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RECYCLED THERMOPLASTICS AS RAW MATERIAL FOR 3D PRINTING

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D. Sc. (Tech.) Marko Hyvärinen

ABSTRACT

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Recycled thermoplastics as raw material for 3D printing

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Keywords: 3D printing, FDM process, mechanical properties, recycled materials

This thesis aims to use the recycled plastics in 3D printing, then comparing the mechanical properties between the different materials. The main mechanical property compared is tensile strength.

Different methods of 3D printing are introduced in this thesis, but in the experiments. The recycled materials and their combination with cellulose are to be printed using FDM technique, tensile strength testing are using standard of ISO 527, and then comparisons are made between different materials. Finally, analyze the testing result and give conclusion about the reliable factors that influence the properties of 3D printed plastics.

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Chen Xiaoyi
Lappeenranta

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LIST OF SYMBOLS AND ABBREVIATIONS

d_L	Elongation [mm]
d_0	Original length [mm]
E_{mod}	Elastic modulus [GPa]
F_{break}	Force when material breaks [N]
F_{max}	Maximum force [N]
v	Coefficient of variation

ABS	Acrylonitrile butadiene styrene
CAD	Computer aided design
FDM	Fused deposition modeling
PLA	Polylactic acid
PS	Polystyrene
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
SLA	Stereo lithography

1 INTRODUCTION

1.1 3D Printing Background

3D printing is acknowledged as AMRP (Additive Manufacturing Rapid Prototyping) or SFF (Solid freeform). About the principle of 3D printing, firstly, based on application, several of materials can be selected, such as plastic, ceramic and metal. Then the selected materials are joined together layer by layer quickly approaching mainstream adoption based on 3D model, which is a highly flexible processing technique. (Stansbury & Idacavage, 2016, pp. 54-64.)

However, 3D printing mainly applied in the manufacture of polymeric parts and models. Because of the ability to choose accessible polymers and usage of its advantages. This technology can make objects in a decent geometric accuracy by adding materials while reducing waste. The process always start with using CAD (computer-aided design) software to create a meshed 3D model by acquired structures or image data. Then a STL (Surface Tessellation Language) file is designed before the meshed file went into a 2D layers and sent into 3D printing machines. In the past decade, there is a dramatic grow in the accessibility of 3D printers for industrial use as well as common use in public, and there are many Thermoplastic polymer materials and thermosetting polymer materials could be used in 3D printing, such as polylactic acid which is always known PLA, ABS acrylonitrile butadiene styrene which state as ABS, polycarbonate which state as PC and epoxy resins. The Figure 1 shows clearly the typical materials that used in 3D printing, and different printing technology choosing depending on the materials properties and patterns. In figure 1, the materials pattern is divided into liquid resin, polymer power, polymer filament and polymer films, those patterns of materials match to different techniques. For example, the thermal polymer filament are suitable using FDM technology while optical polymer power should use SLA or DLP processes. (Wang et al. 2018, p. 7.)

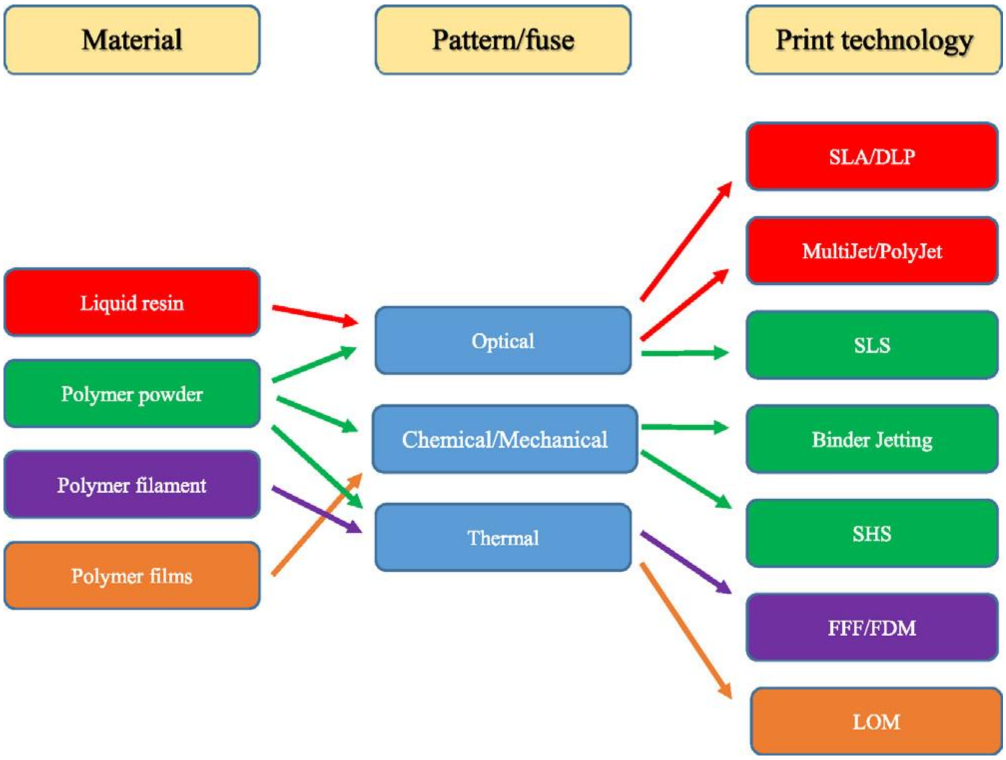

Figure 1. Materials and patterns for different printing technology. (Stansbury & Idacavage, 2016, p. 55.)

The Numerous printing techniques can be applied to fabricate polymer composites. There are some methods in 3D printing are well progressed, such as selective laser sintering and fused deposition modeling, inkjet 3D printing, 3D plotting and stereolithography, but there are still some other technologies need improvement and only small groups of researcher or company are using them. In generating composite objects, every technique has its own advantages and drawbacks. When selecting printing techniques, materials, processing requirements, cost, resolution and performance requirements should be considered. There are many different 3D printing techniques which is summarized in Table 1. The table 1 gives conclusion of the principle, advantages, disadvantages and typical polymer materials for common 3D printing techniques. The summary shows in table 1 compared established rapid prototyping techniques distinctly. (Wang et al. 2018, p. 7.)

Table 1. Comparison of different prototyping techniques. (Wang et al. 2018, p. 7.)

Techniques	State of starting materials	Typical polymers	Working principle	Advantages	Disadvantages
FDM	Filament	Thermoplastics such as PC, ABS, PLA and nylon	Extrusion and deposition	Low cost, good strength, multi material capacity	Anisotropy, nozzle clogging
SLA	Liquid photopolymer	Photo curable resin(epoxy or acrylate based resin)	Laser scanning and UV introducing	High printing resolution	Material limitation, cytotoxicity, high cost
SLS	Powder	PCL and polyamide powder	Laser scanning and heat introducing	Good strength, easy removal of support powder	High cost, powdery surface
3DP	Powder	Any materials can be supplied as powder, binder needed	Drop-on-demand binder printing	Low cost, multi-material capacity, easy removal of support powder	Clogging of binder jet, binder contamination
3D plotting	Liquid or paste	PCL, PLA, hydrogel	Pressurized syringe extrusion, and heat or UV-assisted curing	High printing resolution, soft materials capacity	Low mechanical strength, slow

1.2 3D Printing Methods

The earliest and the original 3D printing methods is SLA (Stereo-lithography) which is started in the year of 1984. Hideo Kodama, a Japanese researcher, first came up with using UV (ultraviolet) light to cure photosensitive polymers at the modern layered access to stereolithography. The process of Stereolithography using an UV laser on the photopolymer resin to complete the additive manufacturing. Manipulating this process start with designing a pre-programmed shape on to the photopolymer vat surface as well as the help of software computer-aided design which is known as CAD as well as computer aided manufacturing which is known as CAM. Because being sensitive to UV light, the photopolymers will form a single layer of the designed 3D product. Before the 3D products finally finished, this process will be repeated. (Chua et al. 2003, p. 52.)

The most common materials applied in SLA are epoxy resins and acrylic. There are many possible factors could influence the quality of the final printing products, such as power intensity, speed of scanning and exposure time, so it is important to understand the curing reactions during the process. SLA printing technology can print high quality component, which is its biggest advantage. In addition, the nozzle-blocking problem will not happen in SLA printing because this technology is nozzle-free. But SLA still have some drawbacks, when applying in the industrial market, the high price of the system always is the main worry, at the same time, Despite these drawbacks, another main concern for application in industry is the high cost of this system. Moreover, another problem is uncured resin and probable toxicity of left photoinitiator. (Hamod, 2018)

SLS (Selective laser sintering) is a common manufacturing technique in 3D printing market. In the SLS printing technology, nylon or polyamide are always used. Using a laser to sinter material which are powered and then building a solid object. The laser scan cross-sections of a 3D digital object part, always from CAD file or other scan file, on the power bed surface and then select to fuse the powdered material, the laser involved is a high power laser, such as a carbon dioxide laser. The materials could be metal, ceramic, small particles of plastics or glass. Every cross-section will be scanned and the new layer of material will bring into the top after the thickness of the layer decreased. The whole process will be repeated until the whole object finished printing. The quality of the object is influenced by laser power, the size of powder particle, scan speed and scan spacing. (3D Print HQ, 2018)

FDM or FFF (Fused deposition modeling or fused filament fabrication) was first introduced in 1990s. FDM commonly use preformed polymer as the operating material, which is like SLS technique. However, in the FDM process, there is a pre-deposition stage to melt the polymer material and then put the melt material into a print head or nozzle. The figure 2 shows the main process in FDM technology which are filament pass through heated nozzle. (Cui et al. 2008, pp. 655-661.)

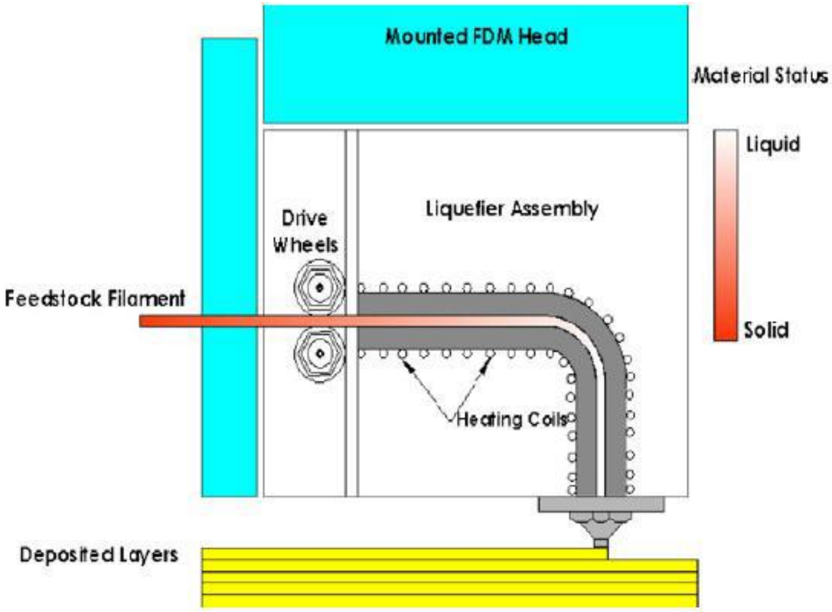

Figure 2. Main process in FDM process- filament through heated nozzle. (Cui et al. 2008, p. 660.)

Apart from need mold, this technique is comparable to traditional extrusion or injection molding, and there are heated building units whose character is reduce the thermal distortion. The FDM technique have many advantages compared with the SLA or SLS methods because it produce larger anisotropy, as well as its potential for remaking the design step. Moreover, over the last few years, FDM has been paid more attention in the science because it can achieve easy and quick manufacturing. The branded material extrusion process can shape complex objects and without limitations in the geometry. Furthermore, it can be used many different applications of prototyping or tool manufacturing, for example, aeronautics market, automotive engineering application, construction or medicine market. Because there are many available materials could be used in FDM. This technology has become the most popular additive manufacturing techniques recently, and there are a wide range of materials which can be used including polymer and composites. FDM technology has many benefits; first, this technology is clean, easy to use and office friendly, which can be used in small space and meet demand for small company and laboratory. Second, the thermoplastics printed by this technology are always mechanically and stable. Third, this technology make complicated geometries and shapes possible and practical. (Isa et al. 2015, pp. 8-12.)

1.3 FDM process

In this study, FDM is the main technology in use. FDM is developed by S. Scott Crump in the late 1980s. The Stratasys Company make FDM technology (Fused Deposition Modelling) commercial in 1990. (Chua et al. 2003) After decades of development, FDM technique has come to be one of the most common rapid prototyping methods and been applied in many different area. Basic principle of FDM is fuse fiber material deposition on a drop-down stage. There are many materials could be used in FDM technology, among them ABS is the most common on, include PLA, Polyphenylsulfone (PPSF), ABSi, polycarbonate (PC), PETG, Ultem 9085 and mixtures, even new materials such as composites are possible to be used in FDM. These materials with some specific properties such as heat resistance could be applied in some unique area, for example, Ultem 9085 is suited for aviation application. Lots of researchers and institutions have been working on expending the application of FDM technology and making the FDM process better. Novel metallic and ceramic materials is on the development because it can meet some certain requirement of the market. (Hiller & Lipson, 2009, pp. 137-149.)

1.4 3D printing materials

There are many materials can be used in the 3D printing technology including plastics, metals and wood. Different materials have different properties and printability.

1.4.1 Plastics

Polylactic acid

PLA is a comparatively new polymer plastic, which always extract from biological materials such as cornstarch and sugarcane so this material is biodegradable. PLA melts at the temperature between about 180 and 200 degrees that is alike to biodegradable packaging materials, but there are still other materials and mixtures are added into the PLA in order to improve its properties. After melt, PLA cool down fast and then an opaque resilient material is formed. However, on the property of heat tolerant, ABS is better than PLA. When the temperatures is over 60degrees, the PLA will smell like popcorn being microwaved because it being heated. (Anderson, 2017, pp. 110-115.)

Comparing with other 3D printing materials, PLA have the biggest advantages that is suitable for low-cost 3D printers, and PLA can stick to the surfaces easily so make the manipulation simple than ABS. When using the white glue or blue painter’s tape at the printing process, PLA stalk on the machine base well, that mean there will not be a demand for a heated print bed. PLA is environment friendly like other sugar-based materials and can be decomposed by many typical bacteria eventually but the decomposition process need many years on the nature environment and it will break down only in the positon of buried. PLA have some drawbacks on the application of food industry because it not safe enough to touch with food straightly and when being heated, PLA properties is not steady. Under press, PLA could be brittle, and some companies add chemicals to make it stronger and improve tolerance to heat, that is called tough PLA. (Murariu & Dubois, 2016, pp. 17-46.)

The usage of PLA can be very wide. Application of PLA include stitching and suturing in medical, which is at the professional area, as well as in surgical implants. The forms of implants can be mesh, screws and pins. PLA can be used in medical due to its degradable characteristic. According to the printed objects’ position at human body and its purpose, the PLA will break down within two years. PLA are also suitable for use in consumer products. PLA can be printed faster than ABS and the heated printing bed is not necessary, at the same time, the product being printed by PLA always have decent impact resistance property and durable property. Food packaging and disposable tableware are other examples of application of PLA. (Team, 2018)

Polyvinyl alcohol (PVA)

PVA is a synthetic polymer, which belongs to the new 3D printing materials and being commonly applied as making object support. The melting point of PVA is around 200 degrees, when being heated to over 200 degrees; some noxious chemicals can be released. The properties of PVA is various, such as PVA is suitable in the application of biodegradable products because after using, PVA can be dissolved and do little harm to the naturel environment. Examples can be find as medical equipment and fishing lures. One of the reason of PVA is usually chosen in 3D printing is its property of water-soluble. (Angjellari et al. 2017, pp. 12-21.)

The process started with melting PVA material on a heated, glass printing bed, the melting PVA can stick on the bed well and form the supporting part in order to help backing the designed objects. After the designed objects is completed, the supporting part, that is PVA part, will dissolve within the water and leaving the wanted parts behind. In this way, researchers and companies can make complicate 3D printing objects, even the object need supporting or require moving parts. However, using water to deal with after-used PVA can have a problem that is the dissolved material can block drains, so before using check the professional water company in the local community. But the biggest advantages of PVA still is water soluble making it easy to printing and suitable for printing objects with supporting parts. The disadvantages of PVA is can release harmful gas on high temperature, needs safe disposal high cost. Application of PVA varies from paper adhesives to personal hygiene products. (Tymrak et al. 2014, p. 242.)

Acrylonitrile Butadiene Styrene (ABS)

ABS is a lightweight thermoplastic which is generally applied in injection molded and extruded. Comparing to HDPE, ABS has better properties in mechanic. Comparing to PLA, ABS is less brittle and needs less strength to extrude because of its low friction coefficient. In addition, ABS is easy to buy and the characteristics make it fit on small 3D printing part. In the application of extruders, PLA can handle high temperature. ABS is inexpensive materials and it is very flexible and lightweight. In the 3D printing market, ABS is one of the most favored material as well as in keen armatures area. The disadvantages of ABS is that it requires higher temperature, is about 105 degrees, when being extruded. 230 degrees is the standard temperature for ABS printing. In fact, there is no melting point for ABS because it is amorphous. ABS is petroleum-based material which make it cannot be biodegrade. In poor ventilated environment, ABS can create unpleased smell. Traditional manufactures use ABS in plastic wrap, bottles and cups. As applied in 3D printing, ABS can be printed for automotive objects, children toys, kitchen objects and instruments. (Tymrak et al. 2014, p. 246.)

Nylon (Polyamide)

Nylon is started to be used because of replacing silk and nylon is a very tough material with high tensile strength. To use nylon in 3D printing requires high temperatures and the objects made from it can stand heavy weight and there is no chemical reaction between nylon and most common chemicals. Therefore, there are an increasing researches doing on applying this material on 3D printing. On the other hand, using nylon in printing is a rather new attempt but nylon has many advantages such as high tensile strength, durability and innocuous and the products being printed are tough and not easy to break which provide with high quality. Most importantly, nylon is inexpensive and have been applied in many other industries already. It is especially suited for consumer applications, containers and mechanical components. However, nylon does has downsides; the biggest problem is when printing, nylon is hard to stick to the printing bed and requires high temperatures than other 3D printing materials. 250 degrees is the needed temperature, many extruders cannot get to this high to print. (Mehat & Kamaruddin, 2011, p. 1989.)

High-density polyethylene (HDPE)

HDPE sometimes is known as HIPS. HDPE is a light material, and HDPE can be recycled when it is used in packages or plastics. The melting point of HDPE is about 230 degrees, if the temperatures get to higher, it can produce nasty gas. Nevertheless, easy dying and molding make HDPE suitable for 3D printing and it flexible to stick well on other materials. (Lei et al. 2009, p. 1719.)

Comparing HDPE with ABS in 3D printing, the biggest advantage of HDPE is its light and strong properties. Moreover, HDPE can resist to common chemicals witch make the products have steady quality. However, when ABS being printed, high temperatures are needed and sometimes can release unwanted vapors if temperatures get over high. The advantage of HDPE is that can be dissolved by industrial cleaner, limonene. The product printed by HDPE can have warp problem, because when the material cools, it contract lightly in different part. (Dikobe & Luyt, 2017, pp. 40-50.)

HIPS Filament

High Impact Polystyrene (HIPS) is a bright, white colored material. This material is biodegradable so in some extend is safe and do no harm to consumers and to whom in close contact with it. Similar to PVA. HIPS filament are suitable to works as supporting objects, and HIPS can be printed in the no heating bed printers. Because it works as supporting structure, so it can be dissolved by liquid hydrocarbon quickly. As application in 3D printing, HIPS is the most generally used materials for other filaments. HHPS can also be used in other industries such as food packaging or medicinal trays. (Parandoush & Lin, 2017, pp. 36-53.)

1.4.2 Metal Filament

Metal filaments are combination of PLA with metal powers. Using some kind of polymer glue to stick the metal to the PLA, which make the metal filament, can be printed in the same way as PLA except it looks like metals. Metals such as steel, brass or bronze are all suitable in 3D printing to make the look. Adding the metals to PLA can change the properties. Although common printer which suit PLA can printing these metal filament, some specific requirements also need, such as in order to develop satisfying metal appearance, a good sanding is need. When printing metal filaments, there should be right setting on the printer, different from PLA, to make sure the print succeed. Because the metal filaments are combined with PLA and glue, so the weight is not as heavy as the original metal, and the finished printing object is lighter than solid one. Most of the metal conduct electricity, but the metal filament are not, because the PLA and glue are separated in the material. As application, metal filament is suited for statues, hardware objects and jewelries. (Barui et al. 2017, p. 120.)

1.4.3 Others

Wood Filament

Wood filament is made from PLA or other polymer and suitable wood powders or particles. The name can be misleading to regard wood filament as pure wood material. Instead, the combination of wood and polymer make the filament can be print and polished, at the same time, the look of wood. There are many different types of woods and polymers can be combined together according to the object requirements, such as mahogany, bamboo with PLA, the looks of wood make the printed products more popular and charming which is one of the biggest advantages of these materials. (Kariz et al. 2018, p. 138.)

These wood filaments can be printed as PLA material. When being printing, there is a need for white glue to stick the material to the print bed by using the same machine as printing PLA filament. In some particular wood filament, the temperature should be controlled in order not to change the color of the material, because the appearance of the wood particles get to dark when temperature is too high. Adding wood powers to the PLA make some changes to the printing process and requirements and different wood may have different requirements. Before the wood filaments put into use, a lot of test should be conduct to make sure the successful prints, sometimes there are more work to get a fine wood look, such as good abrasive treatment and sanding based on wood types which increase the working load. (Huang et al. 2018, pp. 11-21.)

Carbon Fiber Mix

The principle of carbon fiber mix is combination of different printing materials such as PLA, ABS with some carbon fiber. Generally, using glue to stick the carbon fiber particles to other printing materials. After adding carbon fiber, the material have better properties, like good rigidity and toughness. At the same time, it have quite low density. However, carbon fiber mix has a problem; it may damage the extruder machine, because it is a very abrasive filament and can wear the extruder end after a few prints. Therefore, there is a need to get extruder replacement. Therefore, the production process can be higher than other materials. (Kariz et al. 2018, pp. 135-140.)

1.5 Markets & Products

1.5.1 Markets

The purposes of using 3D Printing technology include accelerating the process of products, providing products according to customer's desire and improving flexibility in production. 3D printing also make it possible for customer to co-design with manufacturers, at the same time, reduce cost, and advance product costs. More and more companies invest in 3D printing market in order to make it a unique strategy as their advantage. Some companies states their funds on additive manufacturing is continuing growing in the following years. (Forbes, 2018)

Food Sector

3D printing applying in food sector has been boosting in recent few years. There are many advantages of three-dimensional food printing including made-to-order food designs, unique nutrition design, make the raw food materials supply chain simple and clear and extend the current food sources. Nowadays, the scope of 3D printing using in food sector is varied from military, space food to elderly food and other food area. A fine and successful food printing require the accurate printing technology. Applying this technique in food can achieve some complicate and charming food, which now only can be made by skillful chefs. Moreover, precise printed food are more possible get customers satisfactory because human labor sometime misunderstand the requirement from consumers while printing machine is less made mistake. When using 3D food printing, the whole supply chain is simpler and clearer comparing with traditional food manufactory. Through this technique, more application of this technology make the distance between customers and manufacturers closer, which will decrease cost in transportation and package.(Liu et al. 2017, p. 90.)

Conventional food source like insect, plant and animals based material can be replaced if using 3D food printing technology so broaden the source material. Besides traditional food area, some special food sector have been using this technique including space food and confectionary market. (Liu et al., 2017.) Making a successful 3D food printing depend on mechanic bind and materials. In recent years, there are many companies and researchers want to get the 3D product have end-use properties comparing with conventional ways and want to make more profit than traditional producing way. However, nowadays there are still a need to combine AM technology with conventional manufacturing process, and there are still many difficulties to defeat. (Godoi et al. 2016, p. 48.)

Biological matters

A 3D printer can make bio-printing products by using biological materials such as cells. Normally, the process of biological printing is producing the object layer-by-layer because most of the biomaterials are tiny and complex. The proper dimensional control of biomaterials make it possible to print 3D tissue objects like skin, bone, muscle and so on. (Oliveira et al. 2015, pp. 842-855.)

In selection of materials, 3D bio printing is far more complicated than ordinary 3D printing. Because biomaterials are more sensitive and usually need a specific printing environment to make sure the cell growth or living cell activity. Bio printing depend on accurate layer-by-layer deposition and condition of materials. Inkjet, micro-extrusion and laser assisted printing technology are common techniques. (Munaz et al. 2016, p. 17.)

Cultural Heritage

3D printing technology offer the opportunity for researchers to analyze and repair cultural assets. Moreover, except repair and analyze, this technology can be used for many other purposes: study, diagnosis, formation, education, protection of heritage. This technology allows a quick and precise production of a heritage or a spare part of it, which is rely on the solid printing. Moreover, the copy of complicated figures can be put into use in many different areas, at the same time, avoiding doing harm to the original model and inexpensive. (Balletti et al. 2017, p. 179.)

Clinical & Hospital Applications

3D printing applied in many areas, healthcare is one of them. Some specific areas include Cardiology and Cardiothoracic Surgery. (Schmauss et al. 2014) Applications of 3D printing are for pre-surgical arrangement, instruction of operation and implants of patient. Although there are more application for education to patients and physicians using models printed by 3D printing, challenges are still exist including legal regulation or financial restrictions. As the printing technology advanced, more surgeons tried to use this technique for hospital treatment, so as to radiologists, there are many advantages applying 3D printing in the field. The main work of radiologists are acquire suitable image and analyze medical images and some of the images are printed as 3D printing models. If more radiologists and surgeons apply 3D printing technology in their work and it is possible for them to push the technology become more precise and make 3D printing take part in the emerging area and patient care more directly. (David et al. 2018, pp. 52-65.)

There are more investigation in 3D printing in recent years, and as the development of this technology, the cost has decreased and more capabilities is formed, so make it possible to apply in many areas. Image manipulation is the most core work of 3D printing basically, but now in many country, the main pushing force are from specific surgical experts. Therefore, there is a phenomenon that 3D printers run and confine separately in different departments. However. 3D printing technology are playing more important role in radiological scientific. (Eley, 2017, p. 271.)

Applications in oceanography

As 3D printing technology improve its capabilities and low costs, there are more field can using this technique including automobile components market, medical treatment, space area, robot science. Etc. Nowadays, a new opportunity is forming to utilize this technology in oceanography. Some 3D printed components, which is used in motor or vehicles underwater are good examples. it is known the health of the ocean system can be demonstrate by whales, and because of decreased cost and advanced robotic science, there is possible for researchers to get better cetacean observation and long distant sample collection in unsafe sea environment. (Gibson & Shi, 1997, p. 131.)

Recently, there is a development of printing components for multirotor SnotBot UAV, the 3D printed legs and frames are putting into the airtight place witch containing electronics. Relying on that, scientists can gather data and samples from living creatures. More examples can be found on a similar mobile manipulation with a printed hand that also being used underwater. (Cho et al. 2005, p. 162.)

Scientists and researchers are now trying to utilize extent the application of 3D printed components in oceanography, application contains vehicle or motor surface and sometime underwater. Collecting image and data from living marine creatures is more likely to happen and give biologists opportunity to observe accurately. Allowing 3D model escalate creature organisms to get higher Reynolds number is an important superiority of 3D printing technology. In this way, researchers can get to know the changes and influences to ordinary organisms at high flow marine environment. At the same time, researchers can mime more specifics of ocean creatures. More researches and experiments conduct relating to 3D printed technology can reduce the whole cost and improve vehicles speed. Fluid flow at internal parts of marine creatures can be easily observed though 3D printed products. (Mohammed, 2016, p. 100.)

1.5.2 3D printing products

3D printing, or additive manufacturing, can print three-dimensional products including prototypes and assembly parts by using the layering method of materials. As the technology developing, there are more possibilities to convert the digital image into solid object. Applying the 3D printing technology in many different areas, personalized products in a short time is becoming popular. This technology provides more personalized and more competitive products to consumers. Several products being produced by 3D printing are list below. (Tuan et al. 2018, pp. 172–196.)

Phone Cases

Phone cases are one of widely produced products by 3D printing technology. Customers can order a special, unique and innovate phone case in the internet or online shop. After ordering, consumers just wait for several days and the personalized phone case can shipped to their home. In the design process, customers are provided with many options to select their own design. Options include color, text, patterns and images. Customer can observe different angles of the phone cases using the 3D model computer program. In the 3D model program, it is possible to zoom in and out to see the details and panoramic of the cases. In the Figure X, it is an example of designing phone cases, in which a name or text can be added at both sides of the phone cases. (All3DP, 2018)

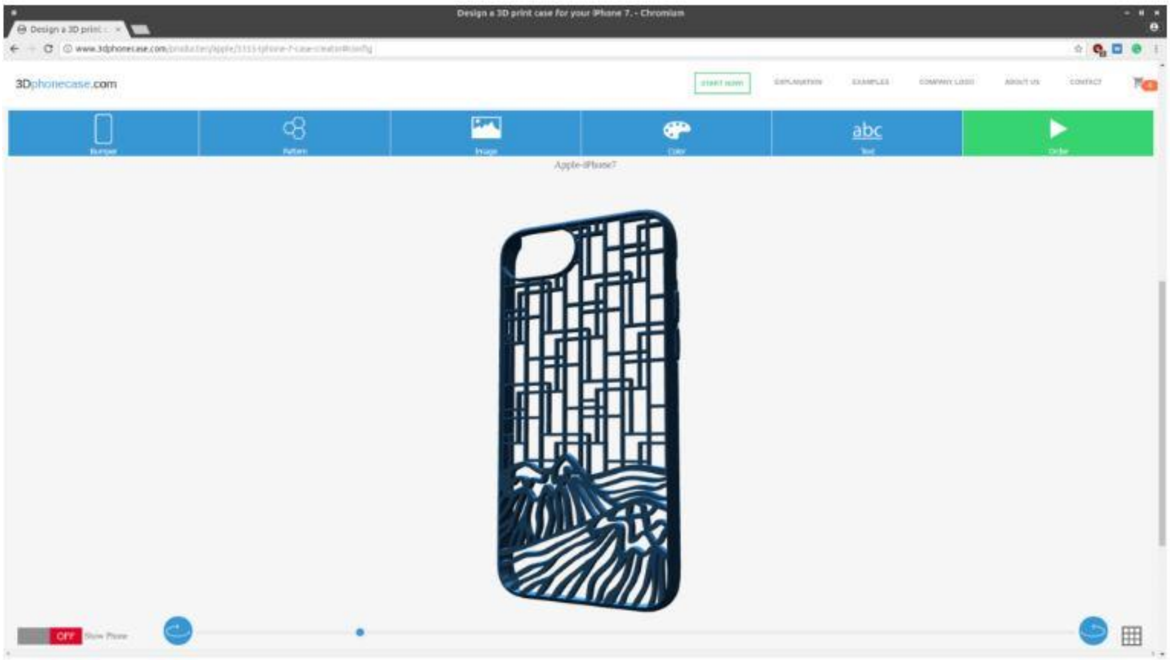

Figure 3. 3D printing of phone cases. (All3DP, 2018)

Furniture and house

3D printing technology can print not only small objects, but also larger products. Furniture is one of them. In furniture market, a new fashion is utilizing old fridge materials to make new personalized furniture. There is some collaboration between MIT Lab and global furniture company; they create a rapid liquid printing program, this innovation of 3D printing make it possible to produce large, custom furniture within a short time. The process contains liquid materials including rubber, foam, plastics. Using gel to combine those materials and harden by chemical interaction. (O'Neal, 2018)

In the last few years, engineers and researcher have been working on the construction of house and structures of buildings. The 3D printer for houses are bigger than the normal printers, and the materials is more thinker comparing to common concrete. Using 3D printing technology has less limitations of building constraints. Sustainability can be increase because building materials can be evaluated about its life cycle and choosing more sustainable materials is possible. (Sakin & Kiroglu, 2017, p. 706.)

3D Printed Organs

3D printing technology use patient's own cells to make the organs, which has vital meaning in the medical area. Traditionally, patients have to wait for a long time for organ donor, and the implanted objects always made by human hands, the whole process will take a long time and in some cases, patients cannot wait for so long which will influence the cure period. 3D printing applied in this area reduce the time and improve the process to produce the desired organs. The process started with printing scaffold and then it will be coated with the living cell. More researchers are putting effort on the artificial scaffolds, and they want to print the living cells at the same time, which is another way to reduce the time that patients should wait. (Munaz et al. 2016, p. 12.)

Toys

In the toys market, 3D printers are provided to schools and some laboratories by some companies which is in order to introducing 3D printing technology and building 3D labs at the same time. In this way, companies also can expanding their market share. In the labs, children and students of different ages can make toys by their own thoughts and interests, for the equipment is accessible around the world, and there is a huge demand for toys, especially in this new ways of producing it. 3D printing can create complicated toys in the simple and easy manufacturing way and more attractively, some companies provide novel toy apps to people to build their own toys by 3D printing, which have more than 150 options being provided. Producing toys by 3D printing have many benefits, besides offering the opportunity to children to engage in the 3D printing process, 3D printing technology can involve in the daily life and people can learn more about this technique more and make life more innovative. (Indiegogo, 2018) Different forms of toys is possible to achieve by setting up the 3D printer program. The figure 4 is showing an example of a 3D printed toy which use the material of PLA. (Support.office.com, 2018)

Figure 4. 3D printed toys. (Support.office.com, 2018)

More 3D laboratories are built around the world, and there are also more children make their own toys through 3D printing. However, the cost for building a personal 3D printing toys is quite high, as the technology developing and more customers forming, the cost will reduced very soon. (Dredge, 2018)

Cars

3D printing technology can be applied in not only small items, but also big objects such as cars. Some designers have been thinking applied 3D printing technology in car production, and they succeed. In the car market, there are more customers are interested in 3D printed cars because it has many advantages including safety, fuel efficiency, low cost in maintenance. Additionally, Consumers can provide their idea on how the cars looks like before the car manufactured and some unique looks of the 3D printing cars can attract more attention in the market. (Anon, 2018)

Body Parts

3D printed body parts have been a significant breakthrough in regenerative medicine. Archaeological science sometimes can rebuild or reconstruct human body parts, but the traditional methods have many defects. Scientists now try to implant some sections of bone, muscle and cartilage into animals and all of them are function well. The breakthrough promoting the hope of using living tissues to replace or repair the damaged human body. (BBC News, 2018) There have been some successful examples of using 3D printed body parts such as scientists and doctor used a 3D printer to make a jaw for a British woman whose old jaw was deteriorated. More applications will be implement in the following few years such as printed ears. An inspiring news about a project in which 3D printing technology can be used to make low-cost prosthetic limbs for amputees. This can change life of many amputees including war or accident victims. Human are not the only beneficiaries. Animals are also can get 3D printing arms or legs to improve their life standard. (Jang et al. 2018, pp. 88-106.)

Chocolate and other foods

The figure 3 shows the 3D printed chocolate. More complicated shapes can achieve by 3D printer. Chocolate is suitable for 3D printing because of its property of solidifying at common room temperature. The figure 5 shows the 3D printing chocolate which seems no difference with the normal produced one. Food materials like tomatoes is not suitable for 3D printing because it will flow. Other 3D printing food can be cake decorations, pizza and chickpea nuggets. 3D food printers are not only used in produce personalized food, but also in nutrition application. The nutrition application is still on research, it is believed that future 3D food printer will make the processed food more nutritious. It is predicts that 3D printed food will be able to contain desired dosages of nutrients or drugs. Consumers even can order the specific caloric of the food and diet. (Ultimaker.com, 2018)

Figure 5. 3D printed chocolate. (Ultimaker.com, 2018)

Hubble Space Telescope images

3D printing technology can transfer images into 3D objects. This means significant for blind people. Hubble Space Telescope took many amazing pictures and images of the space, blind people cannot see them. NASA states that there is a project to turn Hubble images to 3D pictures. Blind people can experience the beautiful stars, gas, and dust with touching. The astronomers who is taking charge of the project said that they want to make people to feel it with their fingers and hope they would be able to understand the important features and structures. (Dredge, 2018)

Make-ups

3D printed colored makeup. There is device called Mink. It can links to the computer, reads the color of your choice, and transfer the information to the 3D printer. The 3D printer receive signals and then mix the materials and pigments to produce the makeup. The printed makeup is entirely custom made. It could be foundations, lipsticks or eye shadows. In the future, this machine should repeat the red-carpet lip color from internet pictures; people can choose which day and which color to wear. This makeup-printing device is still at debugging period. There is another mature custom makeup offering machine called Finding Ferdinand. They are providing about 65000 color combinations. The made process is simple, consumers can submit their preferred shade or color at the website. (Trotter, 2018)

Personalized Headphones

The headphones can be 3D printed using most 3D printers and the material can be PLA which is recommended because of the good printability. There are personalized headphones in the market now, but the high cost and long producing time make it only approach for small group of people. Applying 3D printing technology in the production of headphones make it more easy and inexpensive. And the sustainability of products is promoting due to easy modular design and easy replacement of the components. (Zhao et al. 2018, p. 384.)

1.6 Aim of the study

Recent years, as the development with more attention on sustainability and advent multi-materials additive manufacturing processes, there is more needs for using recycled materials in 3D printing. In 3D printing, there are many alternative materials could be use, the main of them are PLA and ABS. As the 3D printing technology developing, more materials could be recycled and used in this field. Not only are the pure polymers become popular, but also the combinations with other materials. In this study, the aims is using the recycled polymers and their combination with cellulose in FDM technology and comparing their mechanical properties. The materials used in this thesis are the recycled PLA, ABS, PP, PVC and cellulose.

2 MATERIAL AND METHODS

2.1 Material

In this paper, the tensile test is conducted to five different portion of materials. Length of the samples were 120 mm, thickness of each sample shows on each table. Twelve specimens were measured in each recipe; in order to producing accurate and consistent experiments result, the test is often repeated. The table 2 shows the testing materials.

Table 2. The tensile testing is conducted on the below materials

Material	Explanation
PLA	Pure PLA (Polylactic acid),
PLA+10%B800 arbocel,	PLA = Polylactic acid, 10 % B800 Arbocel= cellulose
ABS + 10% B800 arbocel,	ABS= Acrylonitrile butadiene styrene
PS + 10% B800 arbocel,	PS= Polystyrene
PVC + 10% B800 arbocel	PVC= Polyvinyl chloride

2.2 Methods

Testing tensile properties in the ISO system is ISO 527, but there is another method: ASTM D638. The two measure methods do not have many significant difference and both methods could give desired results depending on the selection. These two methods can be used both in polymer films and in elastomers. (Matweb.com, 2018) Both ISO 527 and ASTM D638 can be used to test the tensile properties. The two methods are different in sample shapes, test speeds and result analysis, but both are suitble for testing polymers. (Schmauss et al. 2014, p. 1044.) In this paper, choosing the ISO 527 methods to test the materials tensile properties.

Tensile Testing of Plastics ISO 527

ISO 527 tensile testing is an main standard to test the plastic mechanical property, it gives key data about elongation of plastics, tensile strength and elongation at extent ambient and temperatures. Tensile testing measures the forece at breaking point of a specimen, at the same time, the extent to which the specimen stretches or elongates. The process of ISO 527 starts with placing specimens in the tester and then the grips pull the sample until it breaks.

In the ISO 527 testing method, the spedd for measuring strength and elongation is 5 or 50 mm/min and for measruing modulus, the speed is 1mm/min. Extensometer are needed to measure the elongation and tensile modulus. Those data from the tensile test are always used for comparision of plastics mechanical properties. (Zwick.com, 2018) The table 3 explain the main characteristics values.

Table 3. The characteristic values. (Zwick.com, 2018)

Tensile stress	force applied to the initial cross-section of the specimen
Strain	change in gage length with reference to the initial gage-length
Tensile modulus	gradient of the curve in the stress-strain diagram
Yield point	stress and strain at the curve plot point at which the gradient is zero
Point of break	stress and strain at the moment of specimen break
Poisson's ratio	negative ratio of transverse strain to axial strain

3 RESULTS

The tensile testing results and data for different 3D printed materials and their combination with cellulose are shown in below tables and figures respectively. Then the data such as elastic modulus, force at break point is compared. The details of testing condition are shown in the table 4.

Table 4. Tensile testing condition

Test standard	ISO 527
Pre-treatment	Conditioning 72h@50% rel. hum+23C
Pre-load	10 N
Speed, E-Modulus	1 mm/min
Test speed	5 mm/min

3.1 Tensile properties of experiment 1

From the Figure 6 and table 5, Figure 6 are strain stress curves of pure PLA, the curves shows the yielding point of PLA is in 2% nominal strain and Force in 195N. The E_{mod} of pure PLA is 3.37GPa, and the F at 0.2% plastic strain is 138N.

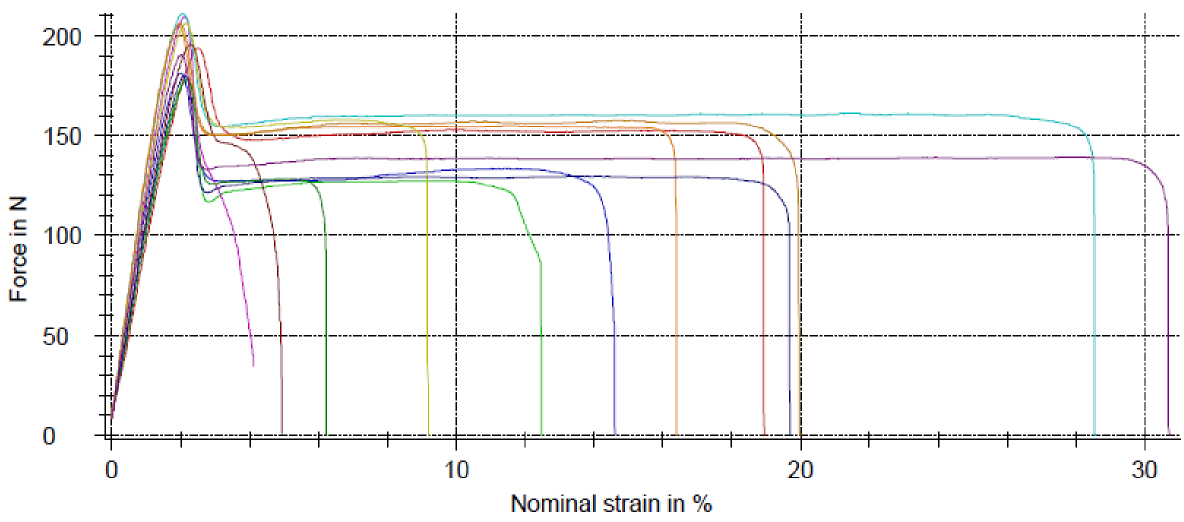

Figure 6. Strain-stress curves for PLA

Table 5. Statistics of tensile testing of PLA

Series n=12	d_0 mm	E_{mod} GPa	F at 0.2% plastic strain N	F_{max} N	dL at F_{max} mm	F_{break} N	dL at F_{break}	S_0 mm^2
x	2,255	7,78	138	195	0,5	91,3	3,8	4,01
s	0,1301	0,51	14,6	12,9	0,0	32,1	2,2	0,45
v	5,77	6,61	10,64	6,61	6,41	35,15	56,50	11,31

The stress-strain relationship is demonstrates on the graph. In the graph, the vertical axis which is y-axis represents stress while horizontal axis which is x-axis represents strain. Elastic modulus is also known as Young's modulus which can be calculate as the slope of linear part of the curve and elastic modulus is most common evaluation of linear elastic behavior for materials. It will tell what kind of extent the material can elastically stretch when being applied certain force. The linear portion of the curve shows the range of stress values that the material stretches elastically. The material can recovery if applied force do not reach the elastic limit. As long as the load reach or over the limit, the material will yield which is begin to plastically deform. The yield point often refer as yield strength, permanent deformation will occur when passing the yield point and failure of the material structure is often possible at that time. (Anon, 2018)

3.2 Tensile properties of experiment 2

From the figure 7 and table 6, the strain stress curves of PLA+10%B800 arbocel. The curves shows yielding point of PLA+10%B800 arbocel is in 1.8% nominal strain and force in 248N. The E_{mod} of PLA+10%B800 arbocel is 3.48GPa. The F at 0.2% plastic strain is 187N.

Comparing the pure PLA with PLA+10%B800 arbocel, we can see that after adding the cellulose into the PLA, The F at 0.2% plastic strain increases for 138N to 187N which means the material is stronger than pure PLA. Since the E_{mod} increase from 3.37 GPa to 3.48 GPa which indicates the materials become a little bit more brittle.

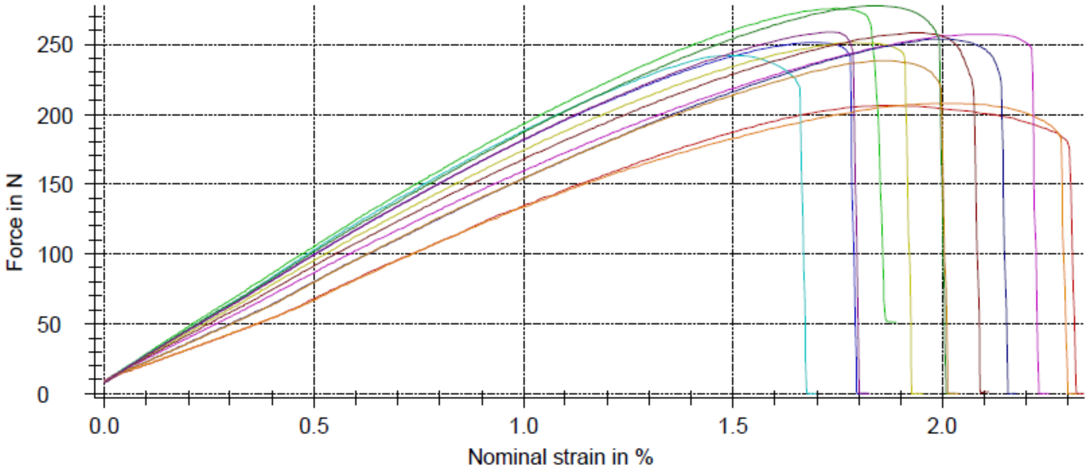

Figure 7. Strain/stress curves for PLA+10%B800 arbocel

Table 6. Statistics of tensile testing of PLA+10%B800 arbocel

Series n=12	d_0 mm	E_{mod} GPa	F at 0.2% plastic strain N	F_{max} N	dL at F_{max} mm	F_{break} N	dL at F_{break}	S_0 mm^2
x	2,756	3,48	187	248	0,4	218	0,5	5,97
s	0,065	0,19	28,3	22,4	0,0	25,9	0,0	0,28
v	2,36	5,31	15,15	9,02	8,20	11,86	9,14	4,73

3.3 Tensile properties of experiment 3

From the figure 8 and table 7, the strain stress curves of ABS+10%B800 arbocel. The curves shows yielding point of ABS+10%B800 arbocel is in 3% nominal strain and force in 153N. The E_{mod} of ABS+10%B800 arbocel is 1.06 GPa. The F at 0.2% plastic strain is 105N.

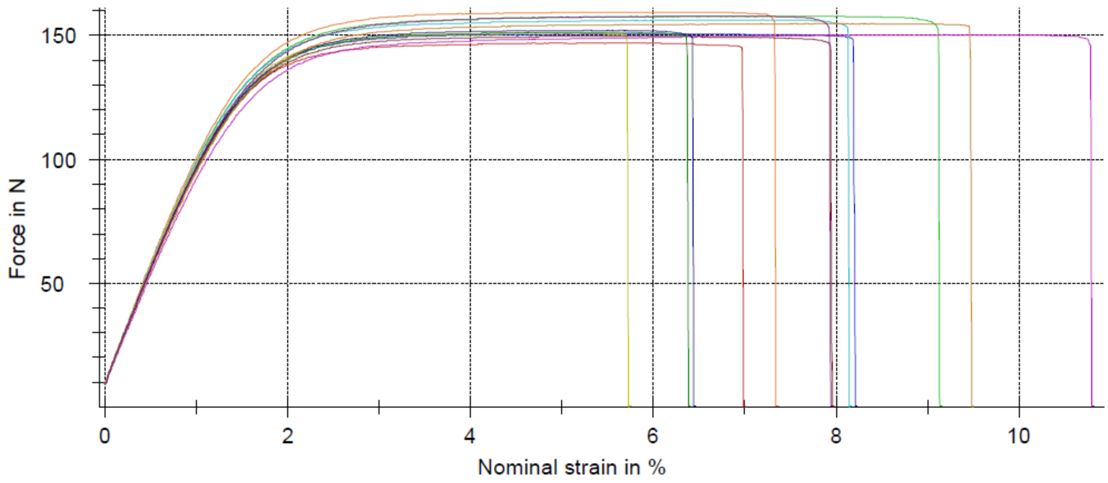

Figure 8. Strain/stress curves for ABS+10%B800 arbocel

Table 7. Statistics of tensile testing of ABS+10%B800 arbocel

Series n=12	d_0 mm	E_{mod} GPa	F at 0.2% plastic strain N	F_{max} N	dL at F_{max} mm	F_{break} N	dL at F_{break}	S_0 mm^2
x	3,62	1,06	105	153	1,6	148	2,0	10,31
s	0,139	0,09	2,87	3,96	0,3	4,94	0,4	0,80
v	3,84	8,86	2,74	2,59	19,43	3,33	18,45	7,75

3.4 Tensile properties of experiment 4

From the figure 9 and table 8, the strain stress curves of PS+10%B800 arbocel. The curves shows yielding point of PS+10%B800 arbocel is in 0.7% nominal strain and force in 41.7N. The E_{mod} of PS+10%B800 arbocel is 0.873 GPa. The F at 0.2% plastic strain is 38.7N.

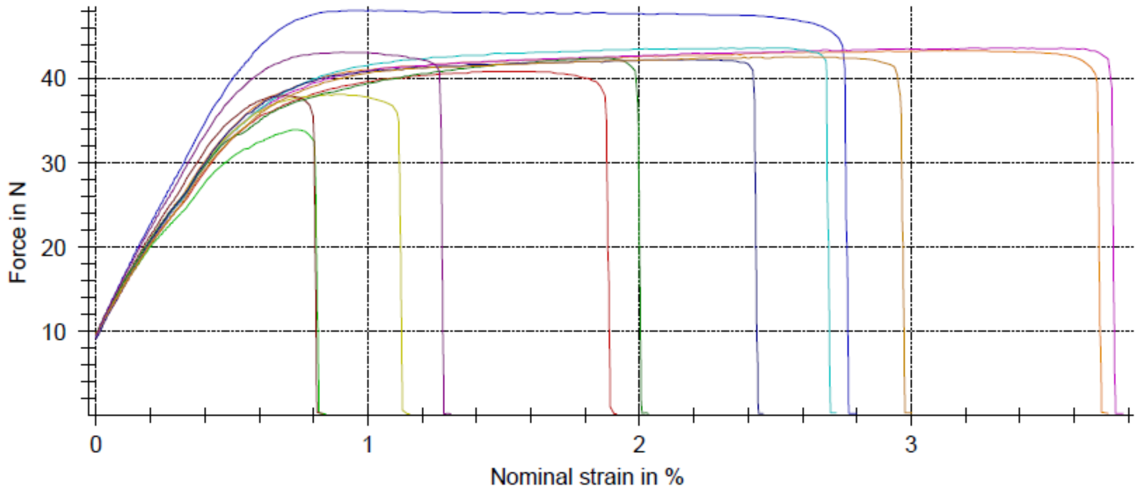

Figure 9. Strain/stress curves for PS+10%B800 arbocel

Table 8. Statistics of tensile testing of PS+10%B800 arbocel

Series n=12	d_0 mm	E_{mod} GPa	F at 0.2% plastic strain N	F_{max} N	dL at F_{max} mm	F_{break} N	dL at F_{break}	S_0 mm^2
x	3,013	0,873	38,7	41,7	0,4	38,9	0,5	7,14
s	0,136	0,121	3,31	3,60	0,2	3,26	0,3	0,64
v	4,52	13,90	8,55	8,65	56,62	8,39	48,90	8,99

3.5 Tensile properties of experiment 5

From the figure 10 and table 9, the strain stress curves of PVC+10%B800 arbocel. The curves shows yielding point of PVC+10%B800 arbocel is in 2.5% nominal strain and force in 189N. The E_{mod} of PS+10%B800 arbocel is 1.43 GPa. The F at 0.2% plastic strain is 122N.

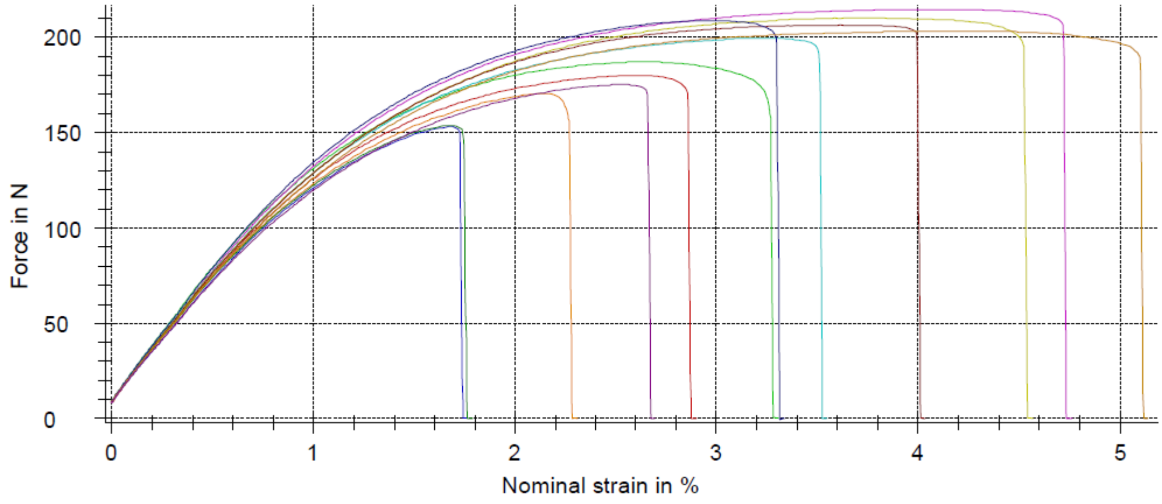

Figure 10. Strain/stress curves for PVC+10%B800 arbocel

Table 9. Statistics of tensile testing of PVC+10%B800 arbocel

Series n=12	d_0 mm	E_{mod} GPa	F at 0.2% plastic strain N	F_{max} N	dL at F_{max} mm	F_{break} N	dL at F_{break}	S_0 mm^2
x	3,811	1,43	122	189	0,7	175	0,8	11,41
s	0,104	0,06	5,31	21,9	0,2	22,0	0,3	0,62
v	2,72	4,02	4,34	11,61	30,93	12,54	34,62	5,40

4 DISCUSSION

The table 10 is the conclusion of tensile statistics for these five materials. The data to be compared are: E_{mod}, F at 0.2% plastic strain, F_{max} and F_{break}. The reason for choosing those data to compare is that the tensile strength can be easily illustrate with them.

Table 10. Statistics of tensile testing for five different materials

Material	Emod (GPa)	F at 0.2% plastic strain(N)	F_{max} (N)	F_{break}(N)
PLA	3,37	138	195	91,3
PLA+10%B800 arbocel	3,48	187	248	218
ABS+10%B800 arbocel	1,06	105	153	148
PS+10%B800 arbocel	0,873	38,7	41,7	38,9
PVC+10%B800	1,43	122	189	175

The elastic modulus can be used to measure the degree of an material deformation under certain force. The larger value mean the material need more stress to achieve extent deformation and the material has greater stiffness, at the same time, more brittle and stronger. Under same certain stress, the material with high value elastic modulus has smaller deformation. The material with low elastic modulus will deform more under extent stress which means this material is easier to deform and has smaller stiffness.

From the table 10. We can see the PLA+10%B800 arbocel has the highest E_{mod} while PS+10%B800 arbocel has the lowest E_{mod} value. Among the five materials, the stiffness from low to high is: PS+10%B800 arbocel, ABS+10%B800 arbocel, PVC+10%B800 arbocel, PLA, PLA+10%B800 arbocel. This stiffness also match with the F at 0.2% plastic strain, F_{max} and F_{break}.

The table 11 shows the tensile and yield strength for common plastics; those statistics are conducted on the pure polymer. Comparing those data to the experiments data. PLA has the highest E_{mod} value that is about 3.5 GPa and after combine PLA with 10%B800 arbocel that means adding specific amount cellulose into the PLA materials. The elastic modulus increased, and the values of F at 0.2% plastic strain, F_{max} and F_{break} are also increased. This means the added cellulose make it become more brittle and stronger.

According to Zhao (2018), there is another way to improve the tensile strength of PLA which is using PDA (polydopamine) as coating material, the study states as "the average ultimate tensile strength before failure of the specimen fabricated from PLA is 46.35 ± 1.08 MPa; it increases to 53.24 ± 1.85 MPa after coating with PDA. These data show that the tensile strength of specimen improved by about 14.9% after PDA coating. -- The ultimate tensile strength as well as the strain at break improved after PDA coating on the surface of fillets. This is a very useful finding with respect to the use of recycled polymer materials for 3D printing applications." Using recycled PLA in 3D printing can reduce the printing cost but the mechanical property of recycled material may not as good as original one, so it is necessary to improve the tensile property. Previous study show using polydopamine as coating can improve the tensile strength of PLA, in this study, Adding extent fiber/cellulose could be another choice to improve the property.

Table 11. Tensile and Yield Strength for common Materials (Xiao, 2008, p. 165, Nielsen & Landel, 1994, p. 20.)

Polymer Type	Tensile Strength(MPa)	E_{mod} (GPa)
PLA	36-64	3,5
PS	30-100	2,1-3,5
ABS	27-45	1,1-3,1
PVC	34-62	2,4-4,1

Table 12. Data changes of elastic modulus for different materials (Xiao, 2008, p. 165, Nielsen & Landel, 1994, p. 20.)

Polymer Type	E_{mod} (GPa)	E_{mod} (GPa) after adding celloluse	Changes
PLA	3,37	3,48	(+) 0,11
PS	2,1-3,5	0,873	(-) 1,227-2,627
ABS	1,1-3,1	1,06	(-) 0,06-2,04
PVC	2,4-4,1	1,43	(-)0,97-2,67

The table 12 shows the changes on the elastic modulus of those materials. As to PS, the pure PS materials has the E_{mod} value for 2.1 to 3.5 GPa, after adding 10%B800 arbocel, the E_{mod} decreased to 0.873 GPa which indicate the cellulose make the stiffness of PS smaller and make it easier to deform.

According to Akbari and Bagheri (2014) "incorporation of organoclay in polystyrene increased its modulus of elasticity and elongation at break and decreased its yield stress." And according to the study of Akbari and Bagheri (2016), Styrene Ethylene Butylene Styrene (SEBE) can be add into the PS to decrease the modulus of elasticity. Comparing different adding materials, the tensile property of PS can be various. Cellulose and SEBS can be adopted to decrease the elastic modulus of PS while organoclay can be used to increase the elastic modulus value.

The elastic modulus of ABS+10%B800 arbocel is 1.06 while E_{mod} for pure ABS is from1.1 to 3.1 GPa. The data shows a little bit decreased. Ten percent proportion of cellulose has extent influence on the property of ABS but not very obvious.

According to Weng (2016), modified montmorillonite (OMMT) can be used to modify the tensile strength of ABS, " the addition of 5 wt% OMMT improved the tensile strength of 3D printed ABS samples by 43% while the tensile strength of injection molding ABS samples were improved by 28.9%. It can be explained that the OMMT has much higher modulus and strength than ABS, resulting in higher modulus and strength of ABS/OMMT nanocomposites compared to pure ABS." Combing with this study, cellulose has smaller impact on elastic modulus of ABS than OMMT. Desired change on tensile property of ABS could be achieve by other substance such as modified montmorillonite, or maybe improve the proportion of the cellulose.

The elastic modulus of PVC+10%B800 arbocel is 1.43 GPa, comparing to the pure PVC whose E_{mod} is from 2.4 to 4.1 GPa, The decrease on the E_{mod} value are contributed by 10% cellulose. The added cellulose make the elastic modulus value decreases almost a half. After adding the cellulose, the stiffness of the material decreased. According to Naim (2017), irradiation and ZnO can be used to modify the mechanical property of PVC, their study conclude that “Gamma irradiation doses were found to play an effective role in nanocomposites' mechanical properties, especially, for high g-doses the sample behaviors are different for low-weight-ratio and high-weight-ratio composites. The elastic modulus is also found to strongly reduced with the addition of ZnO (2.5 wt %); however, the effect diminishes on increasing the ZnO contents in the samples for all radiation doses.” Different substances can be choose according to the desired properties, alternatives include cellulose which is proved in this study, ZnO and irradiation.

5 CONCLUSION

This thesis work covers producing process of different plastics using recycled materials by FDM 3D printing technology and comparing the tensile properties. A serious of recycled materials were printed and tested. The specimen are made by extrusion. It was found that the recycled PLA, ABS, PS, PVC all can be extruded and can be printed by 3D printers. Comparison of PLA, ABS, PS, PVC and their combination with cellulose were conducted to see the influence of the effect of adding cellulose and to see the properties changes of those polymers. With the data of E_{mod}, F at 0.2% plastic strain, F_{max} and F_{break}, Changes can be notice. The tensile testing are conducted and the result is clear. The tensile testing method ISO 527 gives the data of elastic modulus, Force at 0.2% plastic strain, Force at breaking point and the max force. The result is reasonable and clear. Different alternatives to modify the mechanical property of the thermoplastic are also compared.

Elastic modulus value of the tested virgin PLA as average value of 3.37 GPa and the one that is combined with 10% B800 arbocel gives an average value of 3.48 GPa showing a slight increase of 0.11 GPa, which is 3.26% from the original pure PLA. It can be indicated that the stiffness of the PLA+10%B800 arbocel increase slightly and it is contributed by the adding cellulose. So the influence of 10 % cellulose to tensile property of PLA is limited. More proportion of cellulose should add in to see whether significant influence can achieve by fiber on tensile property of PLA. Other options could be coating PLA with polydopamine and has better improvement which is about 14.9% increase on tensile strength.

As to the material ABS, PS, PVC, Elastic modulus value are all decreased after adding 10%B800 arbocel. The statistic changes of pure material and those combined with cellulose are 1.1-3.1GPa decrease to 1.06 GPa, 2.1-3.5GPa decrease to 0.873 GPa, 2.4-4.1GPa decrease to 1.43 GPa respectively Those changes to elastic modulus value demonstrate that after adding cellulose into the ABS, PS and PVC, their stiffness decreased and the materials become less rigid.

As to ABS, the cellulose has limited influence on its elastic modulus value which is only decrease small extent. The result indicate that 10% of cellulose is not ideal ways to modify the tensile property of ABS, change the cellulose proportion maybe possible to have better improvement.

In the experiments of PS, among those three materials, adding cellulose have biggest effect on PS which prove a good way to decrease its elastic modulus and make the material softer. Cellulose decrease its elastic modulus and the decrease on elastic modulus indicates cellulose make the stiffness of PS smaller and make the material easier to deform. Previous studies give that organoclay can decrease the value of elastic modulus and styrene ethylene butylene styrene to increase the value. Cellulose is proved to be another option to modify the tensile property of PS.

As to PVC, 10% of cellulose has been proved to decrease its elastic modulus almost a half. Other studies show irradiation can be used to change the mechanical property of PVC, but the cellulose is easier to operate. And modify the proportion of cellulose may have bigger change and get desired properties.

It can be seen that adding some extent of cellulose/fiber into the plastics will influence their properties. According to the plastic type difference, the modification on the tensile property caused by cellulose are different. Depending on requirements for material properties, a certain amount of cellulose can be added to improve or reduce the value of tensile strength. Cellulose is common substance which have many resources and different resources may have different effects. Comparing with other methods and materials to modify the thermoplastics property, cellulose is a simple operating and cost efficient way.

In the following work, experiments could be done on testing other mechanical properties of different plastics. The other testing could be water absorption and bending strength. Another efforts could be change the proportion of the fiber and then comparing the properties. One example would be adding 20% B800 arbocel or even higher proportion into the pure materials.

LIST OF REFERENCES

Akbari, B. and Bagheri, R. (2016). Deformation behavior and mechanical properties of polystyrene/organoclay/SEBS. Mechanics of Materials, 103, pp.11-17.

All3DP. (2018). 3D Printed Phone Cases - 5 Best Sources to Create Your Own | All3DP. [online] Available at: https://all3dp.com/1/3d-printed-phone-cases-sources/ [Accessed 16 Apr. 2018].

Anderson, I. (2017). Mechanical Properties of Specimens 3D Printed with Virgin and Recycled Polylactic Acid. 3D Printing and Additive Manufacturing, 4(2), pp.110-115.

Angjellari, M., Tamburri, E., Montaina, L., Natali, M., Passeri, D., Rossi, M. and Terranova, M. (2017). Beyond the concepts of nanocomposite and 3D printing: PVA and nanodiamonds for layer-by-layer additive manufacturing. Materials & Design, 119, pp.12-21.

Anon, (2018). [online] Available at: https://all3dp.com/1/3d-printed-car-3d-printing-cars/https://all3dp.com/1/3d-printed-car-3d-printing-cars/ [Accessed 14 Apr. 2018].

Balletti, C., Ballarin, M. and Guerra, F. (2017). 3D printing: State of the art and future perspectives. Journal of Cultural Heritage, 26, pp.172-182.

Barui, S., Mandal, S. and Basu, B. (2017). Thermal inkjet 3D powder printing of metals and alloys: Current status and challenges. Current Opinion in Biomedical Engineering, 2, pp.116-123.

Cho, Y., Lee, I. and Cho, D. (2005). Laser scanning path generation considering photopolymer solidification in micro-stereolithography. Microsystem Technologies, 11(2-3), pp.158-167.

Chua, C., Leong, K. and Lim, C. (2003). Rapid prototyping. New Jersey [etc.]: World Scientific.

Cui, Y., Lee, S., Noruziaan, B., Cheung, M. and Tao, J. (2008). Fabrication and interfacial modification of wood/recycled plastic composite materials. Composites Part A: Applied Science and Manufacturing, 39(4), pp.655-661.

David H, Ballard MD a, Taryn, H. (2018). Clinical Applications of 3D Printing: Primer for Radiologists: Radiology Research Alliance, 52, pp. 52-65

Dikobe, D. and Luyt, A. (2017). Thermal and mechanical properties of PP/HDPE/wood powder and MAPP/HDPE/wood powder polymer blend composites. Thermochimica Acta, 654, pp.40-50.

Dredge, S. (2018). 30 things being 3D printed right now (and none of them are guns). [online] the Guardian. Available at: https://www.theguardian.com/technology/2014/jan/29/3d-printing-limbs-cars-selfies [Accessed 14 Apr. 2018].

Eley, K. (2017). Centralised 3D printing in the NHS: a radiological review. Clinical Radiology, 72(4), pp.269-275.

Forbes.com. (2018). Forbes Welcome. [online] Available at: https://www.forbes.com/sites/louiscolumbus/2017/05/23/the-state-of-3d-printing-2017/#4ae568dc57eb [Accessed 13 Apr. 2018].

Godoi, F., Prakash, S. and Bhandari, B. (2016). 3d printing technologies applied for food design: Status and prospects. Journal of Food Engineering, 179, pp.44-54.

Gibson, I. and Shi, D. (1997). Material properties and fabrication parameters in selective laser sintering process. Rapid Prototyping Journal, 3(4), pp.129-136.

Hamod, H. (2018). Suitability of recycled HDPE for 3D printing filament. [online] Theseus.fi. Available at: http://www.theseus.fi/handle/10024/86198 [Accessed 11 Apr. 2018].

Hiller, J. and Lipson, H. (2009). Design and analysis of digital materials for physical 3D voxel printing. Rapid Prototyping Journal, 15(2), pp.137-149.

Huang, P., Xia, Z. and Cui, S. (2018). 3D printing of carbon fiber-filled conductive silicon rubber. Materials & Design, 142, pp.11-21.

Indiegogo. (2018). Toybox 3D Printer: Draw & Make Toys. [online] Available at: https://www.indiegogo.com/projects/toybox-3d-printer-draw-make-toys-kids-technology#/ [Accessed 14 Apr. 2018].

Isa, N., Sa'ude, N., Ibrahim, M., Hamid, S. and Kamarudin, K. (2015). A Study on Melt Flow Index on Copper-ABS for Fused Deposition Modeling (FDM) Feedstock. Applied Mechanics and Materials, 773-774, pp.8-12.

Jang, J., Park, J., Gao, G. and Cho, D. (2018). Biomaterials-based 3D cell printing for next-generation therapeutics and diagnostics. Biomaterials, 156, pp.88-106.

Kariz, M., Sernek, M., Obućina, M. and Kuzman, M. (2018). Effect of wood content in FDM filament on properties of 3D printed parts. Materials Today Communications, 14, pp.135-140.

Lei, Y., Wu, Q., Clemons, C. and Guo, W. (2009). Phase structure and properties of poly(ethylene terephthalate)/high-density polyethylene based on recycled materials. Journal of Applied Polymer Science, 113(3), pp.1710-1719.

Liu, Z., Zhang, M., Bhandari, B. and Wang, Y. (2017). 3D printing: Printing precision and application in food sector. Trends in Food Science & Technology, 69, pp.83-94.

Matweb.com. (2018). Tensile Property Testing of Plastics. [online] Available at: http://www.matweb.com/reference/tensilestrength.aspx [Accessed 15 Apr. 2018].

Mehat, N. and Kamaruddin, S. (2011). Optimization of mechanical properties of recycled plastic products via optimal processing parameters using the Taguchi method. Journal of Materials Processing Technology, 211(12), pp.1989-1994.

Mohammed, J. (2016). Applications of 3D printing technologies in oceanography. Methods in Oceanography, 17, pp.97-117.

Munaz, A., Vadivelu, R., St. John, J., Barton, M., Kamble, H. and Nguyen, N. (2016). Three-dimensional printing of biological matters. Journal of Science: Advanced Materials and Devices, 1(1), pp.1-17.

Murariu, M. and Dubois, P. (2016). PLA composites: From production to properties. Advanced Drug Delivery Reviews, 107, pp.17-46.

Nielsen, L. and Landel, R. (1994). Mechanical properties of polymers and composites. New York: M. Dekker.

O'Neal, B. (2018). Toy Maker: 3D Print Toys at Home with New App from AstroPrint. [online] 3DPrint.com | The Voice of 3D Printing / Additive Manufacturing. Available at: https://3dprint.com/193970/astroprint-toy-maker/ [Accessed 15 Apr. 2018].

Oliveira, S., Reis, R. and Mano, J. (2015). Towards the design of 3D multiscale instructive tissue engineering constructs: Current approaches and trends. Biotechnology Advances, 33(6), pp.842-855.

Parandoush, P. and Lin, D. (2017). A review on additive manufacturing of polymer-fiber composites. Composite Structures, 182, pp.36-53.

Sakin, M. and Kiroglu, Y. (2017). 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. Energy Procedia, 134, pp.702-711.

Schmauss, D., Haeberle, S., Hagl, C. and Sodian, R. (2014). Three-dimensional printing in cardiac surgery and interventional cardiology: a single-centre experience. European Journal of Cardio-Thoracic Surgery, 47(6), pp.1044-1052.

Stansbury, J. and Idacavage, M. (2016). 3D printing with polymers: Challenges among expanding options and opportunities. Dental Materials, 32(1), pp.54-64.

Support.office.com. (2018). Every Project plan is a triangle. [online] Available at: https://support.office.com/en-us/article/Every-Project-plan-is-a-triangle-2B74C21B-A406-4727-8D74-26648A56924A [Accessed 16 Apr. 2018].

Wang, X., Jiang, M., Zhou, Z., Gou, J. and Hui, D. (2018). 3D printing of polymer matrix composites: A review and prospective.

Weng, Z., Wang, J., Senthil, T. and Wu, L. (2016). Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing. Materials & Design, 102, pp.276-283.

Team, P. (2018). 3 Types of Plastic Used in 3D Printing |. [online] Polymersolutions.com. Available at: https://www.polymersolutions.com/blog/plastic-in-3d-printing/ [Accessed 13 Apr. 2018].

Trotter, C. (2018). Top 40 On Demand & 3D Printed Products in Retail - Insider Trends. [online] Insider Trends. Available at: https://www.insider-trends.com/top-40-on-demand-3d-printed-products-in-retail/ [Accessed 14 Apr. 2018].

Tuan, D., Alireza, K., Gabriele, I., Kate, T.Q., David, H. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B ,143, pp. 172–196.

Tymrak, B., Kreiger, M. and Pearce, J. (2014). Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions. Materials & Design, 58, pp.242-246.

Ultimaker.com. (2018). Sweet taste of innovation: 3D printed chocolate | Ultimaker. [online] Available at: https://ultimaker.com/en/blog/39183-sweet-taste-of-innovation-3d-printed-chocolate [Accessed 16 Apr. 2018]

Xiao, X. (2008). Dynamic tensile testing of plastic materials. Polymer Testing, 27(2), pp.164-178.

Zhao, X., Hwang, K., Lee, D., Kim, T. and Kim, N. (2018). Enhanced mechanical properties of self-polymerized polydopamine-coated recycled PLA filament used in 3D printing. Applied Surface Science, 441, pp.381-387.

Zwick.com. (2018). *Zwick Roell Materials Testing Systems*. [online] Available at: https://www.zwick.com/ [Accessed 9 May 2018].

3D Print HQ. (2018). How Does Selective Laser Sintering Work?. [online] Available at: https://3dprinthq.com/how-does-selective-laser-sintering-work/ [Accessed 12 Apr. 2018].