Natural Fibre Composites For 3D Printing

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ABSTRACT	
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Abstract:

3D printing has been common option for prototyping. Not all the materials are suitable for 3D printing. Various studies have been done and still many are ongoing regarding the suitability of the materials for 3D printing.

This thesis work discloses the possibility of 3D printing of certain polymer composite materials. The main objective of this thesis work was to study the possibility for 3D printing the polymer composite material composed of natural fibre composite and various different thermoplastic materials. The natural fibre composite (UPMFORMI GP40) was mixed with different polymers (HDPE, LDPE, PS and PP) at different ratio and the mixture was extruded to obtain the filament. The obtained filament was experimented with 3D printer to study its feasibility. The thesis explains the selection of materials, extrusion process for filament extraction and possibility of forming new product through 3D printing.

The study reveals the polymer composite filament obtained from the extrusion shows the possibility of making new product through 3D printing. However, the expected result was not obtained due to various limitation and required further research.

Keywords	Extruder Machine, 3D Printer, Natural Fibre, Drying Machine, UPMFORMI, Thermoplastic, Bio composite
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Acronyms and Abbreviations

NF: Natural fibre
GF: Glass fibre
NFC: Natural fibre composites
FRP: Fibre-reinforced Polymers
FRC: Fibre-reinforced composites
GFC: Glass fibre composites
HIPS: High-impact polystyrene
CAD: Computer aided design
CAM: Computer aided manufacturing
DH: Drying hopper
NDT: Non-destructive testing
PP: Polypropylene
PVC: Polyvinylchloride
PP: Polypropylene
PE-HD: Polyethylene high density
PE-LD: Polyethylene low density
PVC: Polyvinyl chloride
PS: Polystyrene
PLA: Polylactic acid
RPM: Revolution per minute
GP30: UPM ForMi GP30 granule
GP40: UPM ForMi GP40 granule
GP50: UPM ForMi GP50 granule
RPM: Revolutions per minute
Tm: Melting temperature
Tg: Glass transition temperature
°C: Degree Celsius, temperature measurement

Acknowledgement

I would like to dedicate this Thesis work to my parents, who have always been a great source of love and support in my life.

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Helsinki, April 2015
Kapil Pandey

1. INTRODUCTION

1.1 Background

In the past two decades, growing interest for the research in Natural fibre composites has increased in extensive scale. The reasons behind increasing of the popularity of bio composites or natural fibre composites (NFCs) are its abundant availability, competitive quality and their environmental friendliness. Furthermore, the possibility of production of new natural fibre products through injection moulding and extrusion has shown the viability to be a future material.

Recent researches and developments has shown the interest on the natural fibres is significantly all around the world. The high tech industries has also shown the interest on the natural fibre like flax, hemp, Jute, coconut and sisal for the production of new products. Natural fibre is an interesting alternative to synthetic fibre for the composite technology. Surprisingly, the natural fibres are cheaper and possesses better stiffness in terms of weight compared to synthetic fibre. These fibre products are lighter in weight and environmental friendly. Their mechanical properties restrain the fibres for using them in high-tech applications.

Current global market have been driven with growing building, construction and automotive industries. The demand for natural fibre composites has been increasing in the real estate, construction-infrastructure and automotive industries. The use of natural fibres has been rapidly growing in the automotive and mechanical industries. Plant fibres are attractive to automobile manufacturer as they are light in weight and mechanically strong. Plant fibre composites can be used instead of synthetic fibre as rein material. The moulding and shaping process of plant fibres requires less energy than moulding artificial fibre as well as produced automobiles consume less fuel due to their weight, which not only saves money but also preserve the nature. Furthermore, automobiles made from coconut natural fibres are more comfortable for users than those filled with plastic foam. Therefore, consumers are becoming aware of the environmental benefits and cost effectiveness offered by natural fibre composites. (Application of natural fibre composite , 2014)

1.2 Objective

This thesis work mainly focuses on manufacturing the 3D printable size filament from the UPMFORMIGP 40 natural fibre composites and various polymer pellets (HDPE, LDPE, PS and PP) mixtures through the extrusion. Following are the major objectives set for this research work:

1. To study the possibility to manufacture the filament of 1.75mm diameter (suitable or 3D printer) from the extruder machine.
2. To analyse and optimize process parameters for extrusion.
3. To study the possibility of making new product on 3D printer from the filament obtained from extrusion.

1.3 Methodology

This thesis work is mainly divided into two sections; theoretical part, which is based on the theory related to this study and similar research done in the past that supports the practical part of this thesis; the second is experimental (practical) part, which contains the information about the experiment done and the obtained result from the experiment.

The thesis work is initiated with the introduction of the work followed by the literature (theory part). The literature needed for this paper was taken from different books of polymers, plastics and composites, research papers available online via different database, universities and companies archive and websites as well as previous thesis works. The experimental works were carried out with the available material in the plastic laboratory of Arcada - University of Applied Sciences. Various different thermoplastic polymers and the UPMFORMI GP 40 fibre composite materials available in the laboratory were used.

The preparation of sample filament was done by using various machines available in Arcada plastic laboratory. The materials were dried using the flexible modular drying unit. The pellets were extruded by Eco-Ex single screw extruder and the filaments were obtained. The obtained filaments were used in 3D minifactory printer and makerbot 3D printer. The experimental work carried out is analysed with the theory. The overall work is concluded at the end of this research work.

The referencing of the thesis paper is done according to the Harvard system as per Arcada thesis guide recommendation.

1.4 Scope and Limitation

This thesis work focused on manufacturing the filament from the extruder machine and using it on 3D printer for making a product. NFC is a combination of different thermoplastics and natural based fibre, which are much more environmental friendly with improved mechanical and physical properties compared to thermoplastics. The thesis work focuses on producing the filament by mixing thermoplastics with NFC as the extrusion of NFC solely doesn’t result in production of filament. Hence, the scope of this thesis work is to study the possibility to make the NFC extrudable by mixing it with thermoplastics.

The practical work and the thesis was done depending on the availability of natural fibre and other thermoplastic polymers in the laboratory of Arcada UAS. Due to the poor cooling system of the extruder used for the production of natural fibre filament, the mechanical properties of the obtained filament might not be optimum. In addition, the difficulties in collecting the extruded filament due to improper collection point might also affect the properties of the filament. The physical mixing of two components might result ununiformed mixing of the natural fibre and thermoplastics, which affects the filament properties. Also, the performance of the laboratory scale machines hinders the properties of the materials.

1.5 Significance of the Research

The thesis is of very practical importance as it is concerned with production of environment friendly filament through extruder machine. The experimental result concerning the extruded natural filament can be of great importance in finding the possibility of producing different types of product. Moreover, findings of the current research will be great help for any other future researches done in this particular field.

2. LITERATURE REVIEW

2.1 Fibres

Synthetic fibres are commonly referred as fibre in composite material industries. Glass, carbon and other conventional reinforcement materials are common fibre used in commercial scale. Fibres are generally used in manufacturing polymer composite material. Fibres are often used in applications like electrical insulators, boat hulls, aerospace applications and sports goods. Natural fibres, obtained from natural resource has emerged as an alternative to synthetic fibres in the current fibre industries. Their properties are comparable to synthetic fibbers in some regard, especially if specific properties are considered.

2.2 Natural Fibres

Natural fibres are the fibres obtained from the plants and animals, which can be spun into filament thread. Natural fibres are extracted from the leaves of plant, the inner bark of plants or seed crop, from the wool of animals, insect cocoon and from mineral products. The main sources of fibres that could be obtained from plants are cotton, Ramie, Sisal, Jute, sea grass Flax, Hemp.

Table 1: Properties of Natural Fibre (Myrtha Karina, 2007)

Fiber	Density(g/cm^3)	Tensile Strength(Mpa)	Specific Tensile Strength(Mpa)	Elastic Modulus(Gpa)	Specific Elasic Modulus(Gpa)
Cotton	1.5-1.6	400	250-267	5.5-12.6	3.5-8.1
Kneaf	1.45	930	641	53	36.1
Sisal	1.5	511-635	341-423	9.4-22	6.3-14.7
E-glass	2.5	2,000-3,500	800-1,400	70	28
Carbon	1.4	4,00	2,857	230-240	164-171

The most viable structural fibres are fibres typically derive from specifically grown textile plants and fruit trees. Natural fibres are divided into various parts such as bast fibres like flax, hemp, jute, kenaf and leaf fibres like sisal, pineapples and henequen, grass fibres like bamboo and miscanthus, straw fibres like corn and wheat, seed fibres like cotton, pinewood fibres and coconut fruit fibres. (FAO Corporate Document , 2013)

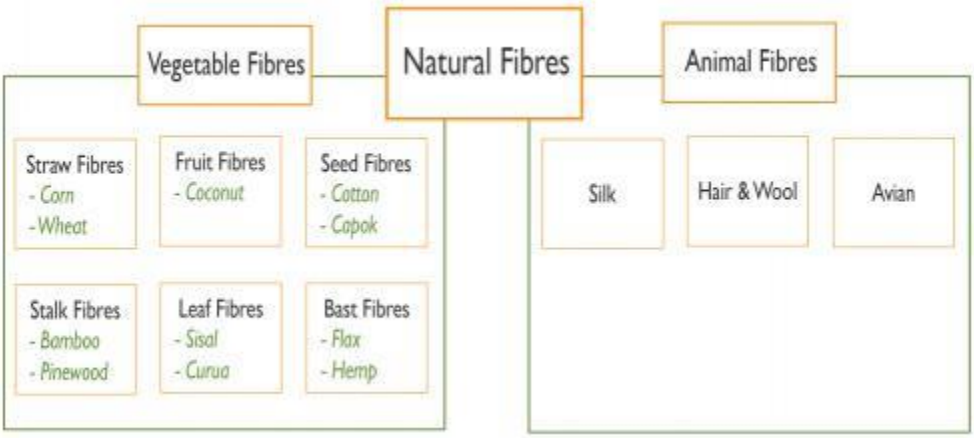


Figure 1: Types of Natural fibre (Bcomp Ltd, 2012)

Following are few common natural fibres.

2.2.1 Jute

Jute is a natural fibre extracted from the bark of jute plant and to a lesser extent from tossa jute. It is golden in colour with silky shine and hence called the Golden Fibre. The agricultural cycle of the Jute plants generally takes around three months. Jute grows in tropical lowland areas with range of humidity of 60% to 90%. Jute is a rain-fed crop that could be easily grown with small amount of fertilizer or pesticides. It is also one of the most affordable natural fibres to produce. Jute is long, soft and shiny having a length of 1 m to 4 m and a diameter varies from 17 to 20 microns. Fibres are composed primarily of cellulose; major component of plant fibre and lignin; major components of wood fibre. The fibres can be extracted by biological or chemical retting processes. Stem biological processes are commonly used method to strip the fibre. Biological retting can be done by either by stack, steep and ribbon processes which include different techniques of bundling jute stems together and soaking in water to help separate the fibres from the stem before stripping. After the process, stripping begins. On the stripping process, non-fibrous matter is taken off, leaving the fibres to be pulled out from within the stem (Future fibre jute , 2015). Normally, a hectare of jute plants consumes around 15 tonnes of carbon dioxide and releases about 11 tonnes of oxygen. Cultivating the jute in crop rotations enriches the fertility of the soil for the next crop. Jute does not generate toxic gases when burnt. Jute fibre is 100% biodegradable and recyclable i.e. environment friendly. The benefits of jute include good insulating and antistatic properties, as well as with low thermal conductivity and moderate moisture retention.

2.2.2 Coconut coir

Coir is extracted from the tissues seed of the coconut palm. Coir are grown on tropical land. Coir fibre are divided in two ways. The division is based on whether they are recovered from ripe or immature coconut husks. The coconut husks of fully ripened coconuts yield are brown coir. Coir are strong and highly resistant to abrasion, the method of processing also protects it from the damaging ultraviolet component of sunlight. Dark brown in colour, it is used for brushing purposes, floor mats, and upholstery padding. On the other side, there is white coir obtained from the husks of coconuts that are harvested shortly before they became ripen. Actually light brown or white in colour, the obtained fibre is softer and less strong than brown coir. Fibre is usually spun into yarn, which may be woven into mats and twisted into twine or rope.

Coir fibres are usually 35 cm in length with a diameter of 12-25 microns. Generally, a coconut harvest occurs once in 45 days. Around from 1000 coconuts it would be possible to extract 10 kg of coir. Among vegetable fibres, coir contains highest concentrations of lignin, which helps on making it stronger but less flexible than cotton and unsuitable for dyeing. Though the tensile strength of coir is low compared to abaca fibre, it has good resistance to microbial action and salt-water damage and needs no chemical treatment. (The cocunut palm, 1968).

Coir is only natural fibre, which is resistant to salt water. It is used for making nets for shellfish harvesting and ropes for marine applications. Coir is becoming a popular choice for making geotextiles because of its durability, eventual biodegrade-ability, ability to hold water, and hairy texture, which helps it cling to seeds and soil. (The cocunut palm, 1968).

2.2.3 Cotton

Cotton is a plant that produces natural fibres, which are commonly used for textile production. Different parts of the cotton plant can be used for different purposes. The long cotton fibres can be used for making clothes, the short fibres could be used in the paper industry. The seeds of coconut plants could also be used in making oil margarine. The leaves and stalks of the cotton plant are lowed to the ground to increase the fertility of soil. Coir fibres measure up to 35 cm in length with a diameter of 12-25 microns. Among vegetable fibres, coir has one of the highest concentrations of lignin, making it stronger but less flexible than cotton and unsuitable for dyeing. The tensile strength of coir is low compared to abaca, but it has good resistance to microbial action and salt-water damage. (Coir Natural Fibre, 2009)

2.2.4 Sisal

Sisal is a hard fibre which are extracted from the leaves of sisal plants. Sisal plants are perennial succulents that grow best in hot and dry areas. Sisal are biodegradable and also doesn't require high amount of pesticide or fertilizer during the time of cultivation. They are also environmental friendly fibres.

Sisal fibres are very long, with an average length of 0.6 to 1.2 m and it is creamy white to yellowish in colour. Sisal Fibres are very strong, durable and has the ability to stretch. It also has good insulation properties and it is highly resistant to bacterial damage. They are also deterioration in salt water. Every leaf contains an average of about 1000 fibres. The fibres are of only about 4% of the plant by weight. Sisal is considered a plant that grows on tropics and subtropics, since production rate benefits from temperatures above 25^{o}C and sunshine (Sisal Natural Fibre , 2015).

Sisal fibre lies along the length of the leaf, longer the leaf more fibre can be obtained which results a long and strong fibre. The interior fibres which are weaker, and they are usually removed during processing. The Fibres are extracted by a process known as decortication, where leaves are crushed and beaten by a rotating wheel and knives, so that only fibres remains. Globally, where the production is typically on large scale, the leaves are transported to a central decortication plant, in which water is used to wash away the waste parts of the leaf. The fibre is made dried, brushed and baled for export. Drying is very important as fibre quality depends largely on moisture content. By the several process the artificial drying process has been found to be a better grades of fibre than sun drying, but is not efficient in all countries where sisal is produced. In some part, Sisal is mainly grown by smallholders and the fibre is extracted by teams. Fibre is continuously cleaned by brushing. Dry fibres are machine combed and sorted into various grades, largely on the basis of the previous in-field separation of leaves depending in the size group.

Sisal Fibre is highly durable with a low maintenance and could be easily recyclable. Sisal fibres are obtained from the outer leaf skin, removing the inner pulp. Sisal fibres are Anti-static do not attract or trap dust particles and does not absorb moisture or water easily. The perfect texture is easily dye able and offers the largest range of dyed colours of all natural fibres. It exhibits good sound and impact absorbing properties.

2.2.5 Flax

Flax is also called as linen. The flax plant yields the fibres for linen cloth. The fibre plant grows 80 cm- 120 cm high including few branches and small flowers. The stems contains around 70 percent cellulose. On the basis of fibre harvesting, Seeds are removed from the plants then straw or barks are separated for the fibre purpose. Later on, flax is rolled and stored for use. Flax plants are pulled from the ground instead of cutting to retain the full length of the fibres, and to prevent fibre from discoloration. (Flax and Linen, n.d.).

2.3 Composites

Composites are highly engineered manufacturing products that are made from two or more different materials. The mixture of two different materials can make materials strong, unique, strong in properties, light weight and more versatile. The different various components retains its identity in the composite and maintains its characteristic structure and properties. “Composites materials are marked by different physical or chemical properties which are categorized as “matrix” or “reinforcement” – combined in a way that they act in concern, yet remain separate and distinct at some level because they don’t fully merge or dissolve into one another” (American Composites Manufacturers Association, 2015).

A materials in composite consist of binder or matrix. The reinforcement is stronger and stiffer, which are supporting as a backbone, while the matrix keeps the reinforcement in a stable place, the binder also protects the reinforcement, which may be brittle or easily breakable. Normally, composites have excellent compressibility combined with good tensile strength, making them versatile in a wide range .The combination of different physical properties materials results on better performance which are called fibre-reinforced composites.

Composites helps to raise performance levels, address material design limitations, and support for the development of new product solutions. Nowadays, composites are highly used in many industrial purposes, military services, infrastructure and aerospace applications. Durability of any material is determined by its resistance capacity to the damaging effects of an influence like ultra-violet radiation, maximum temperature, exposure to aggressive chemicals, stress cycles. Durability is assessed by measuring an appropriate material properties like strength, modulus, holding capacity before and after exposure with one or more such influence for a certain period of time under favourable conditions. Higher level of property retention is consistent with good durability. In this respect, a lifetime of the material may be measured with the time of exposure that shows in a particular property remaining above a certain criteria. Most of the composites materials are durable, water resistant, and thermally stable as well as cannot be rusted easily (McMahon, 2015).

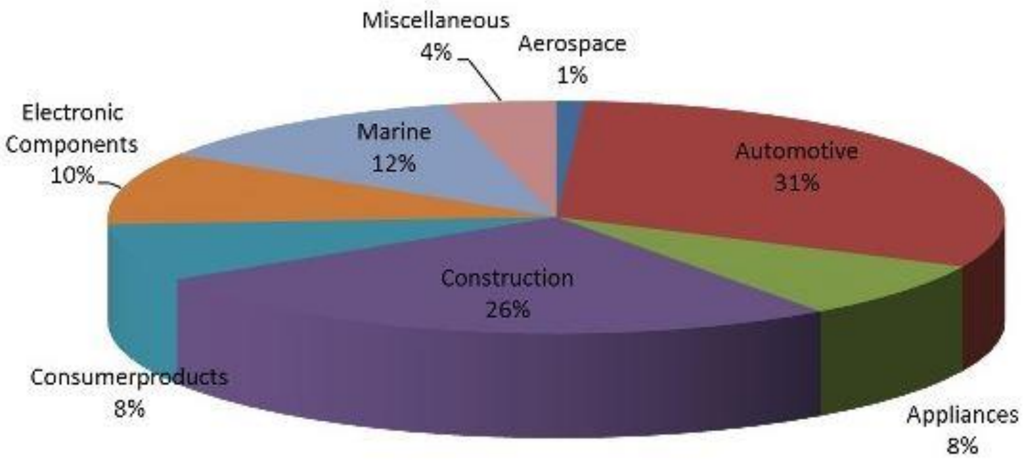


Figure 2: Market Share of composite Materials (Fibre Composites , 2011)

Composites, especially Fibre Reinforced Polymer (FRP) composites has many advantages, some of them are mentioned as below:

- Lightweight: This composites have a properties of higher specific strength than most materials used in similar applications. They can also deliver more strength per weight than many metal alloys.

- High strength: FRP composites are very powerful on providing high strength components. They can be manufactured by using a specific range of mechanical properties, including flexural, impact, tensile, and compressive strengths. Composite parts engineered with oriented reinforcement can provide strength, stress or flexural properties at specific locations within a single part.

- Corrosion Resistance: FRP composites do not rust or corrode. There are numerous resin binder systems available which could last for long-term resistance to most chemical and temperature environments. Properly manufactured FRP composites parts have long service life and minimum maintenance compared to traditional building materials.

- Durability: FRP composite technology is new technology compared to the materials that it could replaces such as steel, concrete and wood, so the full life expectancy for many composite components is still being developed. However, there are many examples of FRP composite manufactured boats, tanks and other products that are in use after more than 60 years continuously.

- Design Flexibility: FRP composites can be designed into various shape. An application can be complex in configuration, small or large structural, attractive, or a combination of these. Designers are doing researches on new concepts, from prototype to production.

- Parts Consolidation: Depending on the design and fabrication flexibility of composites, single composite parts can changed with complex assemblies units of multiple fasteners parts that are produced from traditional materials such as steel, wood and aluminium.

- Dimensional Stability: FRP composites maintain their shape and properties under environmental and mechanical stresses. FRP composites typically do not exhibit the cold-creep functionality of thermoplastics.

- High Dielectric Strength: FRP composites have wonderful electrical insulating properties, making them a highly propriety of choice for components in current available applications.

- Low Thermal Conductivity: FRP composites are naturally bad conductors, which makes them great for applications such as window lineal, exterior cladding, door skins and other products where insulation are mostly needed. However, thermally conductive or electrically conductive materials can be incorporated into the composite part when high thermal or electrical conductivity is required. (History of Composite Materials, 2015)

2.4 Natural Fibre Composites

Wood is a composite material which is made from long cellulose fibre held together by a much weaker substance called lignin. Though cellulose is also found in cotton, but without the lignin for binding together it is much weaker. The two weak substances like lignin and cellulose with combining together makes much stronger. Natural fibre composite materials are also commonly known as Bio composites. Natural fibres composites materials are gaining heavily industrial interest in a world focused on environmental outcomes. From a research perspective the interest on the Natural fibre composites has been increasing for well over a decade. The challenges, expectations and interest on plant fibre-based Bio composites, are increasing every day. (Natual fibre composites, 2014)

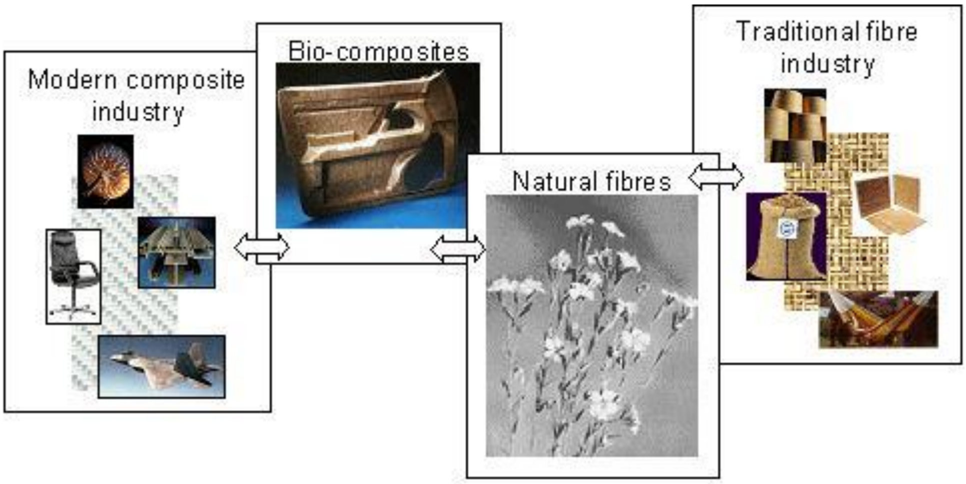


Figure 3: Natural Fibre as link between modern and traditional Industries (Application of natural fibre composite , 2014)

A standard of biodegradable polymers has been also developed from plant sources such as starch. These polymers are beginning to be obtained on the competitive prices. Recently, the applications for composites with these biodegradable polymers include different single-use products such as disposable crockery.

A major area of development on Natural fibre composites is the development of treatments including around surface treatment. A considerable amount of application is concentrated on the use of plant fibres with synthetic polymers. The hydrophilic surface of the fibre needs to be compatible with the hydrophobic polymer for the optimize adhesion. The fibre functions also can be improved by focusing on water taking behaviour, addressing breakdown through fungus, fireproof and similar other sources. The challenge and new technologies for the industry is increasing high processing consistency, in which relatively uniform features and chemistry functions can occur on the fibre surface during maintaining the cost advantage of natural fibres. Different researches on natural fibre processing generally includes a stage to modify the surface, commonly with two different materials to provide a consistent bonding surface. (Natual fibre composites, 2014)

2.5 Formi Composite

The new composite material ForMi GP is manufactured by UPM and is made of polypropylene and cellulose. The ForMi GP composite consists of four variants with cellulose concentrations of 20%, 30%, 40% or 50%. ForMi GP composite is one of three ForMi grades and is good for general use for manufacturing process. UPMFormi is a new materials which is sustainable composite products in a wide range of industrial and consumer applications. UPM Formi is a recyclable composite material with high quality. This materials have a new possibilities on injection moulding and extrusion by combining high-quality to sustainability.

UPMFORMI is specially designed for injection and extrusion applications. Up to 50% of UPM Formi's raw material can be renewable. Cellulose fibres continuously increase the stiffness and strength of polypropylene. UPM Formi granulates offer smooth and reliable process ability. Due to high quality of raw material, UPM Formi granulates result in perfect and odourless composite products. A specially selected mixture of plastic completes the mould ability of granulates for a wide range of end products with details. In addition, UPM Formi offers unlimited dyeing possibilities and great paint ability (INNOVATIVE BIOCOMPOSITE, 2014).

Figure 4: UPMFORMI granules of various concentration (20%, 30%, 40%, 50%) (Natual fibre composites, 2014).

2.5.1 UPM FORMI GP 40

UPMFORMi40 is a natural fibre (wood) reinforced plastic composite. It is high quality and durable natural fibre for injection and extrusion moulding. Since the fibre reinforced is wood fibre (cellulose), it is recyclable and odourless bio composites.

Figure 5: UPMFORMIGP40 pellets on ARCDA UAS LAB

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

The physical and mechanical properties of PP (UPM FORMIGP40) are mentioned as:

Table 2: Energy and Materials Technology Laboratories, (Technical specification of UPMFOMI GP, 2011)

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

2.6 Polymers

Polymers are made by combining a very large molecules that are made up of thousands and even millions of atoms that are bonded together in a repeating pattern. The structure of a polymer can be easily visualized by imagining a chain. The chain contains many links that are connected together. In the same style the atoms within the polymer are bonded to each other to form a long links in the polymer chain. The molecule which are links in the polymer chain are called repeat units and are formed from one or more molecules called monomers. The repeat unit can vary widely and depends on the raw materials that make up the polymer. Polymers are not always straight chains of regular repeating monomers; sometimes, they also consist of chains of varying length or even sometimes chains that branch in multiple directions. Mixtures of monomers are often found together with the polymers create and gives the molecules additional properties (Advance in polymer science , 2013).

2.6.1 Synthesizing Polymers

Polymers are made through chemical reactions which are known as polymerizations. The majority are produced through two basic types of reaction. The two types of polymerization process are mentioned as below:

- Condensation polymerization
- Chain-growth polymerization.

2.6.1.1 Condensation Polymerization

The polymers are one of two products made in condensation polymerisation reactions, the other product being a small molecule often water. The formation of cellulose is an example of a condensation polymerisation reaction:

n(HO–C6H10O4–OH) → H–(O–C6H10O4)n–OH + (n – 1)H2O (Condensational Polymerization, 2011)

During the formation of cellulose, n glucose molecules combine to form the cellulose chain and (n – 1) molecules of water, that is in this case the small molecule product which is characteristic of such reactions. When two glucose monomers start reaction, a hydroxyl group from each combine to condense a water molecule, leaving an oxygen atom linking the two monomers. This process repeats continuously to form a chain. (easy chem, 2013)

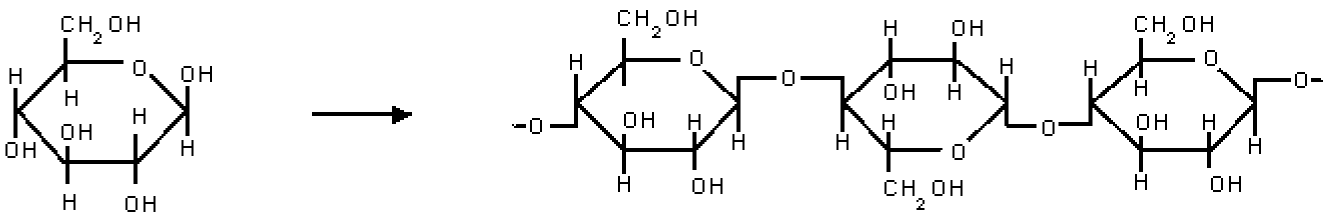


Figure 6: The condensation polymerisation reaction of glucose to cellulose (easy chem, 2013)

2.6.1.2 Chain Growth Polymerization

Chain growth polymerization, an initiator molecule starts the reaction. Monomers are then joined onto an initiated chain. Chain growth polymerization is a fast process that produces long chains soon after the reaction begins. A chain is terminated when no more monomers are available or when the chain reacts with another chain.

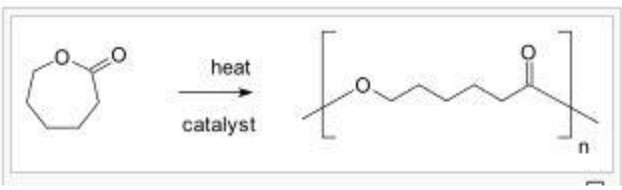


Figure 7: Chain growth Polymerization by ring opening polycaprolactone (Bishop, 2013)

2.7 Classification of Polymers

There are two main groups of plastic polymers, they are: thermosets plastics and thermoplastic:

2.7.1 Thermosets plastics

A thermosetting polymer also known as a thermoset. This are the petrochemical material that cures irreversibly. The cure may be induced by heat, generally above 200 °C, through a various chemical reaction or suitable method. Thermoset materials are usually liquid or malleable prior to curing and designed to be moulded into their final form. Normally thermos plastic are use as adhesive in semiconductors and integrated circuits (IC). Once thermoset resin are hardened than it is not possible to reheat and melt to be shaped differently. Thermosetting resin can be contrasted with thermoplastic polymers which are commonly produced in pellets and shaped into their final product form by melting and pressing for the use of injection moulding and extrusion.

2.7.2 Thermoplastics

A thermoplastic are those type of plastic which are made from polymer resins that becomes a homogenized liquid when heated and hard when cooled. When frozen, a thermoplastic becomes glass-like and subject to fracture. These characteristics, which lend the material as a reversible. Thermoplastics can be reheated, reshaped, and frozen repeatedly. The quality of this materials also makes thermoplastic recyclable. The polymers which are discussed in this thesis work are mostly used as matrixes for composites material. The commonly used polymer matrixes for manufacturing of composites are described below.

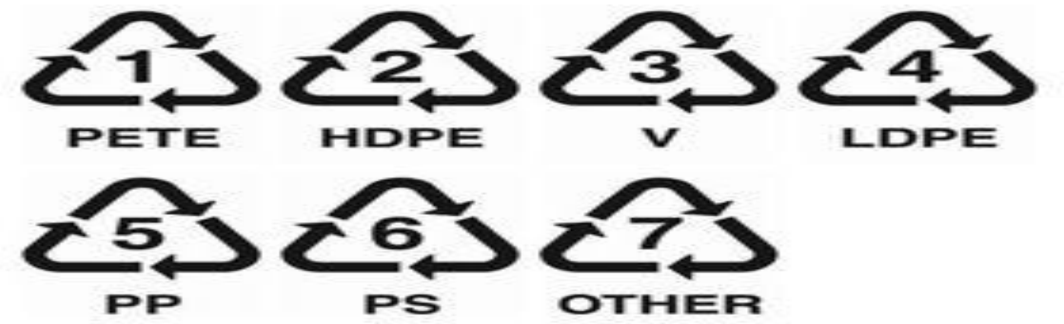


Figure 8: Types of Recycling Plastic (Luke, 2011)

2.7.2.1 Poly Propylene (PP)

Polypropylene is a plastic polymer with the chemical formula C3H6. It is used in many different settings, both in industry and in consumer goods, and it can be used both as a structural plastic and as a fibre. This plastic is often used for food containers, particularly those that need to be dishwasher safe. The melting point of polypropylene is very high compared to many other plastics, at 320°F (160°C). This contrasts with polyethylene, another popular plastic for containers, which has a much lower melting point. Polypropylene is also very easy to add dyes to, and it is often used as a fibre in carpeting that needs to be rugged and durable. Polypropylene is denoted by number 5 (WIise Greek , n.d.).

Polypropylene is known for being both lightweight and extremely rugged, but can have different textures depending on which polymerization takes place. Isotactic polypropylene is formulated with all methyl group atoms attached to one side of its atomic chain, which creates a rigid polymer. On the other end of the spectrum contains a rubbery-textured tactic polypropylene, whose elastomeric qualities come from the methyl group atoms located on both sides of its atomic chain.

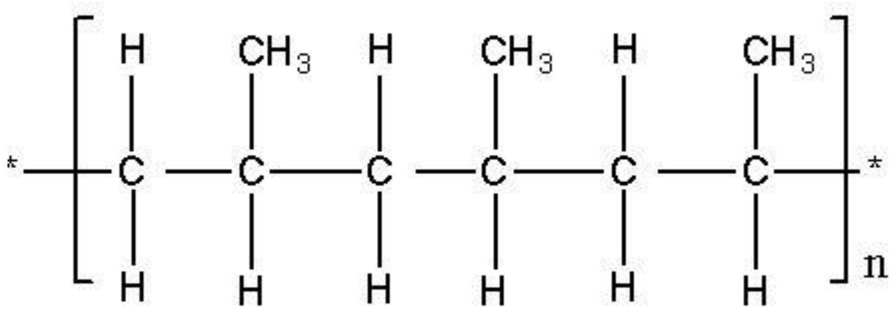


Figure 9: Three unit of Polypropylene Chain (McGuigan, 2008)

2.7.2.2 Polystyrene (PS)

Polystyrene is a type of polymer with thermoplastic properties produced from the petroleum-derived monomer, styrene. In solid form, it is a colourless and rigid plastic, but it may also be returned to a liquid state by heating, and used again for moulding or extrusion. It is used to produce many products for industrial and consumer use. The chemical structure of this material allows it to be classified as a liquid hydrocarbon, meaning that it is composed exclusively of hydrogen and carbon. It's an aromatic hydrocarbon that participates in covalent bonding with every other carbon atom being attached to a phenol group (Wise greek conjectur corporation, 2015). It is produced through free radical polymerization, which means that the reaction involves breaking the bonds between electrons and leaving them free to form new bonds. When burned, this material yields black carbon particles, or soot. When completely oxidized, only carbon dioxide and water vapour remain.

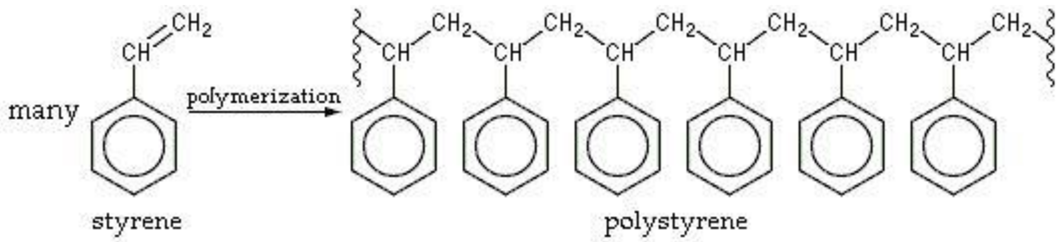


Figure 10: Formation of Polystyrene (Uchiyama, 2013)

2.7.2.3 High Density Polyethylene (HDPE)

High-density polyethylene (HDPE) is one of the most commonly used plastics. It is typically found in milk jugs, plastic bags and refillable plastic bottles. In addition to plastic lumber and recycled plastic furniture, recycled HDPE is used to manufacture lawn and garden products, buckets, crates, office products and automobile parts. HDPE plastic has several properties that make it ideal as a packaging and manufacturing product. HDPE are stronger than standard polyethylene, acts as an effective barrier against moisture and remains solid at room temperature. It resists insects, rot and other chemicals. HDPE creates no harmful emissions during its production or during its use by the consumer. Also, it leaks no toxic chemicals into the soil or water.

In general, high density grades of polyethylene have densities up to 0.9 g/cm^3. Low density grades are as low as 0.91 g/cm^3. Normally, the high-density material is more linear and consequently more crystalline. As might be expected, this higher crystallinity permits use at temperatures up to 130^oC with somewhat better creep resistance below that temperature (Maier, 2015).

2.7.2.4 Low Density Polyethylene (LDPE)

LDPE is produced by polymerization of ethylene gas at higher pressure and temperature. LDPE is widely used for production of various films and bags. Films made of low-density polyethylene are tensile and compression resistant, impact-resistant, vapour and water proof. However, they are vulnerable to gases and, therefore, are inadequate for packing the products sensitive to oxidation. LDPE does not extract toxic substances in the environment. It is harmless for human body in case of direct contact.

LDPE is defined by a density range of 0.910–0.940g/cm^3. It is not reactive at room temperatures, except by strong oxidizing agents, and some solvents cause swelling. It can withstand temperatures of 80 °C continuously and 95 °C for a short time. Made in translucent or opaque variations, it is quite flexible, and tough. It is denoted by number 4 (Chemial Econoics Handbooks, 2015).

2.8 Extrusion Moulding

Moulding refers for a manufacturing process which involves shaping of the material using a different rigid frame called a pattern. Extrusion moulding flow the process for creating a tube-shaped objects from a variety of materials. Extrusion is the process where a solid plastic (resins), usually in the form of pellet is continuously fed to a heated chamber and carried along by a feed screw. The feed screw is driven through motor, speed and torque control is major important for product quality. During the process the pellets are compressed, melted and forced out of the chamber at a steady rate through a die. After the process is completed, the cooling is done immediately and it shows the solidification of materials. The obtained plastic continually draw piece in which the cross section matches the die pattern. The die has to be manufactured and designed to ensure that the melt flows in a desired shape (Introduction to extrusion molding , 2015).

The extruder used in this project was a KFM lab ex 18 with a screw L/D ratio of 25/D and a screw diameter of 18mm. It was a small single screw extruder suitable for lab use

Figure 11: KFM Eco Ex model extruder machine on Arcada UAS

2.8.1 Extruder Machine

An extruder machine is a device which pushes or pulls a material through a shaped die to form a continuously length of product with a pre-set cross section. The extrusion process uses various polymers in big number to produce many products. Extruder as a manufacturing process offers many benefits such as the wide range of complex cross sections possible and the ability to form brittle materials. On the basis of materials, an extruder machine may form the material cold or hot with some types of materials being completely melted prior to extrusion (what is extruder machine? 2014).

An extrusion machine is used for manufacturing a large variety of products from an equally wide range of raw materials. It is also an excellent alternative for other manufacturing processes, because it allows for a larger selection of profiles and is good for use with soft materials. In industrial applications, plastics are extruded for the different purposes such as insulation, to produce food packaging film, automotive parts, cladding sheets and tubing products like plumbing pipes and electrical appliances. Alloys and steel are extruded to form rods, wires and pipes as well as steel conduits and construction members for electrical and light engineering.

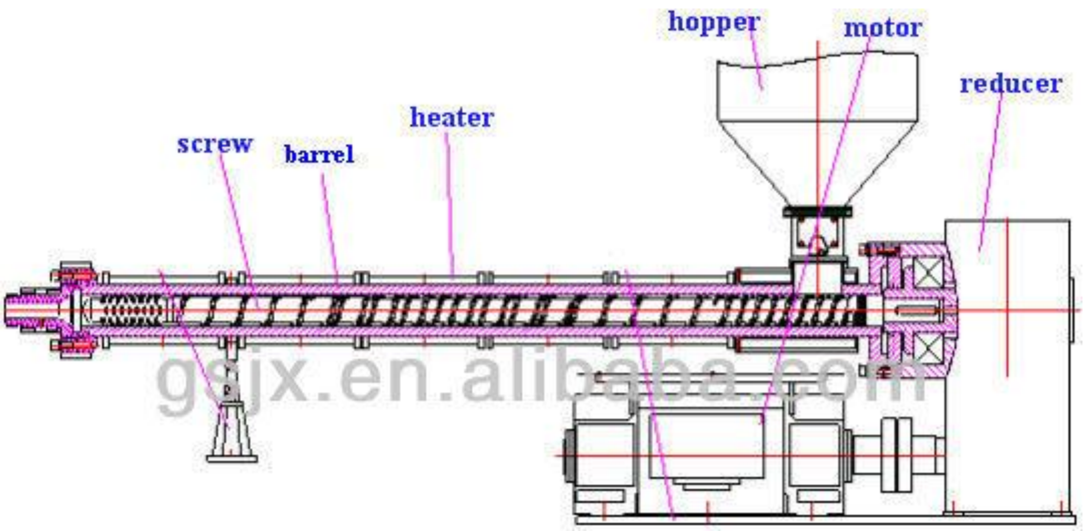


Figure 12: Various component of Extruder machine (Plastic Extruder machine , 2012)

2.8.1.1 Hopper

The hopper is a large funnel shaped structure that holds the raw plastic in either granular or pellet form. During the process, the hopper sends a continuous stream of raw plastic into the Heating barrel and screw of the extrusion machine

2.8.1.2 Heated Barrel

The holding chamber of an extrusion or injection moulding machine. The barrel holds the resin as the screw melts and mixes it. The heated barrel of a plastic extrusion machine consists a long, horizontal cylinder. The barrel is heated internally through the shear stress produce by the friction of moving pellets and a five channel heating system. When the plastic is fed into the by the hopper, the plastic melts from the heat. A helical screw down the centre of the barrel start to rotates and pulls the molten Plastic down its length.

2.8.1.3 Screw

The extruder screw is one of the most important component of the machine. The design is crucial in the mixing and process ability of the polymer, with respect to the other different type of polymer to be process. The screw is design into different sections known as zones. Depending on the polymers the screw design may be different; some designs may not have the entire zone. Three zones are usually identified in most screw which are;

Feed zone- The feed zone is the place where the resin enters the extruder. In this zone, the width of the screw is the same, and the channel distance is usually the same all over the zone.

Melting zone- On this zone the melting of pellets begins, as the screw rotate, more and more resins are melted with increased temperature inside the barrel and the channel depth gets more and more reduced.

Metering zone- This is the zone in which channel depth is again the same throughout the zone, melting of the end particles and mixing of the polymer to a various temperature and composition occurs in this zone. Barrel heaters may contribute some energy needed to complete the melting.

2.8.1.4 Die

The extruder die is the component of the machine which gives the final shape of the product. So, design of die is important both for specification and accuracy. The extruder die create a way through which molten polymer exit the extruder with the help of pressure built up in the barrel during the process. The molten polymer coming out from the die has a constant exit velocity across the entire die exit. The flow to avoid changes in the flow passage that may cause stagnation areas. If the flow of the polymer is not constant it may result to the degradation of the stagnated polymer alone the barrel channel after a considerable period of time.

2.9 Filament

Extruder heads are obtainable on multiple sizes. However, two basis of filament size diameter are suitable for 3D printer which are 3mm and 1.75 mm. Some printers can accept both, many of them only take one or the other.

- 1.75mm 3D Printer filament: This finer filament is great for small parts and intricate detail. It requires less torque to melt and push the filament through the nozzle on the extruder head.

- 3mm 3D Printer filament: Printers that use this filament also print faster, making it great for quickly building larger items. It is s good for rough prototypes, or large runs of simple devices.

2.10 Lay Wood Filament

Recently, the lay wood filament is being for producing a new product from the wood filament. Lay wood printable wood filament is a composed mixture of real wood fibres and a binding polymer compound. It is pretty flexible and the filament has a rough surface, but nevertheless tight diameter tolerance. A pleasant side effect of the embedded wood fibres is the forest like smell that emerges during printing with Lay Wood (Form Utura, 2015).

Printing guidelines

For successful printing correct printing settings are essential. The fibrous filament, nozzle diameters of at least 0.35mm are advised, to minimize the risk of clogging the nozzle. The mainly use nozzle diameter is 0.50 mm.

Table 3: Setting of 3D printer for Lay wood filament. (Form Utura, 2015)

Melting Temperature	190 °C
Nozzle Temperature	200 °C
Heated Bed Temperature	40 °C
Bed Material	Kapton covered glass

The above mentioned values as a starting point, optimal values for your specific printer may varies depending on e.g. nozzle diameter, printing speed and layer height.

Lay Wood has also an interesting color property. Its color is dependent on the actual nozzle temperature. So when changing the nozzle temperature, it would be able to print different shades.

Figure 13: 3mm Diameter Lay wood Filament for 3D Printer (3D printing for beginers , 2015)

Figure 14: 3DPrinted lay wood vase (3D printing for beginers , 2015)

2.11 3D Printer

3D printing is a manufacturing process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is obtained using additive processes. In an 3d printing process an object is created by laying down successive multiple layers of material until the entire object is finalized. Each of the layers can be notice as a thinly sliced horizontal cross-section of the eventual object. (what is 3Dprinting, 2015)

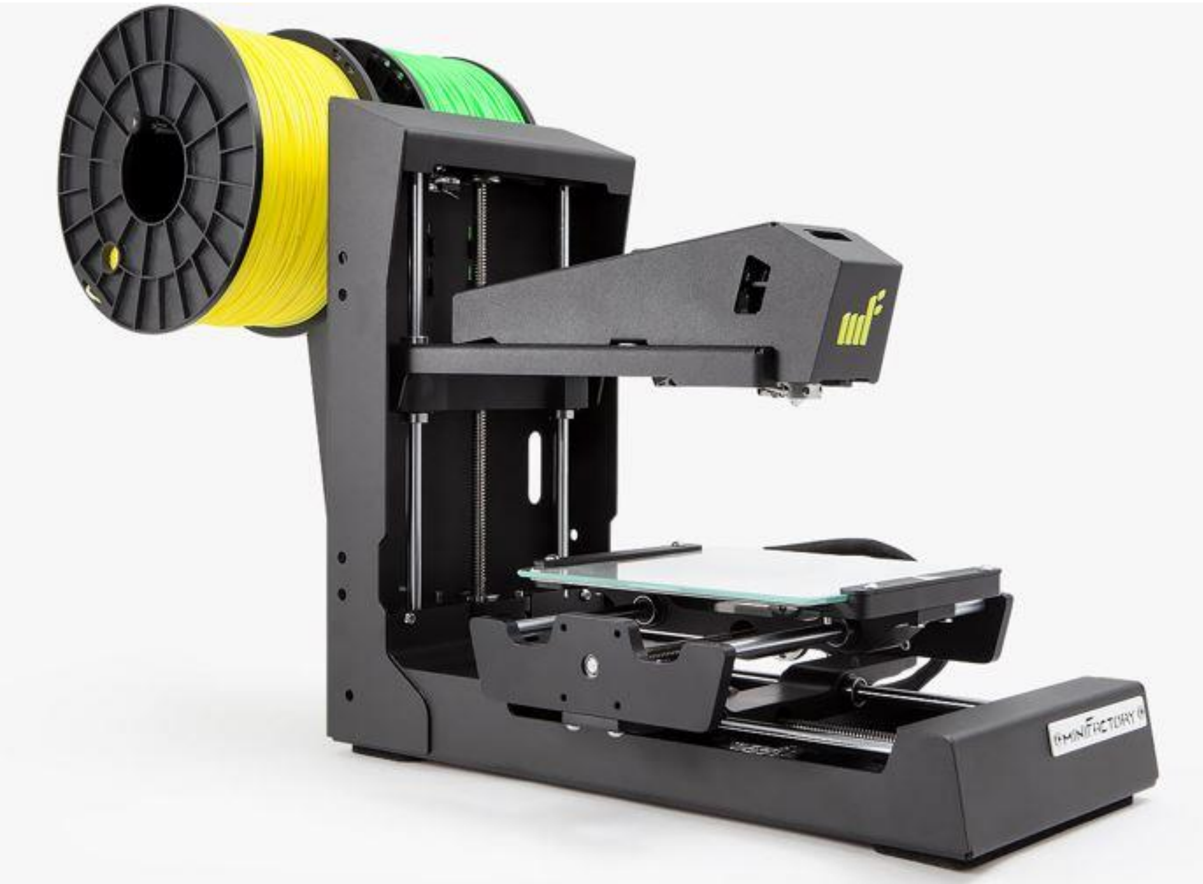


Figure 15: Minifactory 3D Printer (minifactory, n.d.)

Some technical information regarding to minifactory 3D printer are mentioned as below:

GENERAL INFORMATION OF 3D Printer

- Travel speed 80 mm/s
- Layer height 0.02mm - 0.64mm
- Maximum print size: 150mm x 150mm x 150mm
- A filament holder for two filament reels
- External dimensions: 43,5cm x 34cm x 30cm
- Weight: 11kg

PRINTING FEATURES

- Filament width 1.75mm (optional extra 3.00mm)
- Nozzle diameter 0.4mm (optional extra from 0.3mm to 0.8mm)
- The temperature range: between +30°C - +300°C

- Material options: Thermoplastic materials, for example for example: PLA, ABS, NYLON, HPDE, PVA, Laywood, T-GLASE, TPE, Laybrick, Hips, Bendlay, And Polycarbonate etc.
- Changeable and heat able printing platform

2.12 Working Principle

It all starts with making a virtual design of the object according to desire. This virtual design is made by using the different software such as CAD, Solid works, solid edge .The file uses a 3D modelling program for the creation of a totally new object or with the use of a 3D scanner to copy an object. The scanner makes a 3D digital copy of an object and place it into a 3D modelling program. To prepare the digital file created in a 3D modelling program for printing, the software start slicing the final model into multiple times of horizontal layers. When the final file is uploaded in the 3D printer, the printer start creating the object layer by layer. The 3D printer reads every slices and proceeds to create the object blending each layer together without any sign of the layering visible, resulting in one final three dimensional object (what is 3Dprinting, 2015).

2.13 Methods and Technologies of 3D Printing

Most of 3D printers uses their own technology to realize their objects. There are various ways to do it and all those available because of the additives and the way layers are built to create the final object. Some 3D printing technologies uses melting or softening material to produce the layers. Selective laser sintering (SLS), fused deposition modelling (FDM) and Stereo lithography (SLA) are the most common technologies using this methods of printing. Another way of printing is to lay liquid materials that are manufactured with different technologies.

2.13.1 Selective Laser Sintering (SLS)

SLS technology uses a high power laser to fuse small particles of metal, plastic, glass powder or ceramic into a mass that has the desired to produce on three dimensional shape. The selective laser fuses the powdered material by scanning the layers generated by the 3D modelling program on the surface of a powered bed. After every cross-section is scanned, the powder bed is lowered by single layer thickness. Every new layer of material is applied on top and the process is repeated until the final object is obtained. All unused powder remains as it is and becomes a support structure for the object. Therefore there isn't required for any support structure which is a good advantage over SLS and SLA (Materialise, 2015).

2.13.2 Fused Deposition Modelling (FDM)

The FDM technology works by using metal wire or plastic filament which is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow off and on. During the process, the nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, which is directly controlled by a computer-aided manufacturing (CAM) software. After extrusion from the nozzle, the object is produced by extruding melted material to form layers. The software that comes with this technology automatically generates support structures if required. The machine uses the two materials, one for the model and one form a disposable support structure (Stratasys, 2015).

2.13.3 Stereo Lithography (SLA)

The main technology in which photo polymerization is used to produce a solid part from a liquid is SLA. One at a time, this technology employs an ultraviolet curable photopolymer resin and an ultraviolet laser for building the object's layers. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure with the ultraviolet laser light cures and solidifies the pattern traced on the resin and joins it to the layer below. After the completion of pattern tracking, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05 mm to 0.15 mm. Then, a resin-filled blade sweeps across the cross sectional layers of the part, re-coating it with fresh material. On the new liquid surface, the subsequent layer pattern is traced, by joining with the previous layer. The final three dimensional object is formed by this project. SLA needs the use of supporting structures which serve to attach the part to the elevator platform (solid Concepts, 2014).

2.14 Component of 3D Printer

2.14.1 Print Bed

The print bed is the surface of 3D prints which are built on. The size of a printer's print bed will vary from one printer to the next, ranging from $100mm^2$ to $200mm^2$. The print bed is used to prevent warping or cracking of prints as they cool and to create better adhesion between the first layers of the print and the print bed surface. The surface of the print bed is often made from either glass or aluminium to better spread the heat across the area for a smooth level. Glass provides the smoothest surface to print on while aluminium conducts heat better for a heated platform. For saving the object from lifting off the surface in mid print, these surfaces are often covered in one kind of tape or another to provide a surface that is inexpensive to replace periodically.

2.14.2 Motor

Motors are needed, four at least – three for the spatial movement and one for the extruder. A major design choice whether they are ordinary DC or stepper.

2.14.3 Printer Head (Extruder)

The print head (extruder) the warm plastic. Extruder component needs to work for the printer to function. This component is most vital, and under the heaviest stress. In other words, it would be first to fail if there is fault on design and building process. The plastic extruder parts are: a motor to push the raw material, a chamber/nozzle, a heating coil, a temperature sensor, and, something to hold it all together.

2.14.4 Reptier Host

Reptier-Host software has the ability to modify the G-code file and see the alterations in real time in the preview pane. This software indicate some unprecedented access to the nuts and bolts of the 3D printing process. This host uses Slicer as its default slicer application. The software is fairly new printer control application, so long-term reliability and updated.

Some of the special features of reptier host are mentioned as below:

- Easy and intuitive to handle
- ALL-IN-ONE software solution – 3d printing was never easier
- Supporting several slicers for best printing results
- Possible of preview resulting print with selectable layer ranges
- Good support for multi extruder printing
- Able to send push messages on status changes to the Reptier-Informer app.
- On having a preview of printer action and temperature curves

2.15 Microscope Test

Microscopes having magnification of high power, can be successfully working for testing and identifying the fibre contents of a fabric. Microscope test is very operative for testing the natural fabrics. Various Hindrances could be faced while testing synthetic fabrics as many of them have similar appearance. However, Researcher should have a knowledge about the fibre look like under a microscope as many final processes like mercerizing and decluttering, change the appearance of fibres under microscope. Apart from it, dark colored fabrics cannot be tested with microscope as light cannot pass through dark substances. For those fabrics, either the textile dyes have to be removed by stripping and bleaching or they have to be chemically tested.

Natural fibres have their own structures, spots, lines and other marks that help in identifying them. Some examples of natural fibre and the properties which is visible under a microscope are as below:

Cotton: The cotton fibre is a single elongated cell. Under a microscope, it looks like flat, spirally twisted ribbon like tube with rough granular surface. However, mercerized cotton doesn't have natural twist. The finishing process makes them swollen, straight, and smooth and round. (Textile Exchange, 2011)

Linen: Linen fibre under a microscope, looks like having multiple sided cylindrical filaments with fine pointed edges. The filaments show nodes at intervals. Typically, it looks like a bamboo stick having joints that results into a little disorder. (Textile Exchange, 2011)

Wool: Wool fibre has irregular, roughly cylindrical, multi cellular structure with tapered ends. Under a microscope, three basic layers are shown- epidermis (outer layer), cortex (middle layer) and medulla (inner layer). Medulla is seen only in coarse and medium wool fibres and under a highly powerful microscope. (Textile Exchange, 2011)

Silk: Silk fibre composed of two filaments, has elliptical shape under the microscope. The two fine and lustrous filaments are shown clearly looking like transparent rods with triangular shape. Silk or tussah fibre has different appearance than the cultivated silk. It is flattened, coarse, thick and broader fibre having fine, wavy lines all across its surface whereas cultivated silk is narrower fibre without marks. (Textile Exchange, 2011)

Polyester: Generally, polyester fibre is smooth, straight. It looks round cross sectional. However, with various finishing processes, its appearance changes in context of texture and luste. (Textile Exchange, 2011)

3. MATERIALS AND METHODS

The experimental works for the thesis were done in the plastic laboratory of Arcada University of Applied Sciences. Extrusion machine was used to produce several different filaments from the natural composite polymers. The obtained filament were subjected to experiment on 3D printer for making a product. The whole procedures of laboratory works carried out for the thesis are described below in respective manner.

3.1 Process

The process cycle of the work started with drying of UPMFORMI 40 pellets and mixing it with different thermoplastic pellets before feeding the mixture to extruder machine. The polymer composites filament of different composition were extruded.

3.1.1 Materials

The materials that were used in the experiment are High density Polyethylene (HDPE), Low density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) thermoplastics and UPMFORMI GP 40 natural fibre composite. Following are the materials used for the experimental work.

Table 4: Materials used in this experimental work

Material	Grade	Manufacturer
HDPE	HDPE HMA 02	Exxon Mobil Chemical
LDPE	Purell PE1840 H	Lyondell Basell
PP	HE312 BF	Borealis AG
PS	549 9313	BASF SE
fibre composite (PP composite)	ForMi GP 40	UPM

3.1.1.1 Drying material

Flexible Modular Drying Unit (FMD) manufactured by Labotek A/S was used for drying UPMFORMI GP 40 fibre composite pellets. UPMFORMI materials should be dried before the extrusion moulding process. The presence of moisture on the granules could result the bubbles on filament during extrusion which reduces the mechanical properties of the material. For removing the humidity or moisture from the granules, it is recommended to dry the material at the temperature of 115 ºC for 3 hours. Overheating may cause thermal degradation of material. The maximum processing temperature is 200 ºC. Automatic ignition of UPMFORMI material is possible after purging into the moulding machine. UPMFORMI granulates should be protected from UV-light and should store in closed place in dry conditions at the room temperature. Content of air humidity could increase moisture of the material and have negative effects on the end product properties.

Figure 16: FMD drying machine on Arcada UAS Lab

3.1.1.2 Mixing the composite materials

While mixing, it was very important to choose the appropriate thermoplastic component for UPMFORMIGP40 materials. The mixture polymer composite was made mixing UPMFORMIGP40 material with each thermoplastic material at different ratios. The percentage ratio of chosen thermoplastic and UPMFORMIGP40 ranges from 30:70, 40:60, 50:50, 60:40, 70:30 percent respectively . Although many different ratios mixture were tested during this extrusion experiment, the thesis work focuses only on equal proportions during the use of 3D printer.

Figure 17: Mixture of UPMFORMIGP 40 and thermoplastics

3.1.1.3 Temperature of Materials

The processing condition (rotation speed, temperature) of extruder should be optimized in order to obtain good filaments. The correct temperature settings for all the materials were obtained from past research as well some experiments were carried out. After analysing the required condition and the procedures for extrusion, the extrusion with a material of different ratios were carried out and the filament were obtained.

The following table further shows the different processing conditions of different mixture material of equal ratio.

Table 5: Mixing 50% of UPMFORMIGP 40 and 50% of LDPE on different zones and temperatures

Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Room Temperature	167 °C	162 °C	164 °C	161 °C	164 °C
Room Temperature	165 °C	161 °C	165 °C	161 °C	164 °C

Set Value: 6RPM

Production Value: 6RPM

2.8 AMP

Table 6: Mixing 50% of UPMFORMI 40 and 50% of PP on different zones and temperatures

Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Room Temperature	176 °C	177 °C	180 °C	182 °C	178 °C
Room Temperature	168 °C	179 °C	182 °C	183 °C	179 °C

Set value: 5RPM

Production Value: 5RPM

2.6 AMP

Table 7: Mixing 50% of UPM FORMI 40 and 50% of Poly Styrene on different zones and temperature

Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Room Temperature	167 °C	170 °C	169 °C	169 °C	169 °C
Room Temperature	170 °C	168 °C	169 °C	171 °C	170 °C

Set Value: 6RPM

Production Value: 6RPM

2.7 Amp

Table 8: Mixing 50% of UPMFORMI GP 40 and 50% of HDPE on different zones and temperature

Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Room Temperature	177 °C	175 °C	174 °C	176 °C	180 °C
Room Temperature	176 °C	175 °C	174 °C	174 °C	178 °C

Set Value: 6 RPM

Production value: 6RPM

2.6 AMP

Figure 18: Temperature setting during the extrusion process at Arcada UAS LAB

3.1.2 Extrusion Process

The filament was produced using Eco Ex single screw extruder manufactured by KFM machine AB, Sweden. The extruder machine has six temperature zones. The first two zones function as feed zone heating temperature, the second two zones was the compression zone heating while the last two zone heats the pumping zone and the die. In the beginning, the extruder machine was cleaned with purging material to obtain the better properties of cellulose filament. For controlling the excessive temperature on the extruder machine water cooler was turned on. The extruder machine took around 30 minutes to stabilize on required temperature. The mixture pellets was poured into the hopper by gravity and the air cooling was prepared. The rotating screw started to push forward through the heating zone. When the pellets reached the heat zone the force of friction and the heat applied. Due to the increased in temperature inside the zone the pellets started compressing, the friction and shear stress produced by pellets acts as an initiator for melting plastic. In addition, the five channel temperatures were maintained on the barrel through the compression zone and the pressure was created by molten pellets and screw on the pumping zone and die. Finally, the filament was extruded from the die. Air cooler was used to solidify the melted filament. The puller was used of 7voltage for pulling the filament and stand was used to for balancing the process. The obtained filament was rolled on the roller for the use on 3D printer.

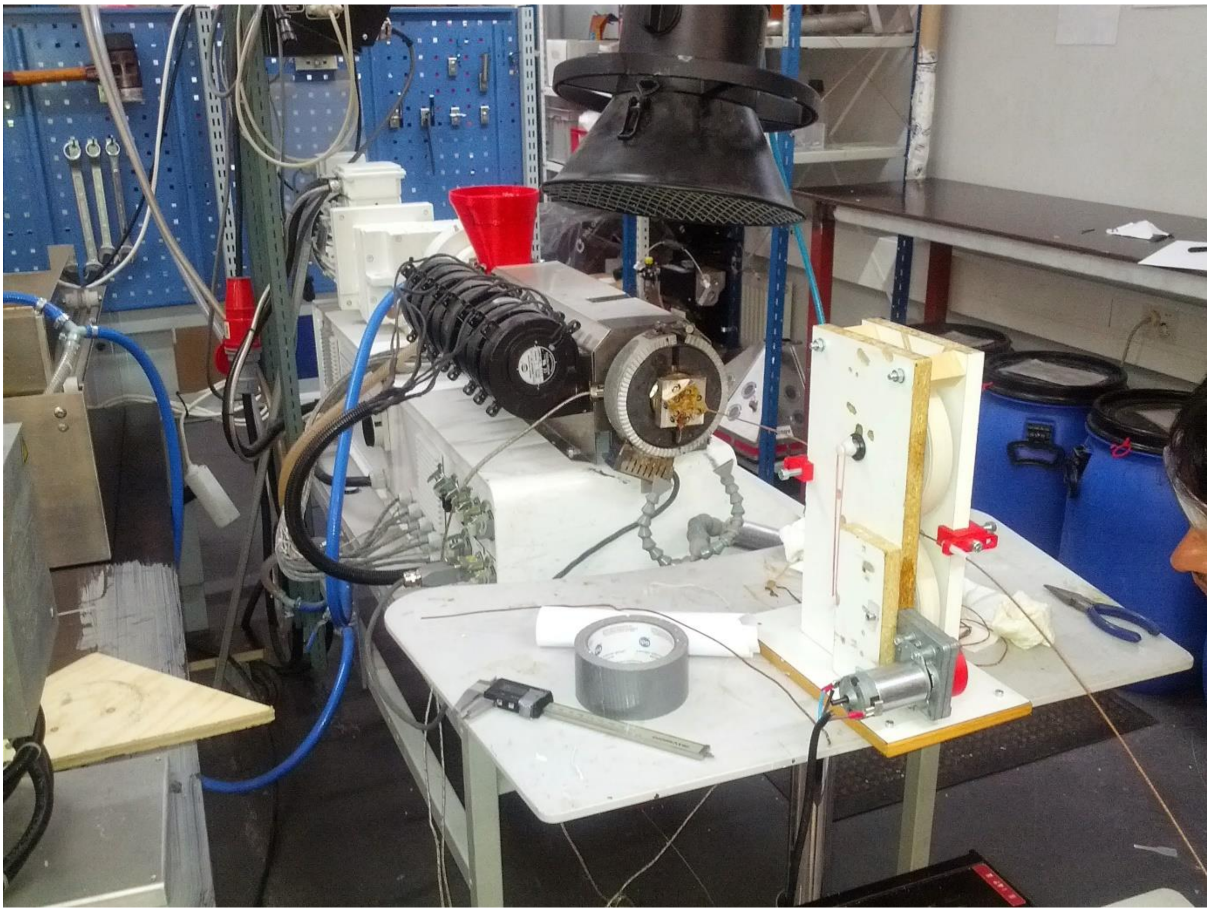


Figure 19: Filament Extruding Process on Arcada UAS

3.1.3 Microscopic View of Filament

Electron microscopy test was performed on Arcada UAS for viewing the surface finishing of filament. Required safety precautions were followed for the microscopic specimen preparation and observation of magnified filament. The microscopic view was observed of the filament with equal ratio of UPMFORMI40 and thermoplastic during the thesis research. The lenses used for the magnification purposes were 5X/0,13HD, 10X/0.2HD,20X/0.4HD and 50X/0.7HD. The smoothness of the surface of filaments were observed and analysed.

3.1.4 3D Printing Process

The sample of filaments was tested on the 3D printer manufactured by Minifactory Oy Ltd was used for the 3D printing to see the filament compatibility. The printer was available at Arcada laboratory. The printing bed was cleaned by using acetone for preventing from contamination of pervious material used. The glue was applied on print bed to ensure the stickiness of the first layer. The printing process is controlled by the Reptier host software.
The four different filaments of various composition were experimented in 3D printer. The following technical settings were maintained during the printing process.

Table 9: Setting of 3D printer for Equal ratio of (UPMFORMIGP40 and LDPE) Filament

Extruder Temperature	190 °C -220 °C
Bed Temperature	55 °C
Bridge Fan speed	100mm/s
Printing speed	200mm/s
First layer height	0.3mm
layer height	0.4mm

Table 10: Setting of 3D printer for Equal ratio of (UPMFORMIGP40 and PP) Filament

Extruder Temperature	215°C-240°C
Bed Temperature	60°C
Fan speed	110mm/s
Printing speed	210mm/s
First layer height	0.3mm
layer height	0.4mm

Table 11: Setting of 3D printer for Equal ratio of (UPMFORMIGP40 and PS) Filament

Extruder Temperature	185°C-215°C
Bed Temperature	50°C
Fan Speed	100mm/s
Printing Speed	190mm/s
First Layer Height	0.3mm
Layer Height	0.4mm

Table 12: Setting of 3D printer for equal ratio of (UPMFORMI40 and HDPE) Filament

Extruder Temperature	210°C-235°C
Bed Temperature	55°C
Fan Speed	90mm/s
Printing Speed	210mm/s
First Layer Height	0.3mm
Layer Height	0.4mm

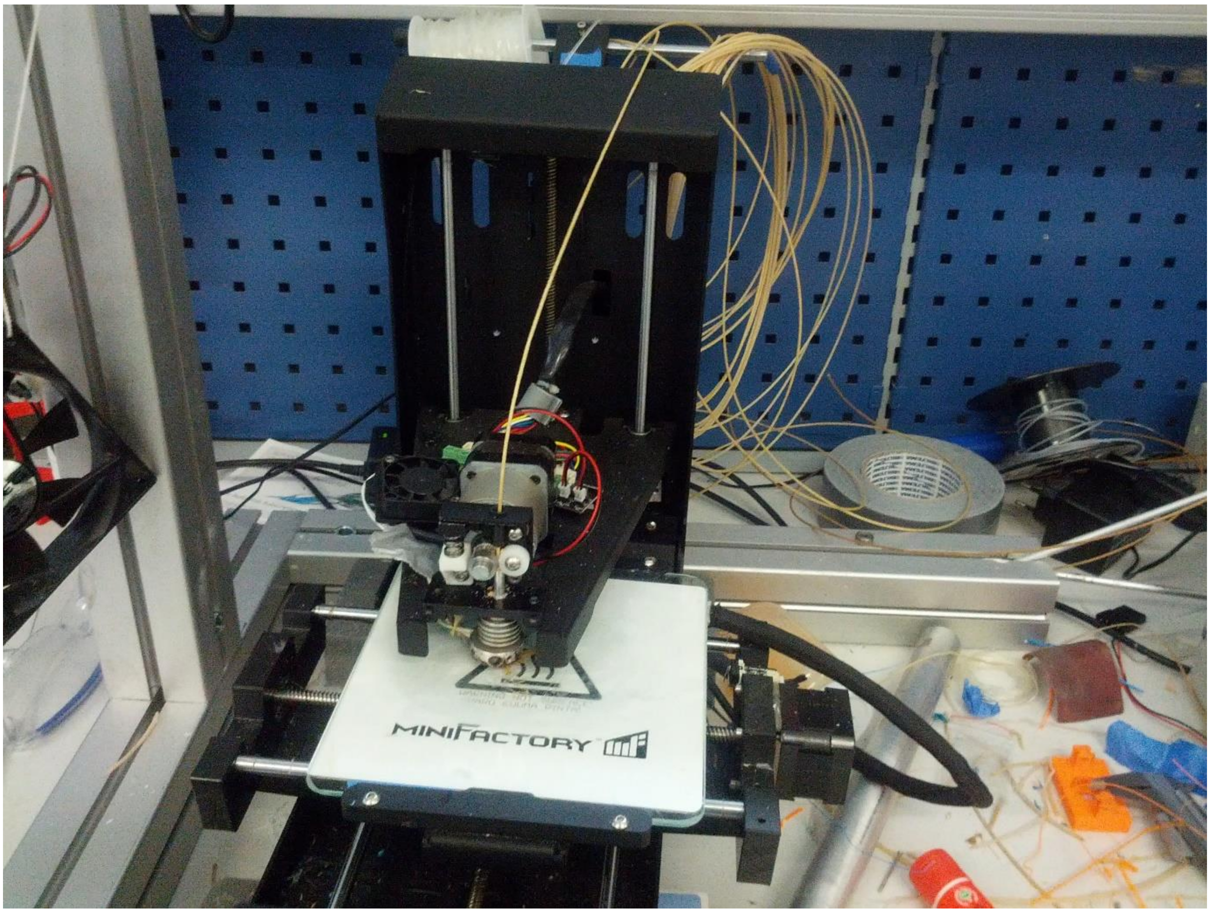


Figure 20: Printing process on Minifactory 3D printer on Arcada UAS

3.2 Further Experiment Done on Aalto University

Due to the difficulties with the 3D printing in Arcada lab, we decided to further experiment it using different 3D printer available in the laboratory of Aalto University. MakerBot 3D printer manufactured by MakerBot® Industries, LLC was used in Aalto University. The equal ratio of UPMFORMI 40 and thermoplastic filaments were chosen for printing a product. The print temperature was set as 190°C-245°C depending on the required filament Temperature. The duct tape was used on the printer bed for stickiness of first layer .The bed temperature was set to 50°C. The dimension of 40mm*30mm throated box (relatively small) was chosen as the design for the experiment.

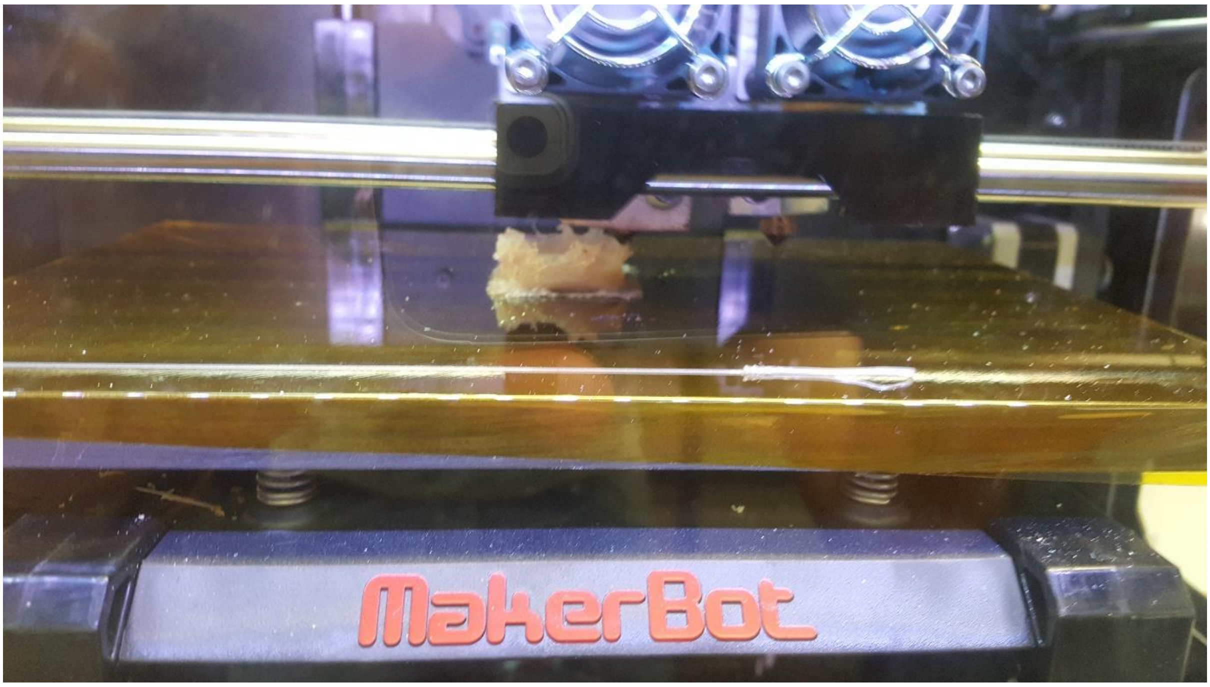


Figure 21: Printing a throated box by using makerbot 3D printer

4. RESULTS

4.1 Extruded filament

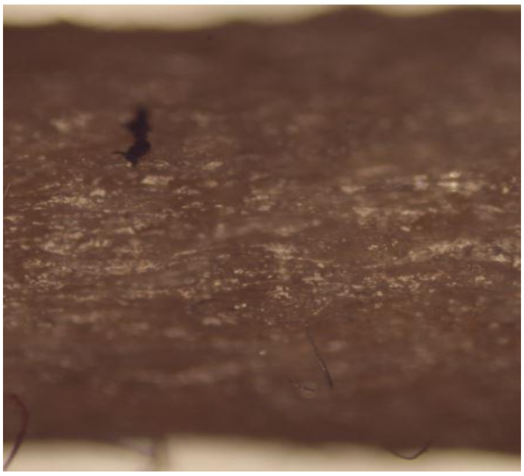
The extrusion of the polymer composite seems challenging initially. Since, we extruded the UPMFORMIGP 4O fibre material independently to experiment the material behaviours before extruding the mixture material. We found the extrusion of UPMFORMIGP4O to be very difficult. The extruded filaments behaves to be delicate and breaks often during the extrusion process even during the recommended extrusion condition of the material. After certain period of extrusion, the filament started to burn even on the extruding temperature of the fibre pellets.

As one of the objective of thesis work was to study the possibility of making fibre composite material extrudable and 3D printable, the experimental study was further carried out by mixing the fibre composite pellets with thermoplastics. The extrusion was continued with the mixture of UPMFORMIGP040 and different thermoplastics. The extrusion work seems challenging initially. However, after the optimization of an appropriate temperature for extrusion, the filaments of diameter of around 1.75mm (suitable for 3D printer available in the lab) was obtained from the extruder machine.

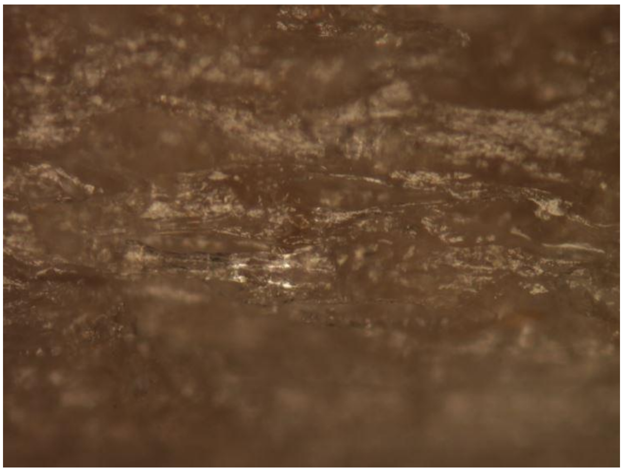
Figure 22 : Obtained filament of mixing UPMFORMIGP40 with different thermoplastics.

4.1.1 Microscopic view

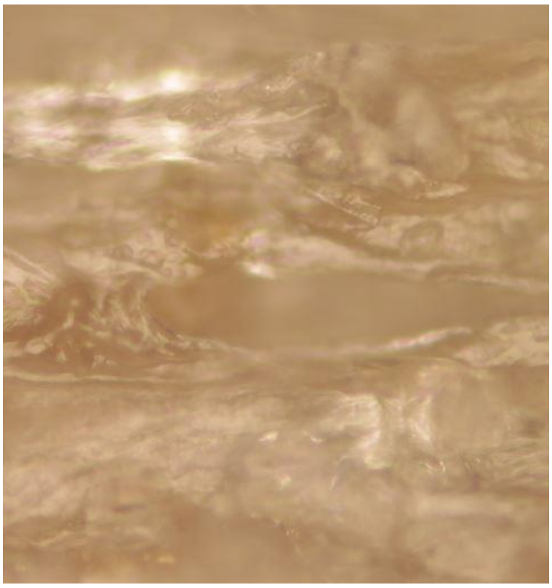
Different views were obtained from different magnifying lenses, the images of which are shown below. The pictures below represents views of materials with different composition through all the magnifying lenses. The four respective figures indicates the use of 5X/0,13HD, 10X/0.2HD,20X/0.4HD and 50X/0.7HD magnifying lenses respectively.



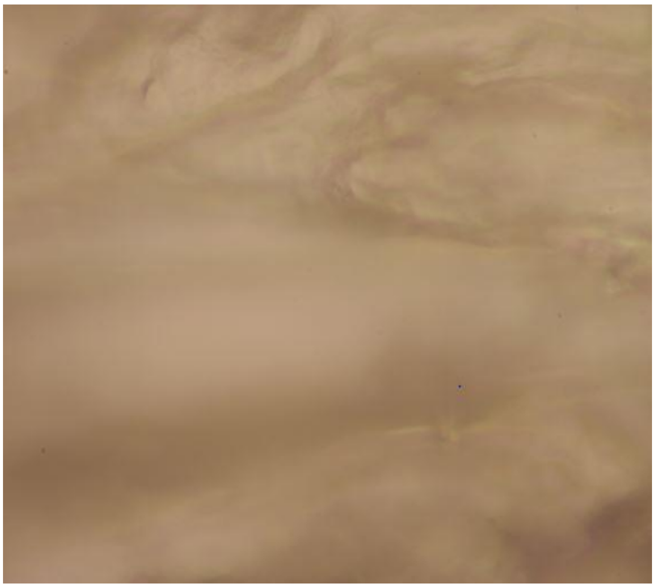
Result on 5X/0,13HD magnifying lens



Result on 10X/0.2HD Magnifying lens



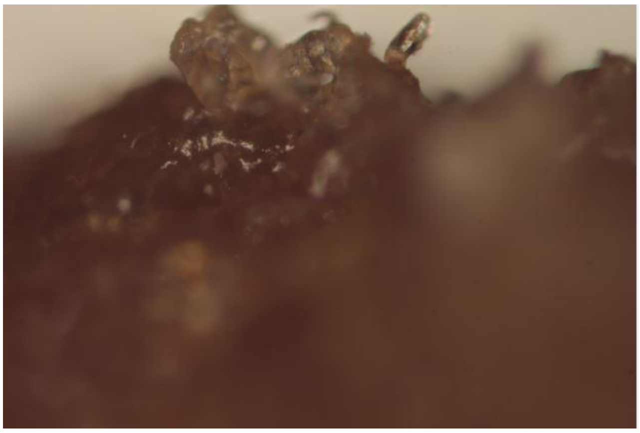
Result on 20X/0.4HD magnifying lens



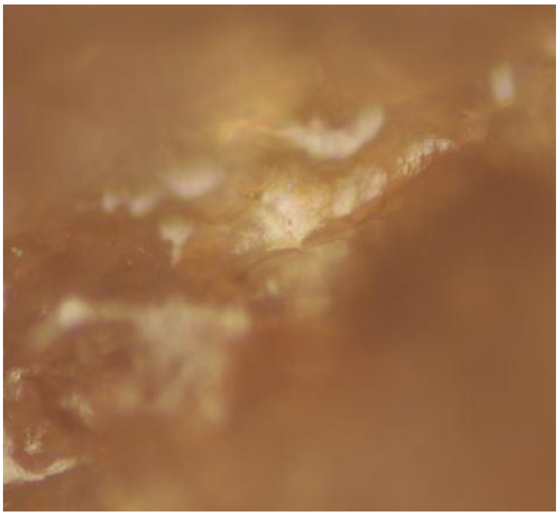
Result on 50X/0.7HD magnifying lens

Figure 23: The surface finishing of UPMFORMIGP40 and LDPE (50/50) specimen on all magnifying lenses

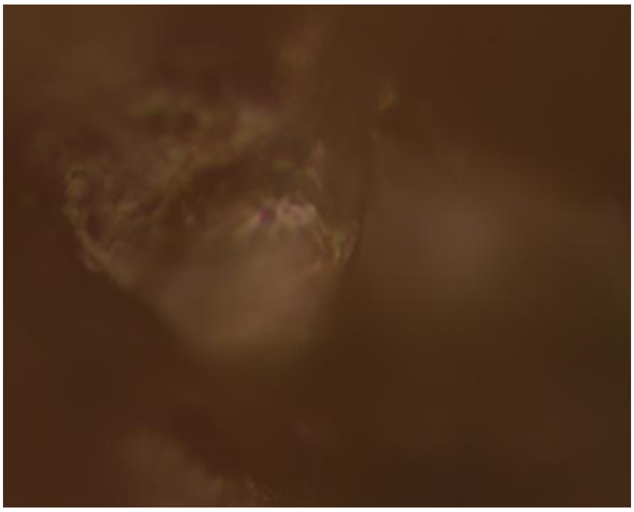
Result on 5X/0,13HD magnifying lens



Result on 10X/0.2HD Magnifying lens



Result on 20X/0.4HD magnifying lens



Result on 50X/0.7HD magnifying lens

Figure 24: The surface finishing of UPMFORMIGP40 and PP (50/50) specimen on all magnifying lenses

Result on 5X/0,13HD magnifying lens

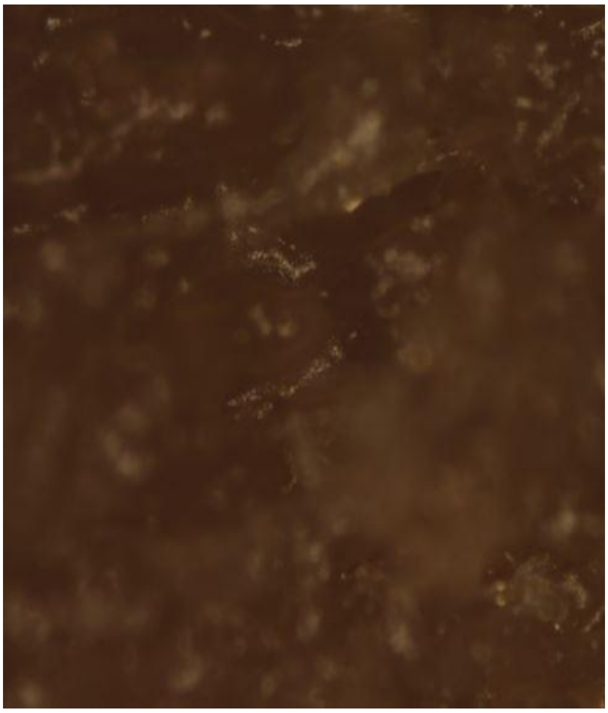
Result on 10X/0.2HD Magnifying lens

Result on 20X/0.4HD magnifying lens

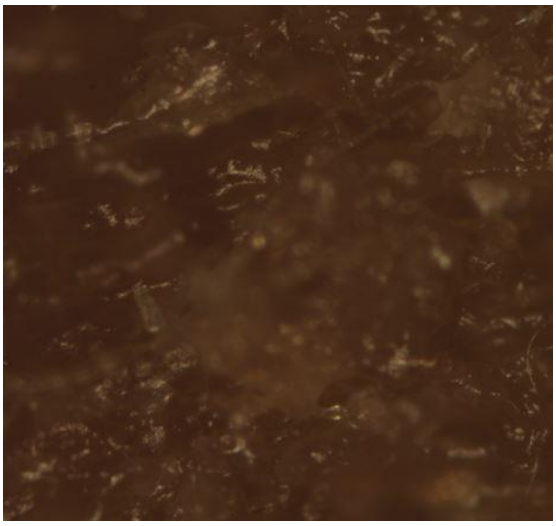
Result on 50X/0.7HD magnifying lens

Figure 25: The surface finishing of UPMFORMIGP40 and PS (50/50) specimen on all magnifying lenses

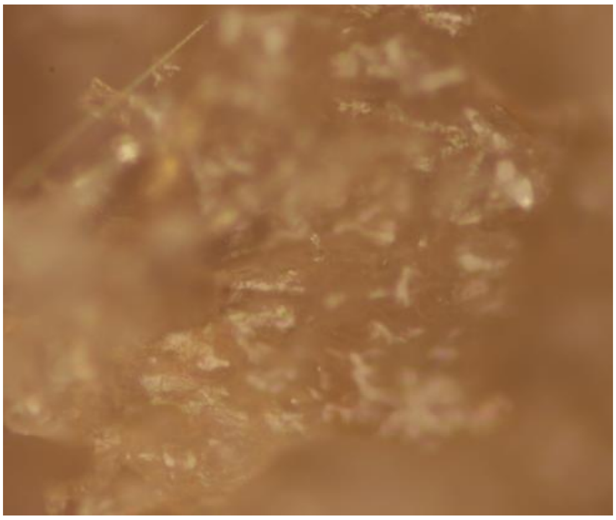
Result on 5X/0,13HD magnifying lens



Result on 10X/0.2HD Magnifying lens



Result on 20X/0.4HD magnifying lens



Result on 50X/0.7HD magnifying lens

Figure 26: The surface finishing of UPMFORMIGP40 and HDPE (50/50) specimen on all magnifying lenses

4.2 3D Printing

The result discloses the polymer composite filament (mixture of UPMFORMIGP and thermoplastic) obtained from extrusion is printable with the 3D printer machine. However, the result obtained is not as expected. Air humidity, Moisture, variation in filament's diameter, breakage of filament during extrusion could affect the result.

Figure 27. Throated box sample printed by Makerbot 3D Printer

5. DISCUSSION

The aim of this thesis work was to make a product by 3D printer using the natural fibre composite materials. Even though, the work was successful; the practical result does not meet the expected result. There were few obstacles during the extrusion moulding and 3D printing process. The problems during the process occurred due to various reasons. On the beginning, the researchers has only basic knowledge on appropriate drying time and proper barrel temperatures. The inappropriate drying and processing of the fibre could have degraded its properties, which affects the mechanical strength of the final product. Secondly, rather transporting granulates of the fibre composites directly from the dryer into the hopper of the extrusion-moulding machine; it was stored for certain period of time, which might also change the properties of the material. Since, dried fibre composites are highly hygroscopic in nature and can easily absorb humidity from atmosphere, it deteriorates its properties if special care is not done while storing. Apart from these things, there were also difficulties in maintaining the smooth flow of the composite granulates through the hopper.

In addition, the physical mixing of the materials might result deviation in the properties of filament.

Natural fibre composites granulates, especially UPMFORMI gp40 were quite large compared to plastic granulates and had significantly big impact during flow through the hopper to the barrel of the extrusion moulding machine. The hopper of the extrusion machine has narrow neck which made the smooth flow of granulates quite difficult and as a result, the machine could not prepare enough consistency. This resulted an incomplete formation on diameter of the filaments. To carry out any such natural fibre composites extruding in future, the hopper system with larger neck diameter should be replaced or granulates of composites to be ordered has to be relatively smaller or the extruder with bigger diameter should be used.

During the 3D Printer process, the feeding of the filament was not smooth. Sometimes, the irregular pulling of the filament results in the breakage of filament, which hinders the work process. The breakage and sticking of the material in the hot end section of 3D printer makes the printing work difficult. Hence, the further experiment was done in Aalto University laboratory with the Makerbot 3D Printer machine, which have both pulling and pushing mechanism of filament.

Furthermore, the fluctuate surface finishing of filament was as observed from the microscopic view.

The research was intended to provide brief and positive information to all the plastic students about natural fibre composites and the production technique using extrusion-moulding machine. The result of this study not only points out the advantages of natural fibre composites 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 optimize processing condition of the composite material as well as the operating condition regarding 3D printer. One could also examine the compatibility of the materials as well possible additives and compatibilizers to enhance the composite properties

6. CONCLUSION

The results acquired from the project was not fully satisfiable as the objective were not fully fulfilled. The end result deviates from the expectation. However, the different practical and production steps were executed somewhat successfully and it was shown that there is a good possibility that UPMFORMIGP 40 can be mixed with thermoplastics and extruded for the production of filament. This kind of project might need some extrusion consulting and more knowledge regarding compounding. The extrusion process was relatively demanding due to the lack of extruding experience and the new materials.
The major conclusive results that were made during the thesis work are discussed on the following steps:

1. Natural fibre reinforced composites can be produced from different using extrusion moulding technique, the technique that is commonly used in thermoplastic product manufacturing. The fibre material and the thermoplastic added during manufacturing process clarifies the properties of the NFCs as well as its percentage composition also change the behaviour of the polymer composite.

2. Natural fibre composites are flammable and goes thermal degradation at high temperatures so, the barrel temperatures should not exceeded 200 °**C**.

3. 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.

4. Several trials carried out during the production of filament out of NFCs presented the fact that NFCs can also be easily processed in the extrusion moulding machine with a good knowledge of moulding parameters.

5. UPMFORMi GP was the good composite material to produce a filament.

6. Though there were some obstacles with the filament for the use on 3D printer which was available on the Arcada UAS lab, we were able to able to have some successful experiments in Aalto University lab. Thus, my knowledge on the properties of the filament and the personal experience I have gained during the experiment, I can easily conclude that a new product can

be printed through 3D Printer using the polymer composite. Therefore, I recommend using UPM ForMi GP40 composite for production process in extrusion moulding machine and 3D Printer.

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