by 10-20% due to the uncertainties associated with specific moulds. Thus, the clamping force required for the mould with the following dimensions (see figure 26), assuming the above formula, is as follows:

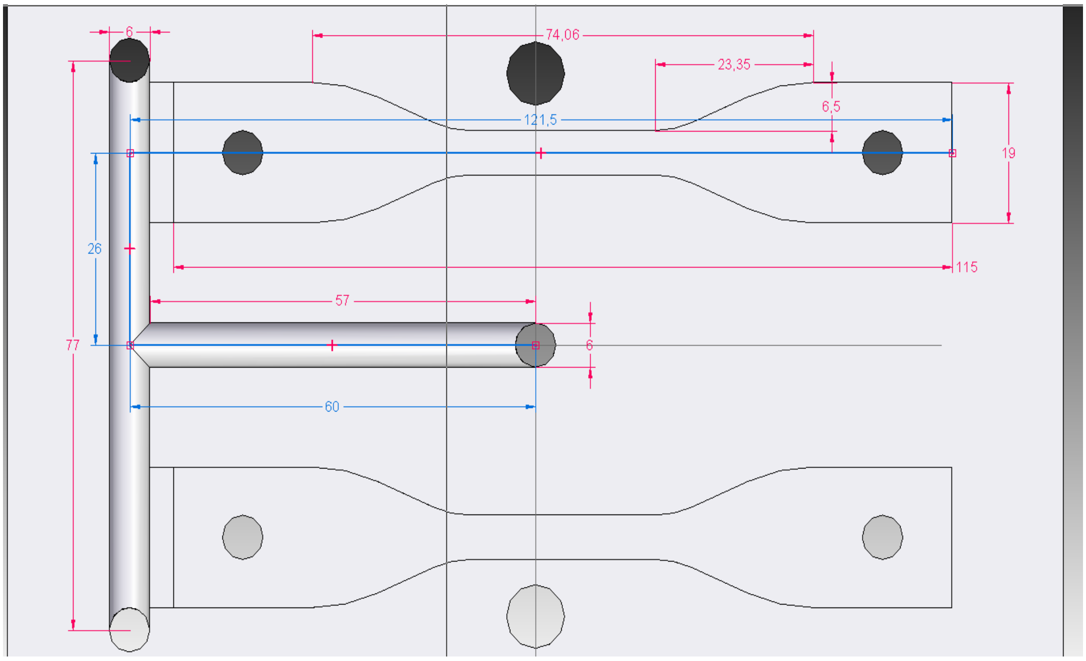


Figure 26 Tensile test piece with dimensions

Calculation:

Area for single cavity mould for tensile test piece,

$$= \left[(115 * 19) - 2(74{,}06 * 6{,}5) + 4\left(\frac{1}{2} * 23{,}35 * 6{,}5\right)\right] \text{mm}^2$$

$$= 1525{,}77 \text{ mm}^2$$

$$= 0{,}00152577 \text{ mm}^2$$

Now, for 2 cavity mould,

Total Area $(TA) = 2 * 1525{,}77$ mm^2

$$= 3051{,}54 \text{ mm}^2$$

$$= 0{,}00305154 \text{ mm}^2$$

Area for runner,

A= $\frac{1}{2}(2\pi RL_1 + 2\pi RL_2)$ − − − − − − − − − − −(area of half circle runner)

A= $\frac{1}{2}(2 * \pi * 3 * 77 + 2 * \pi * 3 * 57)$

= 1263, 43 mm^2

=0,00126343m^2

Flow length,

$$FL = 60 + 26 + 121{,}5$$

$$= 207{,}5 \text{ mm}$$

Now, calculating the flow ratio from the chart,

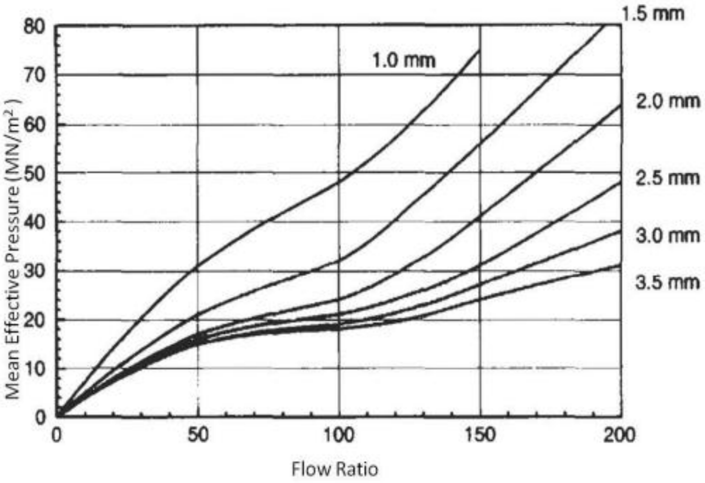


Figure 27 Flow ratio [18]

$$\text{Flow ratio} = \frac{flow\ length}{Part\ thickness}$$

$$= \frac{207{,}5}{3}$$

$$= 69{,}166$$

Thus:

Mean effective pressure $=$ 17 MN/m^2 (approx. value from graph)

Here, the viscosity of polypropylene is used as an example as it is the polymer matrix for two composite.

So, Viscosity factor for polypropylene is 1 [18]

Again, the approximate mean effective pressure

= mean effective pressure *15% uncertainty* viscosity factor

$= 17000000 * 1{,}15 * 1$

$= 1{,}955 * 10^7 N$

Therefore:

Total clamping force:

$=$ Total force for 2 cavities + Total force for runner

$=$ Area* Mean effective pressure

= $0{,}00305154 * 1{,}955 * 10^4 + 0{,}00126343 * 1{,}955 * 10^7$

= $84350{,}056\ N$

= $84\ kN$

Approximately 84 kN of clamping force is required in order to mould the part in the injection moulding machine. This dog-bone piece can be easily moulded in the injection moulding machine located at Arcada plastic laboratory because the total clamping capacity of that machine is up to 500 kN.

3.2 Calculations for the mass flow rate of composites

For **PPMS5050;**

θ = 40°
$\dot{m}$= discharge rate (kg/sec) =?
ρ = 400 kg/m^3
g = gravity acceleration (9.80 m/s^2)
D= 30mm = 0,03m

Mass flow rate ($\dot{m}$) = $\rho\ A\sqrt{\frac{Bg}{2(1+m)Tan(\theta)}}$

$$= 400 * \frac{\pi}{4} * D^2\sqrt{\frac{0{,}030*9{,}8}{2(1+1)Tan(40)}}$$

$$= 0{,}326\sqrt{\frac{0{,}294}{3{,}356}}$$

$$= 0{,}0964 \text{ kg/sec}$$

For **PLMS6040;**

θ = 40°
$\dot{m}$= discharge rate (kg/sec)
ρ = 570 kg/m^3
g = 9.80 m/s^2
D= 30mm = 0,03m

Mass flow rate ($\dot{m}$) $= 570 * \frac{\pi}{4} * D^2\sqrt{\frac{0{,}030*9{,}8}{2(1+1)Tan(40)}}$

$$= 0{,}403\sqrt{\frac{0{,}294}{3{,}356}}$$

$$= 0{,}119 \text{ kg/sec}$$

Similarly, for **UPM ForMi GP;**

θ = 40°
ρ = 645 kg/m^3
g = 9.80 m/s^2
D= 30 mm = 0,03m

Mass flow rate ($\dot{m}$) = $645 * \frac{\pi}{4} * D^2 \sqrt{\frac{0{,}030*9{,}8}{2(1+1)Tan(40)}}$

$$= 0{,}455\sqrt{\frac{0{,}294}{3{,}356}}$$

$$= 0{,}135 \text{ kg/sec}$$

The above calculations explain that PPMS and PLMS composites have quite low flow rates compared to UPM ForMi composites. The obvious reason for comparatively lower mass flow rates for PPMS and PLMS, is bigger granulates than that of UPM ForMi. If the mass flow rate is significantly low than the hopper has to be replaced with another having bigger outlet diameter.

3.3 Price comparison between thermoplastics and composites

Plastics are manufactured mostly using crude oil. Over 2-3% of the total volume of crude oil is consumed to make plastics. Knowing the fact that crude oil is the source for production of plastics, the pricing of plastics greatly depends on the pricing of the crude oil in the global market. Although global crude oil price is the main factor that causes change in plastic prices, there are other factors such as production costs, capacities and demand for the respective plastics that have greater influence on costs. For e.g. the cost of PE, PVC are comparatively less than the cost of PC even though the crude oil content for all these plastics are not much different. Their cost widening is as a result of differences in the manufacturing processes and also the amount of plastics produced (price-volume relationship). Michigan [43]

For comparison of prices, the standard thermoplastics are compared with the natural fibre composites. Polyethylene (PE-LD and PE-HD), polypropylene (PP) and polystyrene (PS) are among the choices as standard thermoplastics to be compared with natural fibre composites. The calculated prices imply only within Europe and they are the offer prices that the company makes, not the transaction prices. Plasticker [44]

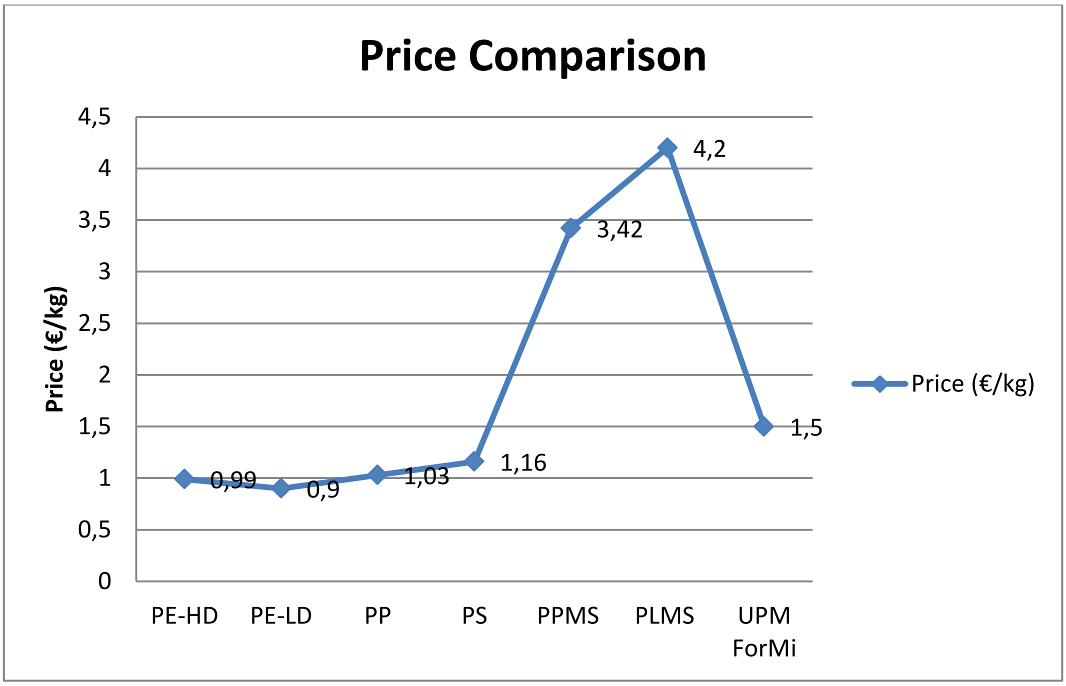


Figure 28 Price comparison chart for different composites and polymers [44]

Figure 28 shows the price comparison between the commodity plastics and NFCs. Commodity plastics come in different grades like regrind and pellets, but figure 28 shows the price of pellets only. The prices of plastics fluctuate quite often depending upon the rise and fall in prices of crude oil and the respective polymer demand. The figure is based only on the price for both the plastics and composites for the month April, 2012. Plasticker [41]

The NFC`s used for the thesis work were the samples from Kareline company and UPM company. According to the information provided by these companies, the present cost, for the year 2012 April, for those NFC`s are as shown in figure 28. Price of Kareline composites seems to be more expensive compared to the prices of UPM composites. The prices of these products are updated monthly and are connected to the oil prices.

The prices for natural fibre composites from Kareline Company seem to be quite expensive, 3 to 4 times the price of plastics. However the prices of UPM ForMi are quite reasonable. Since the fibre composite includes plastics as an important constituent, its prices also depend on the plastic prices. The plastic materials and fibres bought from the market have to be mixed with fibre. So the original price for both the material and the fibres has to be counted. The mixing of these materials can involve either extrusion process or some other techniques available. There are different grades of natural fibre composites depending upon the fibre content and plastic content. Manufacturing these different grades of composite can involve separate procedures. Considering all these facts, the prices for natural fibre composites are relatively higher than plastic. Like plastics, the price for the composite also depends on the production process and demand for the respective composites.

3.4 Setup and procedures

The different composite materials needed for the experiment were ordered from companies named Kareline and UPM. These composite materials were dried up to required pre-drying conditions before being used in injection moulding machine. Several sets of dog-bone structure pieces were produced out of these composite materials. The focus was to produce shrinkage free dog-done pieces out of every composite material and to optimize the injection moulding parameters in order to obtain those pieces.

The dog-bone shaped test pieces have the thickness of 3, 3 mm, width of 12, 8 mm and length of 165 mm. The solid edge drawing of injection moulded dog-bone structure with dimensions is shown in figure 29.

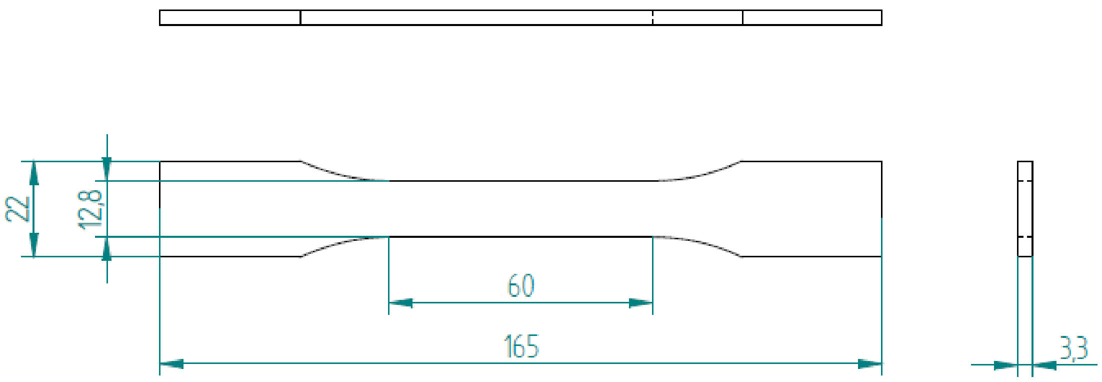


Figure 29 Solid edge drawing of tensile test piece

The standard technical data sheets of the materials were provided by the respective companies which were compared with the experimental values. The experimental values such as stress at peak, strain at peak, young`s modulus were collected from several pieces which were further filtered for the average values. The number of dog bones used from each material for Testometric tensile testing was set to be five.

The experimental procedures were carried out in a similar way for all the three materials. Detail explanation of the procedures for each material is given below:

3.4.1 Drying the material

The composite materials were obtained in the form of granulates. Drying of granulates of all the composite materials is highly recommended because the natural fibres present in the composite materials have higher tendency to absorb moisture even at room temperature. The detail explanation of the drying procedures and the effects of the moist granulate for injection moulding is given in chapter 2.6.1. The drying pre-conditions for all the composite materials were specified by the respective companies.

The drying pre-conditions for some of the thermoplastics and the composites are shown in the table

3.4.2 Injection moulding

The composites materials were poured into the hopper of the injection moulding machine after successful drying. Several dog-bone structured pieces were produced using the moulding machine. The procedures as explained in the chapter 2.5.5 were followed. Each of the composite differs in their physical composition, thereby differing in the chemical and mechanical properties. Basic parameters for injection moulding of each composites provided by respective companies were strictly followed not to break the machine in the worst scenario. Before inserting granulates, it is very important to make sure that the machine heats up to the right temperature profile. Injection moulding procedures carried out for each of the three materials are explained below:

3.4.2.1 PPMS

PPMS granulates were chosen as the first composite material for injection moulding process. The pre-conditions for injection moulding of PPMS composite were set as recommended by the company, which is explained in chapter 2.4.2.2. The PPMS composite depolymerizes at temperatures above 210 °C, so temperature profile was set as recommended by the company. Attention was given not to leave the molten composite in the screw for a long time, so the material was poured manually into the hopper after every cycle. The outlet diameter of the hopper was small with long neck, which made it hard for the smooth flow of the material from the hopper .Therefore plastic funnel was used instead with shorter neck and the material was poured manually each time when the machine was preparing plasticizing shot for the next cycle. Mould temperature was set to be 30 °C.

The parameters such as injection pressure, plasticizing stroke and cooling time were changed accordingly until a good piece of dog-bone was obtained. The initial plasticizing stroke (C1) was 25 mm, and the dog-bone piece obtained was less than half the size of the original piece as shown in the left hand side of the figure 30. In this case the injection pressure was 70 bars. Plasticizing stroke and injection speed were gradually increased. A good dog-bone piece at plasticizing stroke of 45 mm and injection pressure of 75 bars was obtained. Holding pressure time was then gradually increased to get a test piece without a sink mark.

Figure 30 Different sizes of dog-bone pieces obtained during injection moulding

3.4.2.2 PLMS

The pre-conditions for injection moulding of PLMS composite were set as recommended by the company, which is explained in chapter 2.4.2.1.

The PLMS composite also depolymerizes at temperatures above 210 °C, so temperature profile was set as recommended by the company. The material was poured manually in the similar way as during injection moulding PPMS. Mould temperature was set to be 20 °C.

Injection moulding procedures similar to PPMS composites were applied initially. The parameters were adjusted such as injection pressure, plasticizing stroke, cooling time, etc. gradually from a lower value until a good piece of dog-bone was obtained. It was quite easy to produce the test piece of PLMS (fig. 31) because many procedures and parameters were well known during injection moulding of PPMS composite. Special attention was given to obtain the test piece without any sink marks.

Figure 31 PLMS dog-bone piece obtained after injection moulding

3.4.2.3 UPM ForMi GP

The pre-conditions for injection moulding of UPM ForMI composite were set as recommended by the company, which is explained in chapter 2.4.2.3.

The maximum recommended temperature for this composite was 200 °C, so temperature profile was set below that temperature. The material had granulates with small diameter compared to PPMS and PLMS composites and was therefore poured into the original hopper of the injection moulding machine. Mass flow through the hopper was quite smooth and granulates were poured at once rather than after each cycle time like other composites. Mould temperature was set to be +30 °C.

Injection moulding procedures similar to PPMS and PLMS composites were applied initially. The injection moulding procedure was started taking lower parameters for injection pressure, plasticizing stroke, cooling time, etc. The parameters were gradually increased until a good piece of dog-bone as shown in the figure 32, was obtained.

Figure 32 UPM ForMi GP dog-bone piece

3.4.3 Tensile testing

After obtaining several good dog-bone pieces of with minimal or without any sink marks, they were then tested with a Testometric tensile testing machine to test the tensile strength. The necessary dimensions of the dog-bone pieces were inserted in the Testometric software like gage length, width and breadth. The dog-bone pieces were properly clamped at both ends as shown in the figure 33, so as to make sure that the piece does not slip during testing. More information about tensile testing can be found in chapter 2.8.2. After proper gripping of the dog-bone piece, the test was started. When the test is started, the upper part clamp pulls the dog-bone piece until it breaks. Several such tests were carried out and the results were saved for final analysis.

Figure 33 A dog-bone piece clamped to the Testometric machine for tensile testing

4 RESULTS AND ANALYSIS

Several sets of test results which were obtained as a typical force versus elongation graph were collected and analysed. The collected data from the testometric machine is converted into stress-strain graph. In this chapter, tensile strength for each composite material is calculated based on the obtained data and are later compared with general thermoplastics. During the injection moulding procedure some difficulties were faced which are also discussed in this chapter.

4.1 Stress-Strain curve

Figure 34 shows the stress-strain graph for three chosen composites. Stress is calculated in Mega Pascal, whereas stress is given in percentage ratio. Since PPMS and ForMi consists of polypropylene as the base matrix, these composite materials had similar stress-strain curve and possess the plastic property which we can see from bending of the curve. However PLMS curve shows almost no bending or necking region. During processing this composite in injection moulding machine, most of the dog-bone pieces broke into pieced when being ejected out of the mould. It can be concluded that PLMS is more brittle and tougher than other two composites.

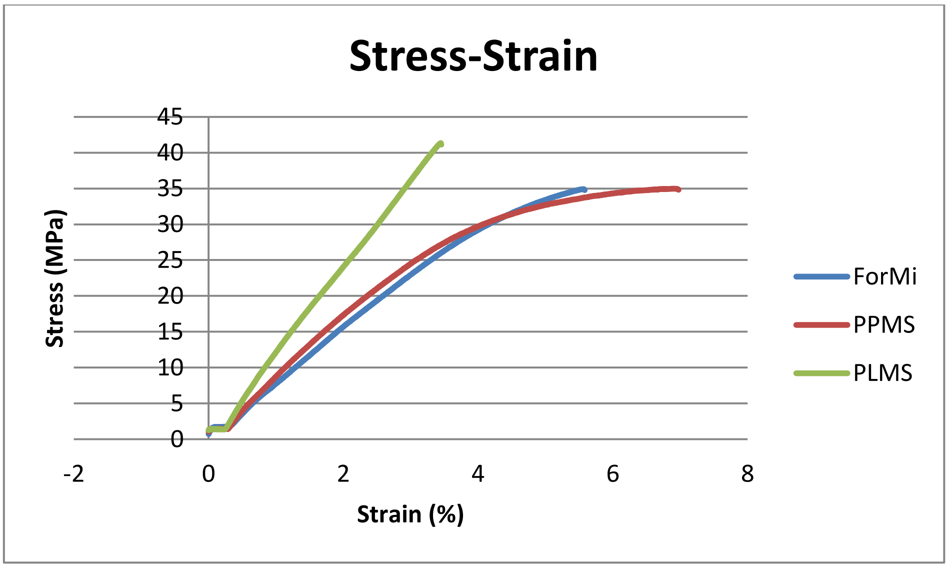


Figure 34 Stress-Strain graph for composites

4.2 Tensile strength

The calculation of tensile strength for 10 different dog-bone pieces for each composite material can be seen in the table 8. The calculated values for each piece show a big difference from the standard value provided by the companies.

Table 8 Table showing tensile strength of different composites in mega Pascal's (MPa)

No. of tests	PPMS (MPa)	PLMS (MPa)	ForMi GP (MPa)
1	32,42	37,46	31,50
2	31,33	41,082	32,10
3	34,38	39,78	32,15
4	32,96	40,01	32,00
5	31,33	40,05	31,99
6	32,66	43,38	32,26
7	30,85	45,15	32,91
8	31,96	44,51	32,45
9	33,51	35,19	32,69
10	32,11	31,56	32,78
Average	**32,351**	**39,8172**	**32,28**
Standard value	**43**	**75**	**50**
Difference (%)	**24,77**	**46,91**	**35**
Standard deviation	**1,08**	**4,21**	**0,43**

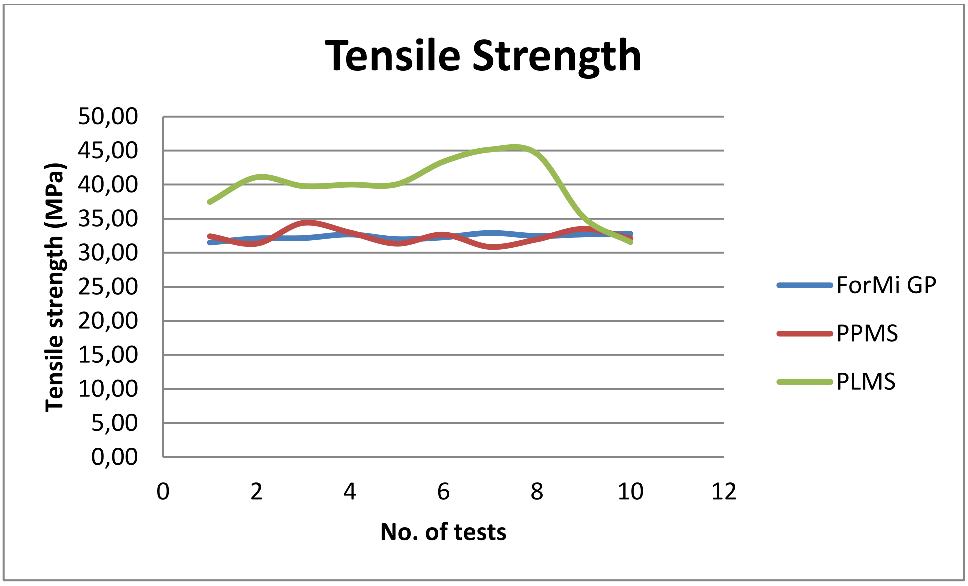


Figure 35 Tensile strength for composites

4.3 Young`s modulus

Table 9 and figure 36 illustrate the results for Young’s modulus of injection moulded composites. The Young’s modulus of moulded composites also shows a big difference when compared with the standard values provided by the companies.

Table 9 Table showing Young`s modulus for different composites

No. of tests	PPMS (MPa)	PLMS (MPa)	ForMi GP (MPa)
1	433	671	508
2	559	903	710
3	405	870	802
4	630	893	519
5	405	730	480
6	507	871	610
7	414	919	758
8	400	1062	616
9	651	1011	801
10	411	1041	846
Average	**482**	**897**	**665**
Standard value	**1700**	**7400**	**3800**
Difference (%)	**71**	**88**	**82**
Standard deviation	**98,69**	**125,55**	**135,94**

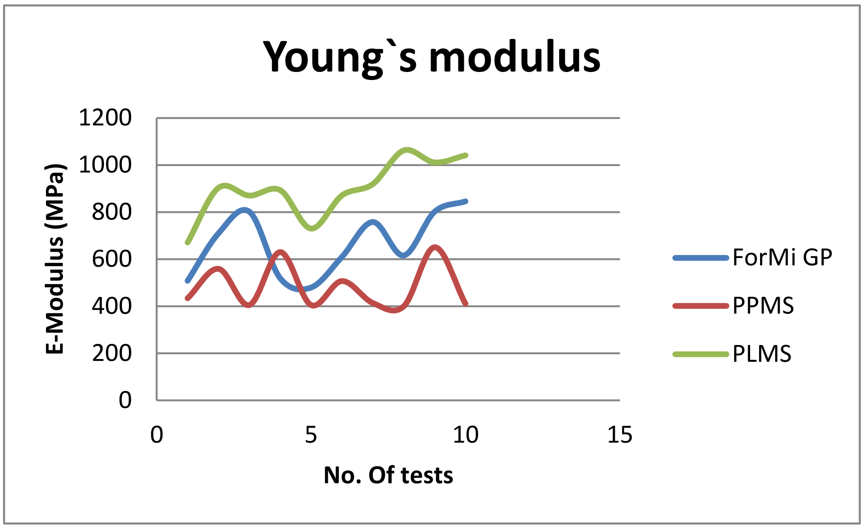


Figure 36 Comparison of experimental E-modulus values between composites

4.4 Comparison of tensile strengths of NFCs to common plastics

The tensile strengths of natural fibre reinforced thermoplastics are found to be higher than those of thermoplastic material that are used as matrix materials. The table 10 and figure 37 shows comparison of tensile strengths of pure thermoplastics and thermoplastics after being reinforced with fibres. The strengths of thermoplastics can be increased up to 50% or more when reinforced with natural fibres.

Table 10 Comparison of tensile strength to common plastics [1], [45] and [46]

Material	LDPE	HDPE	PP	PS	PLA	PPMS	PLMS	ForMi
Tensile Strength (MPa)	**10**	**24**	**22**	**40**	**13-73**	**33**	**40**	**32**

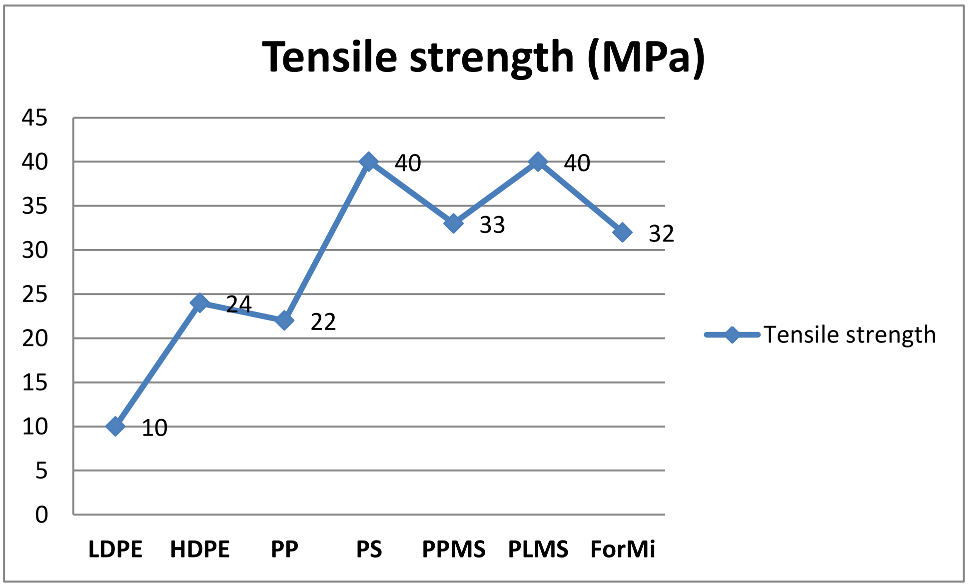


Figure 37 Comparison of tensile strength between composites and polymers

4.5 Optimized parameters for composites

During the injection moulding procedure, some of the basic parameters for each composites at the time when considerably good piece of dog-bone were obtained, were recorded which is shown below in table. Table 11 shows only those parameters that were frequently dealt during the injection moulding procedure.

Table 11 Optimized parameters for composites

Parameters	PPMS	PLMS	UPM ForMi GP
Temperature Profile (^oC)	185-190-195-200	185-190-195-200	180-185-190-195
Clamping force (kN)	350	350	350
Injection Speed (mm/s)	90-90-90-90-90-80-80-65-65-35	90-90-90-90-90-80-80-65-65-35	90-90-90-90-90-80-80-65-65-35
Injection Pressure (bar)	85	80	75
Plasticizing stroke / shot size (mm)	57	55	50
Cooling time (sec)	35	35	35
Holding pressure (bar)	50	50	50
Holding pressure time (sec)	6	8	6

5 CONCLUSION

This chapter shows a conclusion of the thesis with an overview of those results obtained during the whole research procedure. The main objectives of this thesis and if they were all met, is discussed in this chapter of the thesis.

The conclusions drawn are:

1. Natural fibre reinforced composites can be produced in various ways using different existing techniques like extrusion, injection moulding, compression moulding, etc. The percentage of fibre and plastic added during manufacturing process defines the properties of the NFCs.
2. Natural fibre composites are flammable and goes thermal degradation at high temperatures, hence the cylinder temperatures were not exceeded 200 ^{o}C. Plasticizing stroke and injection pressure determined the amount of material to be injected into the mould so until the right parameters were inserted, incomplete dog-bone pieces were formed. Hence, correct parameters for injection pressure, plasticizing stroke and after pressure are necessities for optimization and efficient production of NFC products.
3. The clamping force was calculated to be 84 kN or 8,5 tonnes; meaning that the injection moulding machine (ENGEL CC 90, max. clamp force of 50 tonnes) will be able to provide the sufficient clamping force for the production process.
4. The table 5 clearly shows that the drying time as well as temperature of the air required for drying of NFCs are comparatively higher than those of general thermal plastics; meaning that the fibres contained are highly hygroscopic in nature and requires longer drying time.
5. The cost of granulates of NFCs differed from companies to companies. PPMS (3-3.5 €/kg) and PLMS (4-4.2 €/kg) were found comparatively much more expensive than general thermoplastics like PE, PP and PS costing 0.9 €, 1.03 € and 1.16 € respectively. Whereas ForMi GP from UPM company constituting Polypropylene as its matrix similar to PPMS, was about 1.5 €/ kg.
6. When it comes to price, natural fibre composites should be compared to glass fibre composites rather than thermoplastic polymers because natural fibre composites are mostly used as replaceable material to glass fibre composites in many

areas as it excel in most parameters except strength to that of glass fibre composites. The lower prices and significant performance of NFCs compared to GFCs, creates a huge potential to replace competing materials in different applications like automotive, construction, electronic, etc.

7. The tensile stress-strain graph (fig. 34), clearly explains that PPMS and UPM ForMi possess the plastic property as both of these fibre composites shows bending or necking region. Whereas PLMS fibre composite shows almost no bending, concluding PLMS as the most brittle among those three fibre composites.
8. The tensile strengths of NFCs are found to be higher than those of general thermoplastics; meaning that these NFCs can withstand more stress compared to thermoplastics. Results shows that the strength of thermoplastics can be increased up to 50% or more when reinforced with natural fibres. PLMS were found to be the toughest and most brittle NFC among the three different NFCs tested during the research procedure, whereas UPM ForMi GP was the easiest to process in the injection moulding machine.
9. Several trials carried out during the production of dog-bone pieces out of NFCs presented the fact that NFCs can also be easily processed in the injection moulding machine with a good knowledge of moulding parameters.
10. A conclusion what can be drawn from all these practical results and theoretical explanations is that; natural fibre reinforced composites can be easily processed using injection moulding machine and possesses better strength and toughness compared to thermoplastics. Among the three composites, UPM ForMi GP was the most easiest composite material to produce using injection moulding machine of Arcada University of Applied Sciences and this composite material also had quite consistent value of tensile strength, was cheap and had smaller granulates, making the production process smooth. Therefore, I recommend using UPM ForMi GP composite for any kind of production process in injection moulding machine at Arcada University of Applied Sciences.

6 DISCUSSION

Although the objectives of the research looked quite simple, there were few difficulties during the moulding process. The tensile strength and young’s modulus were rather inconsistent throughout the tensile testing process and showed quite noticeable difference to the standard values as provided by the companies. This big drop in strength could have occurred due to various reasons. First of all, the researchers little knowledge on right drying time and proper cylinder temperatures during the moulding process could have degrade the fibre properties, affecting the tensile strength of the final product. Secondly, rather transporting granulates of the fibre composites directly into the hopper of the injection moulding machine, it was stored in the bucket for a longer period of time. Thus dried fibre composites are highly hygroscopic in nature and can easily absorb humidity from atmosphere. Apart from these things, there were difficulties in maintaining the smooth flow of the composite granulates through the hopper.

Natural fibre composites granulates, especially PPMS and PLMS were quite big compared to plastic granulates and had significantly big impact during flow through the hopper to the cylinder of the injection moulding machine. The hopper of the moulding machine had narrow neck which made the smooth flow of granulates quite impossible and as a result the machine could not prepare enough shot size. This resulted in incomplete formation of dog-bone pieces. Therefore plastic funnel with shorter neck was used instead and the material was poured manually each time the machine was preparing shot for the next cycle.

The comparatively high pricing of Kareline composites makes its product quite expensive compared to thermoplastics, which eventually makes it hard to penetrate into the general customer market. Certain products like cutlery and decoration items were sold only from special outlets and souvenir shops. Since these NFC products are environmental friendly, they have a market scope among environmentally alert population.

To carry out any such natural fibre composites moulding in future, the hopper system with bigger neck diameter should be replaced or granulates of composites to be ordered has to be relatively smaller. The dog-bone mould also had some problem as there was some leakage of composites from the parting line during production. So the mould has to be repaired or some new mould has to be ordered for qualitative production of dog-bone pieces.

There are certain numbers of things that can be done to improve the results of this research. One of them is that the composite granulates after being dried should be directly transported to the hopper of the injection moulding machine. This helps granulates to absorb very less amount of humidity from the atmosphere.

The research was intended to provide brief and positive information to all the plastic students about natural fibre composites and the production technique using injection moulding machine. The result of this study not only points out the advantages of natural fibre composites to that of general thermoplastics but also provides a future reference to the students to mould the products out of natural fibre composites. The future research that might be done following this study is to test the production of Arcada Corr cups and compare its properties with other plastic Corr cups.

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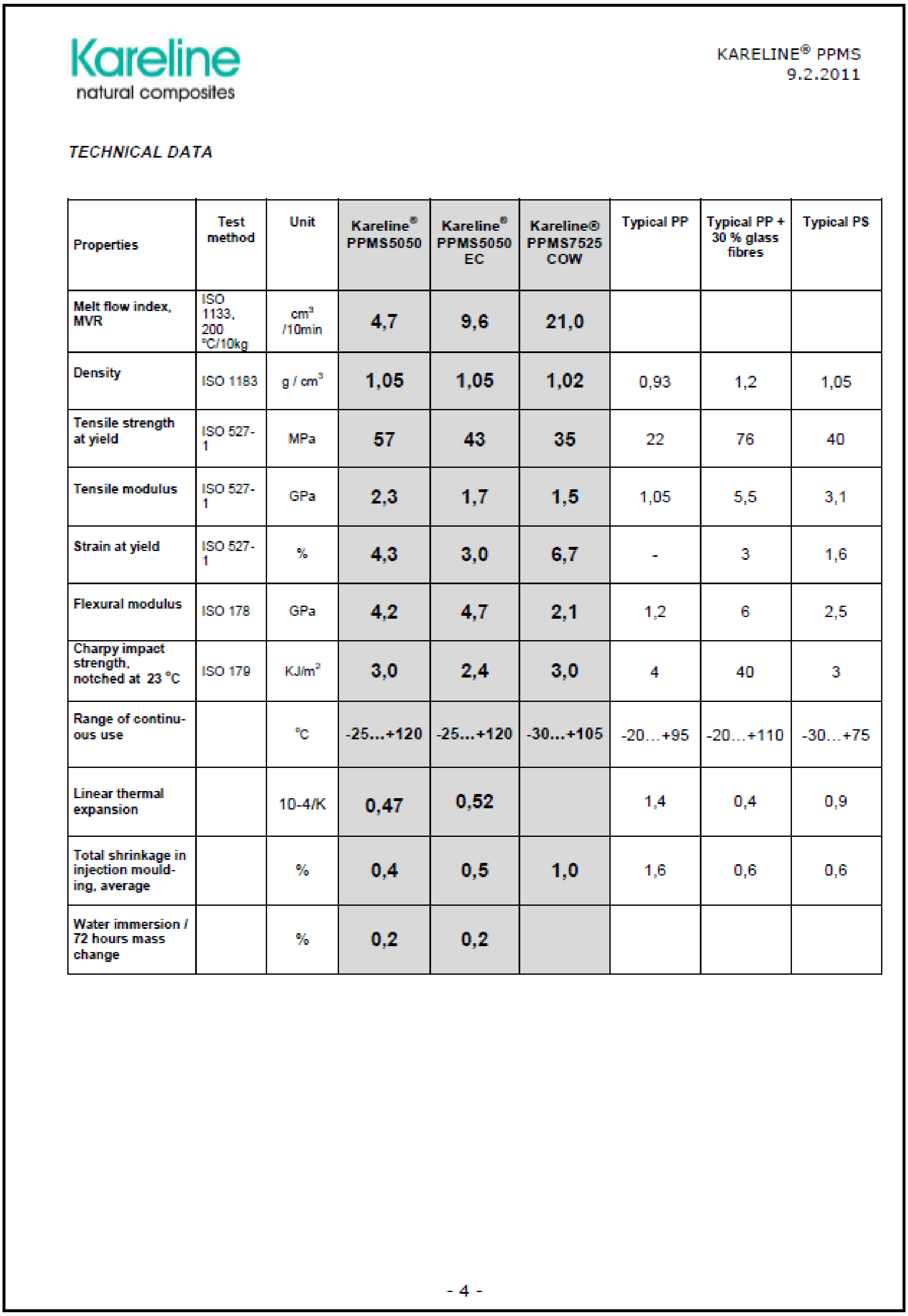
8 APPENDICES

Material: PPMS, PLMS & ForMi GP					
Drying time: Specified in literature review part					
Name: Mukunda Adhikari					
Parameter (ENG)	**Letter code**	**Units**	**PPMS**	**PLMS**	**ForMi GP**
Temperature, °C:					
Nozzle		°C	**185**	**185**	**180**
Cylinder 2		°C	**190**	**190**	**185**
Cylindere 3		°C	**195**	**195**	**190**
Cylinder 4		°C	**200**	**200**	**195**
Hopper		°C	**70**	**70**	**70**
Max pos. Deviation from temp.		°C	**20**	**20**	**20**
Max neg. Deviation from temp.		°C	**20**	**20**	**20**
Oil temperature		°C			
setting		°C	**45**	**45**	**45**
measured		°C	**37**	**37**	**25**
lower limit		°C	**25**	**25**	**25**
upper limit		kp	**55**	**55**	**55**
Parameter (ENG)	Letter code	Units			
Mould temp		°C	**30**	**20**	**40**
Parameter (ENG)	Letter code	Units			
Mould fastening					
1. closing speed	V1 =	%	**50**	**50**	**50**
2. closing speed	V2 =	%	**2**	**20**	**20**
3.closure speed	V3 =	%	**10**	**10**	**10**
Clamping force	SOLL =	kN	**350**	**350**	**350**
measured	mit. =				
Protection pressure	P2a =	%	**20**	**18**	**18**
	P2e =		**20**	**18**	**18**
Opening stroke	A =	mm	**150**	**150**	**150**
	T =	mm	**60**	**60**	**60**
2.speed	W3 =	mm	**145**	**145**	**145**
3.speed	W1 =	mm	**40**	**40**	**40**
Mould protection stroke, start	G1 =	mm	**15**	**15**	**15**
Mould protection stroke, end	G2 =	mm	**0,2**	**0,2**	**0,2**

Mould position measured	SFx =	mm			
Proc. pressure, time	mit =	s	**2**	**2**	**2**
Parameter (ENG)	Letter code	Units			
Mould opening					
1. opening speed	V6 =	%	**5**	**5**	**5**
2. opening speed	V7 =	%	**40**	**40**	**40**
3. opening speed	V8 =	%	**30**	**30**	**30**
start 2. speed	W4 =	mm	**14**	**14**	**14**
start 3.speed	W2 =	mm	**130**	**130**	**130**
Air blow, start	A2 =		**0**	**0**	**0**
Mod opening , start	A1 =	mm	**150**	**150**	**150**
Opening stroke	A =	mm	**150**	**150**	**150**
Mould actual position, measured	SFx =	mm			
Cooling time, act	Z4 =	s	**35**	**35**	**35**
Parameter (ENG)	Letter code	Units			
Injection					
Max injection speed		mm/s	**130**		
Injection speed, measured		mm/s	**90-90-90-90-90-80-80-65-65-35**		
Injection speed					
Limitation of injection pressure	P6 =	bar	**85**	**80**	**75**
Change of pressure in the mould	PF =	bar			
Injection time	Z1 =	s	**5**	**6**	**5**
Intrusion time	Z1N =	s			
Parameter (ENG)	Letter code	Units			
Holding pressure					
Holding pressure	P7-P16	bar	**50**	**50**	**50**
Holding time	Z2 =	s	**6**	**8**	**6**
Cushion	CP =	mm	**12**	**12**	**12**
min	min =	mm	**15**	**15**	**15**
max	max =	mm	**15**	**15**	**15**
measured	CPx =				
Plasticizing stroke	C1 =	mm	**57**	**55**	**50**
Parameter (ENG)	Letter code	Units			
Dosage					
Screw retraction speed	V24 =	%	**60**	**60**	**60**
Intrusion speed	V23 =	%	**15**	**15**	**15**
Dosage speed		%	**25**	**25**	**25**
Back pressure, measured	PSx =	bar	**12**	**12**	**12**
Plasticizing time, max	ZD	s	**20**	**20**	**20**
Plasticizing time, measured	ZDx =	s			

Decompression before plastisizing	C4 =	mm	**0**	**0**	**0**
Shot size / plastisizing stroke	C1 =	mm	**57**	**55**	**50**
Plastisizing ends, measured	C1* =	mm			
Decompression aftre plastisizing	C2 =	mm	**4**	**4**	**4**
Parameter (ENG)	Letter code	Units			
Injection unit					
1. Nozzle forward speed	V9 =	%	**20**	**20**	**20**
2. Nozzle forward speed	V10 =	%	**10**	**10**	**10**
Nozzle speed backward	V11 =	%	**10**	**10**	**10**
Nozzle forward	P35 =	%	**5**	**5**	**5**
Nozzle contact pressure	P5 =	%	**100**	**100**	**100**
Cont. Pres. Build up time	Z5a =	s			
Nozzle return delay time	Z6 =	s	**22**	**22**	**22**
Start 2. nozzle speed pos	J1 =	mm	**10**	**10**	**10**
Nozzle front pos	J =				
Nozzle stroke	K =	mm	**50**	**50**	**50**
Parameter (ENG)	Letter code	Units			
Ejection					
Ejector, start advance	A1 =	mm	**150**	**150**	**150**
1. ejector speed forward	V25 =	%	**20**	**20**	**20**
2. ejector speed forward	V35 =	%	**30**	**30**	**30**
Ejector speed return	V26 =	%	**30**	**30**	**30**
Ejector pressure forward	P25 =	%	**15**	**15**	**15**
Ejector pressure return	P26 =	%	**15**	**15**	**15**
Ejection unit returned	L =	mm	**39**	**39**	**39**
2. ejection speed	L3 =	mm	**45**	**45**	**45**
Ejector intermediate stop	L2 =	mm	**50**	**50**	**50**
Eejction distance	L1 =	mm	**55**	**54**	**54**



Kareline
natural composites

KARELINE® PPMS
9.2.2011

TECHNICAL DATA

Properties	Test method	Unit	Kareline® PPMS5050	Kareline® PPMS5050 EC	Kareline® PPMS7525 COW	Typical PP	Typical PP + 30 % glass fibres	Typical PS
Melt flow index, MVR	ISO 1133, 200 °C/10kg	cm^3 /10min	**4,7**	**9,6**	**21,0**			
Density	ISO 1183	g / cm^3	**1,05**	**1,05**	**1,02**	0,93	1,2	1,05
Tensile strength at yield	ISO 527-1	MPa	**57**	**43**	**35**	22	76	40
Tensile modulus	ISO 527-1	GPa	**2,3**	**1,7**	**1,5**	1,05	5,5	3,1
Strain at yield	ISO 527-1	%	**4,3**	**3,0**	**6,7**	-	3	1,6
Flexural modulus	ISO 178	GPa	**4,2**	**4,7**	**2,1**	1,2	6	2,5
Charpy impact strength, notched at 23 °C	ISO 179	KJ/m^2	**3,0**	**2,4**	**3,0**	4	40	3
Range of continuous use		°C	**-25…+120**	**-25…+120**	**-30…+105**	-20…+95	-20…+110	-30…+75
Linear thermal expansion		10-4/K	**0,47**	**0,52**		1,4	0,4	0,9
Total shrinkage in injection moulding, average		%	**0,4**	**0,5**	**1,0**	1,6	0,6	0,6
Water immersion / 72 hours mass change		%	**0,2**	**0,2**				

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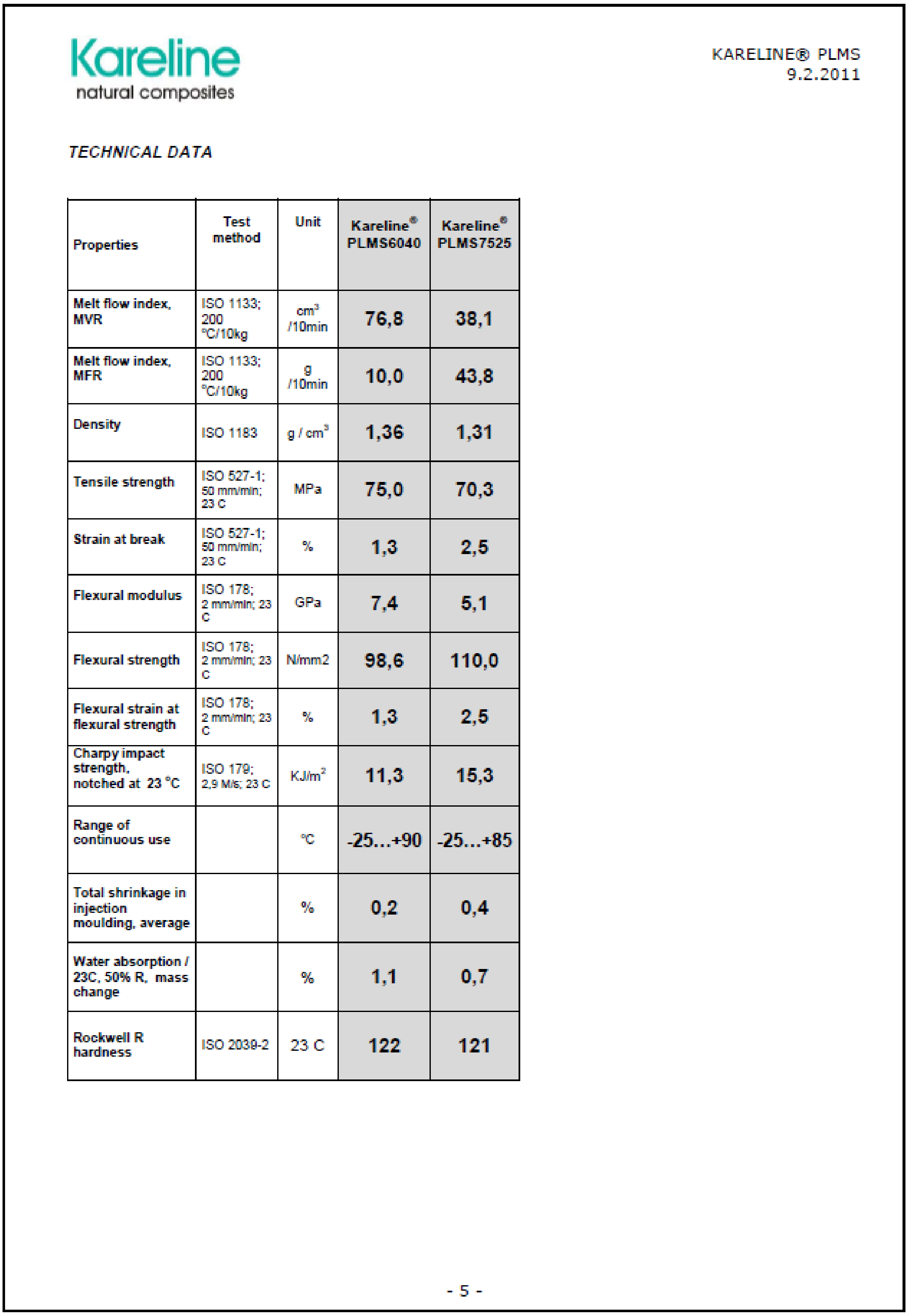

Kareline
natural composites

KARELINE® PLMS
9.2.2011

TECHNICAL DATA

Properties	Test method	Unit	Kareline® PLMS6040	Kareline® PLMS7525
Melt flow index, MVR	ISO 1133; 200 °C/10kg	cm^3 /10min	76,8	38,1
Melt flow index, MFR	ISO 1133; 200 °C/10kg	g /10min	10,0	43,8
Density	ISO 1183	g / cm^3	1,36	1,31
Tensile strength	ISO 527-1; 50 mm/min; 23 C	MPa	75,0	70,3
Strain at break	ISO 527-1; 50 mm/min; 23 C	%	1,3	2,5
Flexural modulus	ISO 178; 2 mm/min; 23 C	GPa	7,4	5,1
Flexural strength	ISO 178; 2 mm/min; 23 C	N/mm2	98,6	110,0
Flexural strain at flexural strength	ISO 178; 2 mm/min; 23 C	%	1,3	2,5
Charpy impact strength, notched at 23 °C	ISO 179; 2,9 M/s; 23 C	KJ/m^2	11,3	15,3
Range of continuous use		°C	-25…+90	-25…+85
Total shrinkage in injection moulding, average		%	0,2	0,4
Water absorption / 23C, 50% R, mass change		%	1,1	0,7
Rockwell R hardness	ISO 2039-2	23 C	122	121

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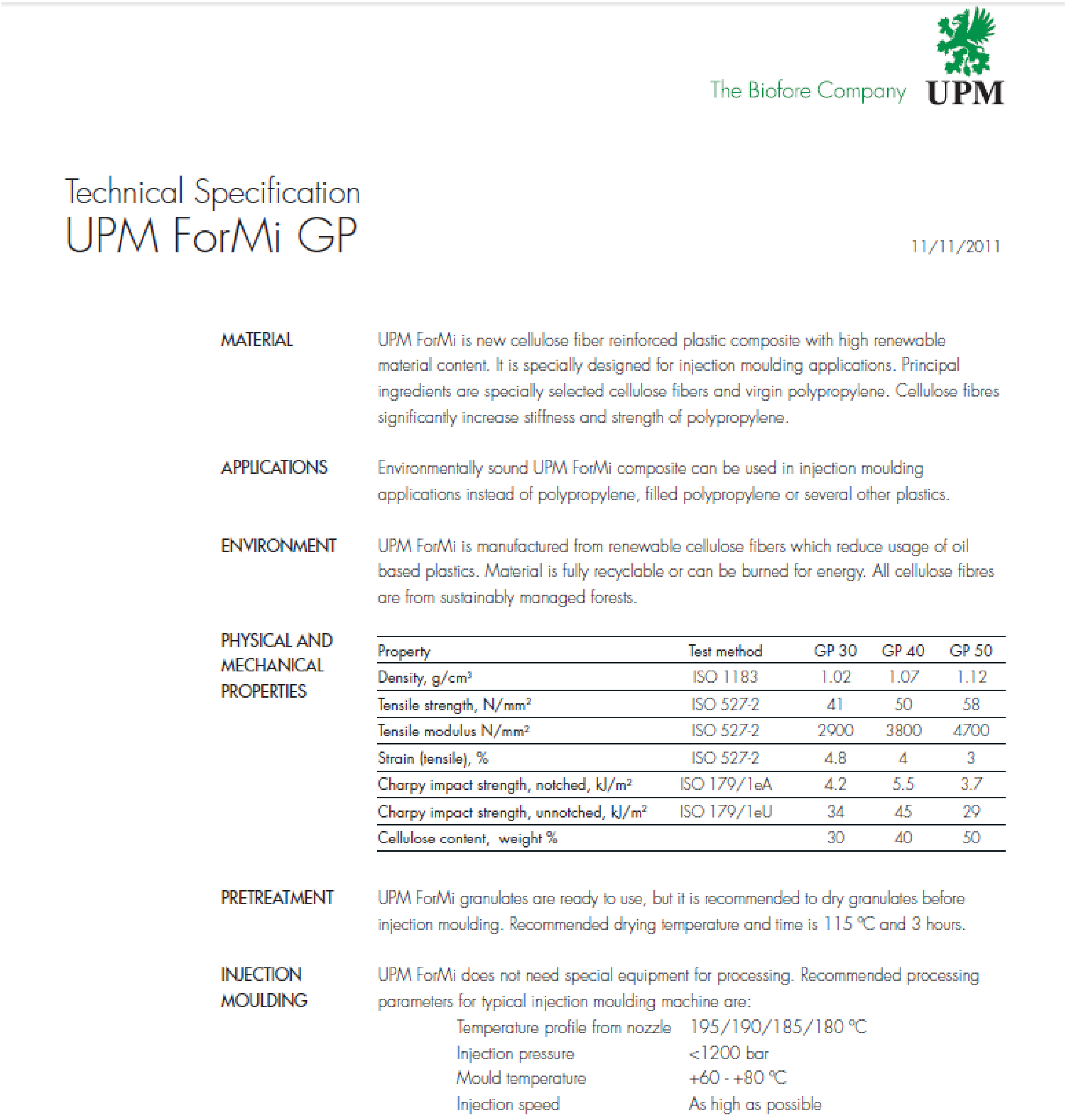

The Biofore Company UPM

Technical Specification
UPM ForMi GP

11/11/2011

MATERIAL

UPM ForMi is new cellulose fiber reinforced plastic composite with high renewable material content. It is specially designed for injection moulding applications. Principal ingredients are specially selected cellulose fibers and virgin polypropylene. Cellulose fibres significantly increase stiffness and strength of polypropylene.

APPLICATIONS

Environmentally sound UPM ForMi composite can be used in injection moulding applications instead of polypropylene, filled polypropylene or several other plastics.

ENVIRONMENT

UPM ForMi is manufactured from renewable cellulose fibers which reduce usage of oil based plastics. Material is fully recyclable or can be burned for energy. All cellulose fibres are from sustainably managed forests.

PHYSICAL AND MECHANICAL PROPERTIES

Property	Test method	GP 30	GP 40	GP 50
Density, g/cm³	ISO 1183	1.02	1.07	1.12
Tensile strength, N/mm²	ISO 527-2	41	50	58
Tensile modulus N/mm²	ISO 527-2	2900	3800	4700
Strain (tensile), %	ISO 527-2	4.8	4	3
Charpy impact strength, notched, kJ/m²	ISO 179/1eA	4.2	5.5	3.7
Charpy impact strength, unnotched, kJ/m²	ISO 179/1eU	34	45	29
Cellulose content, weight %		30	40	50

PRETREATMENT

UPM ForMi granulates are ready to use, but it is recommended to dry granulates before injection moulding. Recommended drying temperature and time is 115 °C and 3 hours.

INJECTION MOULDING

UPM ForMi does not need special equipment for processing. Recommended processing parameters for typical injection moulding machine are:

Temperature profile from nozzle	195/190/185/180 °C
Injection pressure	<1200 bar
Mould temperature	+60 - +80 °C
Injection speed	As high as possible