DEVELOPMENT OF SOFT AND FLEXIBLE FILAMENT FOR 3D PRINTING OF ANATOMICAL MODEL

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by

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LIST OF SYMBOLS

^oC	Degree of Celsius
T_g	Glass Transition Temperature
g	Gram
g/cm^3	Gram per cubic centimeter
g/mol	Gram per mol
ΔH	Heat of melting
kN	Kilonewton
MPa	Megapascal
T_m	Melting Temperature
mg	Miligram
mm	Milimetres
mm/s	Millimetres per second
N	Newton
cm^{-1}	Percentimetre

LIST OF ABBREVIATIONS

3D	3-Dimensional
ABS	acrylonitrile-butadiene-styrene
AM	Additive Manufacturing
ASTM	American Standard Testing Method
CAD	Computer Aided design
DMA	Dynamic Mechanical Analysis (DMA)
DSC	Differential Scanning Calorimetry
EPDM	Ethylene-propylene-diene (EPDM)
FDM	Class Separation Indices
FFF	Class Sample Matrix
FTIR	Class Sample Vector
G-code	Geometric Code
IM	Injection Molding
IR	Infrared
LM	Layered Manufacturing
PA	Polyamide
PC	Polycarbonate
PP	Polypropylene
PCL	Polycaprolactone
PET	Polyethylene Terephthalate
PGA	Polyglycolide
PLA	Polylactic acid
RP	Rapid Prototyping
SBR	Styrene-butadiene rubber
SEM	Scanning Electron Microscopy
SFF	Solid Freeform Fabrication
STL	Standard Triangle Language
TPE	Thermoplastic Elastomer
TPU	Thermoplastic polyurethane

PENGHASILAN FILAMEN LEMBUT DAN FLEKSIBEL UNTUK PERCETAKAN 3D MODEL ANATOMI

ABSTRAK

Filamen fleksibel telah digunakan secara meluas dalam pembuatan bahan tambahan untuk menghasilkan model lembut, seperti model otak manusia. Oleh kerana kestabilannya yang lebih baik, filamen poliuretana termoplastik (TPU) biasanya digunakan di bahagian ini. Ia mempunyai segmen lembut dan keras, yang boleh memberikan sifat terbaik dari segi fleksibiliti tetapi kos yang lebih tinggi untuk setiap filamen. Pendekatan campuran polimer digunakan dalam TPU, menambah getah untuk meningkatkan fleksibiliti dan mengurangkan kos. Kajian ini bertujuan untuk menghasilkan filamen fleksibel daripada campuran polimer yang digunakan untuk model anatomi cetakan 3D menggunakan cetakan 3D lembut yang disesuaikan. Dua jenis getah digunakan untuk komponen kedua, etilena propilena diena monomer (EPDM) dan sebatian getah stirena butadiena (SBR). Untuk pemprosesan bahan, pengadunan 75%TPU/ 25%EPDM dan 75%TPU/ 25%SBR telah berjaya dibuat menggunakan pengadun dalaman dan disemperit ke dalam filamen menggunakan penyemperit skru tunggal. Bentuk “dumbbell” untuk pencirian dan model otak manusia kemudiannya dicetak menggunakan pencetak 3D. Didapati bahawa kedua-dua adunan boleh diekstrusi. Namun, sifat-sifat bahan banyak dipengaruhi oleh jenis getah dan komposisi pengisi tambahan. Pengadunan TPU95A/EPDM lebih disukai untuk fabrikasi model anatomi kerana keliatan yang lebih baik dan kestabilan yang baik, dan ketumpatan pautan silang fizikal yang lebih tinggi disebabkan oleh interaksi linear etilena propilena diena dengan segmen lembut TPU itu sendiri. Di samping itu,

kajian lekatan dijalankan, dan kelajuan pencetakan 35mm/min meningkatkan sifat mekanikal.

DEVELOPMENT OF SOFT AND FLEXIBLE FILAMENT FOR 3D PRINTING OF ANATOMICAL MODEL

ABSTRACT

Flexible filaments have been widely used in additive manufacturing to produce soft models, such as the human brain model. Due to its better stability, thermoplastic polyurethane (TPU) filament is commonly used in this part. It has soft and hard segments, which can provide the best properties in terms of flexibility but are higher in cost for every filament. The polymer blend approach was used in TPU, adding rubber to enhance flexibility and reduce cost. This study aims to produce flexible filament from polymer blending used for 3D printed anatomical models using customized soft 3D printing. Two types of rubber are used for the second component, ethylene propylene diene monomer (EPDM) and styrene butadiene rubber (SBR) compounds. For material processing, the blending of 75%TPU/ 25%EPDM and 75%TPU/ 25%SBR was successfully fabricated using an internal mixer and extruded into filament using a single screw extruder. The dumbbell shape for the characterization and human brain model was then printed using a 3D printer. It was found that both blendings could be extruded and formed into flexible shapes and could be printed into brain anatomy models. Still, the properties of the materials were greatly affected by rubber types and compositions of the added fillers. The blending of TPU95A/EPDM is preferred for fabricating anatomical models due to its better toughness and good stability, and higher physical crosslink density due to the interaction of linear ethylene propylene diene with the soft segment of TPU itself. In addition, the adhesion studies are conducted, and 35mm/min printing speed enhance the mechanical properties.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Additive manufacturing is recognized as high performance manufacturing technology owing to its rapid capacity to generate a complicated product geometry. Additive manufacturing can be categorized into type of manufacturing such as rapid prototyping (RP), solid freeform fabrication (SFF), layered manufacturing (LM), and the term that is most commonly used is three-dimensional printing (3D printing). 3D printing uses a process known as "layering," in which the printed object is constructed one layer at a time until it is finished (Mpofu, Mawere and Mukosera, 2014). In the 1980s, Charles W. Hull was the first person to suggest the concept of 3D printing, which at the time meant making printed polymer items using the process of stereolithography (Liu et al., 2019). Now, 3D printing is known as a fast technology that is transforming the production of products in key industries, such as the food industry, healthcare and medicine, aerospace, automotive, art, textile, and construction.

Fused deposition modelling, often known as FDM printing, is now the most popular and commonly used form of three-dimensional printing owing to its high printing quality, broad range of applications, simple workflow, quickness, and cheap cost. 3D Printing filament is the material used as feedstock for 3D printing where the filament is created using a process of heating, extruding, cooling and winding into continuous plastic thread. Many types of filaments has been made such as Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), Polypropylene (PP), Polycarbonate (PC), polyethylene terephthalate (PET) and many more. Consequently, according to a recent study, PLA is one of the top printing materials in terms of facilitating the process and reducing the amount of time required. (Smith, Michael L., 2017).

However, only a few filaments offer elastic properties such as thermoplastic urethane (TPU) and thermoplastic elastomer (TPE). TPU are recognized as linear multi-block copolymers that contain both soft and hard segments. TPU has a greater tensile modulus than rubber, a higher abrasion resistance, an enhanced resilience to wear and tear, and resistance to oil and many solvents. (Lovenich et al., 2017). Despite its advantages, TPU strength is considered low which make the filament fabrication process a challenge. The relation between strength with the difficulty in handling processing is focussing on the material viscosity and chain mobility itself. The higher strength because of lower chain mobility cause lower in free volume area. Thus, it makes the process become more uniform melt flow. The printing process only effective at a very slow printing speed thus require long time to produce a product.

For a specific application such as medical teaching and learning, physical anatomical models offer a promising material for teaching gross anatomy in 3D representation due to their easy accessibility, accuracy and educational effectiveness in order to bring up the learners' level of gross anatomy knowledge at low cost. Although hard materials are sufficient to recreate anatomical fidelity, it has been challenging to recreate models with tissue characteristics similar to humans. Therefore, this study was done to fabricate customised soft polymer material using 3D printing that allows the construction of complex human anatomy structures which mimic true human anatomy.

According to a recent study, there has been a lot of research on the blending mixing of TPU with the polymer that provides excellent qualities for many types of application (Nazemidashtarjandi et al., 2017), (Liu et al., 2022). To create the hard segments that are included inside the chain of TPU, the diisocyanates, together with a low-molecular-weight diol and diamine, are utilised. Polyether or polyester glycols, on the other hand, are employed in the manufacturing of the soft segments, and diisocyanates may further prolong these segments (Pesetskii et al., 1999). Because diol and diamine form domains, which serve as connectors of physical crosslinking for the soft blocks, an intermolecular chain of hydrogen bonding can connect the hard blocks of molecules. This is made possible since hydrogen bonding can connect diol and diamine forming domains. The formation of a network of physical connections in TPU is dependent, to a significant extent, on hydrogen bonds, which are unstable and can undergo redistribution because of the impacts or changes brought on by temperature.

The amount of micro segregation in thermoplastic polyurethanes (TPU) and the set of features that are typical of these materials are both determined by the distribution of hydrogen bonding. There has been a lot of research on the blending mixing of TPU with the polymer that provides excellent qualities for many types of application (Nazemidashtarjandi et al., 2017), (Liu et al., 2022). It was presumed that the degree to which the extra polymer impacts the micro-segregation of polyurethane in blended systems containing TPU and other polymers would be the determining factor in determining the characteristics of such systems.

In the present work, the potential of blending TPU with ethylene propylene diene monomer (EPDM) and styrene butadiene rubber (SBR) as filament is explored. It is expected that the incorporation of EPDM and SBR would alter the soft and hard segment in TPU filament to produce customized anatomical model (human brain) with improved properties especially the soft feeling. Two commercial TPU were used as a comparison namely TPU 95A and TPU 85A. The developed filament properties were characterized using mechanical properties, surface morphology, thermal analysis (DSC), rheological study (DMA), Swelling Test, FTIR and adhesion test study.

1.2 Problem Statement

The flexible filament is necessary to construct the anatomical model, However, the existing 3D model for learning anatomy has numerous limitations. For instance, the hardness of the model makes it challenging to manipulate, especially while learning the anatomical parts and their relationships. Although the 3D printed model may enhance medical students' grasp of spatial anatomy and their learning pleasure (Wu et al., 2018), the majority of printed models are composed of rigid, non-elastic materials (Garcia et al., 2018). Garcia et al. (2018) stated that despite the fact that hard materials are suitable to mimic anatomical integrity, it has been difficult to develop playable models with tissue qualities comparable to human normal and pathological specimens. In addition, the model's durability is a factor to consider while designing a long-lasting model, as it may be utilised several times despite being vulnerable to damage. Moreover, 3D printed models are a viable option for thrifty departments due to their comparatively inexpensive cost comparing to commercially accessible models (Mardis, 2018). Consequently, 3D printing the anatomical model with flexible blending filament can minimize the model's production cost. Thus, from the part, it clearly shows that the need of flexible filament in order to produce the flexible and soft anatomical model.

TPU is a commonly used flexible filament with excellent soft characteristics (flexibility), however, the rubber filler is expected to soften the flexibility of the TPU filament. To generate a new material with great physical qualities such as softness and flexibility, TPU must be combined with the other second component (soft). The ability to blend the various types of TPU depends on the compatibility between the two phases of the hard component (TPU) and the second component (EPDM and SBR). The parameter used in the fabrication of filament and fabrication of 3D model using 3D printing also influence the final result of filament and 3D model itself. This research will examine the physical, mechanical, morphological, rheological, and thermal aspects of blending in depth.

1.3 Research Objectives

The objectives for this research are to design and development of soft and flexible filament for 3D Printing of Anatomical Model. The specific research objectives are as follows:

i. To fabricate flexible filament from the different type of blending second component with TPU polymer.
ii. To investigate the blending ratio of 75% TPU with 25% soft component responsive, morphology, mechanical, physical, and thermal properties.
iii. To develop an Anatomical model from the flexible filament using 3D printing of FDM technique.
iv. To study the effect of printing speed toward adhesion properties for layer-by-layer of printed sample.

1.4 Thesis Outline

The thesis is divided into five main chapters. The five chapter consists of:

Chapter 1: Presented the introduction to the background of the study which include problem statement, and research objectives.

Chapter 2: Literature review on the past research which consist of brief introduction to additive manufacturing and its classification, overview commercial fabrication of filament also its properties and limitation, and the issue towards compatibility of polymer blending. In addition, the application of soft filament that are used for anatomical model were described in detail.

Chapter 3: Methodology of the research which provides detailed explanation of raw material used in the fabrication of flexible filament, as well as the flow process fabrication of the TPU blending filament which blending TPU95A with EPDM and SBR, fabrication of dumbbell shape using the drawing from solid work, the method for characterization including responsive, morphology, mechanical, physical, rheological, and thermal properties. The fabrication step for the anatomical model also covered in this chapter.

Chapter 4: Results and discussion obtained from the characterization of TPU blending flexible filament through 3D printed sample blending, comparison of mechanical properties between commercial TPU (TPU95A and TPU85A) and TPU blend (TPU95A/EPDM and TPU95A/SBR) samples, responsive morphology for both type of sample (commercial and blending), FTIR analysis, Thermal analysis DSC, rheology study form DMA, Swelling testing and adhesion between layer studies by considering various printing speed through tensile testing and SEM morphology.

Chapter 5: Conclusion on the whole research was summarized as well as a few suggestions for further improvement for future work.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction of 3D Printing

Today's industrial sector is dominated by Three-Dimensional Printing Technologies, which provide feasible and practical solutions in a highly flexible and cost-effective manner (Ngo, Kashani, 2018). The 3D Printing technologies are endowed with very versatile production capabilities, allowing customers to design and build goods in accordance with application-specific specifications. 3D Printing is a technology that is simple to operate and manage. As a result of its speedy and cost-effective prototyping capacity, 3D printing has been widely utilised by architects and designers to develop aesthetics and functionality as prototypes. The user can benefit from 3D printing. The usage of 3D Printing has reduced the additional costs associated with producing a product.

In general, 3D printing is also known as Additive Manufacturing (AM), which is described by ASTM International (ASTM 2792-12) as the process of joining materials to create items from three-dimensional model data, often layer by layer, in contrast to subtractive manufacturing methods (Sharma, 2016). A 3D printer receives digital data from a computer, similar to a conventional printer, but instead of printing the product on paper, it creates a three-dimensional model from a specified material. There are two techniques to redesign a 3D model: (1) computer-aided design (CAD) employing software such as a 3D scanner, digital camera, or photogrammetry software; and (2) computed tomography (CT) conversion of scanned images into 3D printable format images (Yap et al.,2017; Li et al., 2017; Smith et al., 2018; Vaish and Vaish, 2018) In addition, the development of items through 3D printing can minimise production costs and time. The original principle of 3D printing was based on the idea of applying successive layers of A basic material on top of one another to construct a whole structure. In 1984, Charles W. Hull of 3-D Systems Corporation created the first functional 3-D printer. He designated the device the Stereolithography Apparatus (Bogue, 2013). Initially, advanced 3D printing technology was excessively expensive and unavailable to the general public. Nonetheless, the 3D printing idea continues to have a significant influence on other disciplines, such as medical, engineering, and manufacturing. However, as the 21st century proceeded, costs reduced considerably, allowing 3-D printers to permeate several sectors.

2.1.1 Common Issue In 3D Printing

3D Printing is known as the high-performance technology due to its advantages in detailing for fabrication products, but there have several common issues occurred in during printing process, such as:

2.1.1(a) Void Formation

Void generation between successive layers of material is one of the primary limitations of 3D printing. Due to the decreased interfacial adhesion between printed layers, the increased porosity formed by 3D printing can have a significant impact on mechanical performance (X. Wang, 2017). The degree of void generation strongly relies on the 3D printing process and the printed material. In processes that utilise material filaments, such as FDM or contour crafting, the creation of voids is more prevalent and is regarded as one of the key faults that lead to poorer and anisotropic mechanical characteristics. This void creation might also cause delamination between printed layers (G.J. Gibbons, 2010). In a 3D-printed composite utilising the FDM process, increasing the filament thickness lowered porosity but degraded composite cohesion, resulting in a fall in tensile strength and an increase in water absorption. However, the increased porosity of 3D printed objects is not necessarily a flaw and may be used in applications where controlled porosity is viewed as a benefit of 3D Printing, such as the construction of porous scaffolds in tissue engineering. Due of the 3D printing process, (Minas, 2010) takes use of void generation. They added bigger holes to a lattice structure on top of micropores, which were produced by air bubbles within the foam filament. For biocomposites, the greater porosity of the 3D-printed component can introduce hygroscopic qualities by enhancing its propensity to hold water.

2.1.1(b) Layer-by-layer appearance

Due to the nature of 3D-printed concrete structures, layer-by-layer appearance is an additional difficulty. If the 3D printed component is concealed in the end use, such as scaffolds for tissue engineering, the look may not be a significant aspect. In some uses, however, such as structures, toys, and aircraft, a flat surface is favoured over the appearance of layers. Chemical or physical post-processing techniques, such as sintering, can eliminate this flaw (Oropallo, 2016), however they will increase processing time and expense. The number of layers in a part is determined by the layer's thickness and its height. The intensity of layer-by-layer look can therefore be mitigated by limiting the number of layers. The 3D printing technologies that employ a filament, such as FDM, inkjet, and contour sculpting, are more likely to create a layer-by-layer look than powder-bed and stereolithography

2.1.2 Importance Parameter for 3D Printing

Before a final object can be produced, the 3D printing procedure is largely dependent on the printing parameters that must be specified. To print a product using the FDM method, the parameters for the intended output must be substantial and suitable for the fabrication process to assure the product's quality. During the printing process, a number of factors, including infill pattern and density, layer height, shell thickness, printing temperature, and bed plate temperature, must be considered.

Cwika,, et al. (2017) found that infill density and infill pattern are the most important printing factors. Both of these variables can influence the mechanical characteristics of the final product. Increasing the infill density will minimise deformation but reducing it will result in a less dense interior of a 3D-printed item. In addition, when the infill density increases, the mechanical strength of the sample increases. In addition, they mentioned that, for infill patterns, the exact design of material threads inside the interior of 3D-printed items might alter their final qualities. Low-strength patterns include linear and rectilinear, but honeycomb and concentric patterns are more robust. Indicates the possible infill patterns for 3D printing.

Abeykoon et al. (2020) explore the characteristics of 3D-printed specimens with diverse printing process parameters, including infill pattern, density, speed, and printing materials. The results demonstrated that when the infill density grew, the printed parts' Young's modulus increased. In contrast, among the printing speed evaluated in the range of 70 mm/s to 110 mm/s, the optimal infill attained was 90 mm/s. Due to the lowest porosity level and best layer arrangement, the mechanical characteristics were optimal at this speed. In contrast to the research conducted by Wika, et al. (2017), the concentric linear pattern produced the highest tensile modulus compared to other designs because the intervals between individual layers are smaller than in other patterns. In addition, the optimal printing temperature for TPU filament was determined to be 220^{o}C which is comparable with commercially available or previously published data. Aside from that, the research explored how the printing speed of 35mm/s for flexible filament improves adhesion between layers, hence enhancing the characteristics.

2.1.3 Advantages and Disadvantages of 3D Printing

Nowadays industries, Additives Manufacturing (AM) has been common process in producing 3D product with a complex geometry. Most commercially accessible 3D printers are automated and easy to use for creating new goods. Because of some of the new advantages it may offer, the demand has been steadily increasing over time. It, like most technology, has both advantages and drawbacks that must be taken into account. This technique provides a number of benefits over standard production processes. These include benefits related to design, time, and money.

The rapid prototyping enabled by 3D printing enables for the rapid development of new concepts. Consequently, each stage of production may be completed faster. It is cheaper and faster to produce components using 3D printing than machining prototypes since the component may be produced in hours, allowing each design tweak to perform at a much faster pace (Gokhare et al., 2017). To stay up with the competition, firms need to be able to create and print concepts on the same day, which cuts the development time from months to a few days.

Another benefit of on-demand printing over traditional production methods is the elimination of the need for large inventories. This conserves both space and resources by delaying large-scale printing until it is absolutely essential. As long as you have access to CAD or STL files, you can easily find and print your 3D designs (Gokhare et al., 2017). As a result, 3D printing is more efficient and quicker than any other fabrication technology, allowing it to produce objects in hours rather than days or weeks.

The manufacturing process may be made to produce less waste by using 3D printing. Because it uses only the resources for the actual product, additive manufacturing generates far less waste than other methods of manufacturing, such as using huge amounts of non-recyclable materials or wasting material that would otherwise be thrown away. As a result, raw material costs will be reduced, and raw material resources will be conserved. The early creation of low-cost innovations made possible by 3D printing results in better goods and fewer dead ends for product developers.

Furthermore, 3D printing is a single-step manufacturing process in which can saves time and thus, saving cost compared to using other production method. The need of operator to monitor the production process always can be eliminated as the 3D printers can be set up and left to function on their own. As previously stated, this manufacturing process can cut material costs by only using the quantity of material required for the product, with little or no waste. In addition, an expensive investment needs to be allocated for prototyping injection mold tools.

The 3D printing technology allows for much faster manufacturing of components and/or tools than traditional machining. According to Gokhare et al., (2017), The ability of 3D printing in evaluating a design before investing in an expensive moulding equipment is well worth in 3D printed plastic. 3D prints a test prototype is significantly less expensive than to modify or redesign the current mould used in the fabrication process.

3D printing technology has a number of downsides that should be addressed before selecting whether or not to utilise it, such as a lack of materials, a lack of customization options, and other concerns. In the first place, the amount of raw material accessible is quite restricted. 3D printing may be utilised with a wide range of materials, including plastics and metals. According to Gokhare et al. (2017), 3D printers can operate with around 100 different raw materials, but not all metals or polymers can be thermally regulated to enable 3D printing. To make matters worse, just a few of these printing materials are safe for consumption, as noted by the FDA. This is tiny compared to the large range of raw materials that are used in traditional manufacturing processes. More research is required to find methods for enhancing the durability and sturdiness of 3D-printed products.

Another disadvantage of 3D printing is that it may reduce the need for human labour, as the majority of manufacturing is automated and only one operator is required to control many machines. Many third-world countries, on the other hand, are economically dependent on low-wage labour. Manufacturing employment in other nations might be at risk because of new technology that eliminates the need for foreign production. Manufacturers' jobs will be eliminated when new technologies enter the marketplace (Gokhare et al., 2017).

Finally, due to the tiny print chambers present in 3D printers, the size of the items that may be printed is now restricted. Anything more substantial must be printed in sections and then assembled. Because the printer must manufacture more components and manual labour is necessary to join the components, this can lead to increased costs and time for more critical pieces. Because of this, 3D printing technology is currently bound by its size. There are limits to how much 3D printing technology can make.

2.1.4 Application of 3D Printing

The application of 3D Printing technology are very huge applies in any fields but the commonly used in the application of:

2.1.4(a) Biomedical

It is possible to create exceedingly complicated structures by engineering with the materials that are utilised in 3D printing, such as semi-crystalline polymeric composites (Garcia-Gonzalez, 2018). Customization and patient-specific requirements are only two of the many advantages that 3D Printing technology offers in biomedical applications. Biomedical applications must be tailored to each individual patient, from implant placement to the amount of medication. 3D printing has significant promise for patient-specific biomedical goods, including hearing aids, biomedical implants, and prosthetics. According to Chen, (2016), It is also used to plan procedures, improve efficiency and effectiveness, reduce the requirement of subsequent operations to adjust the implant to patient. Compared to traditional manufacturing processes, 3D printing is more cost-effective for modest production quantities in the biomedical business. Adding to that, it eliminates the need to create new tooling fixtures for each new project. Prototypes may be made with 3D printing more quickly than using traditional production processes.

2.1.4(b) Buildings

It is possible to employ 3D printing in the construction business in areas where limits exist, such as geometric complications and hollow constructions. Consequently, it is dependable since it can produce with high accuracy and opens a variety of design options. For automated construction of structures and infrastructure, and for space applications, Khoshnevis, (2004) developed contour crafting (CC) technology. It can be used to build low-income houses and lunar shelters because of its capacity to employ in-situ resources. Using the FDM process, the first 3D printed residential structure was built in Amsterdam in 2014.

2.2 Filament Fabrication

2.2.1 Common Type of Polymer Filament Used in FDM 3D printing

Following manufacturing, the 3D models may be printed in a variety of materials, allowing further customisation (Li et al., 2017). Sadly, anatomical 3D printing has several restrictions due to the fact that the real material qualities are still far from satisfactory (Heo et al., 2020). According to Shahrubudin et al. (2020), biomedical 3D printing has several hurdles, including a restricted selection of materials and a product's mechanical robustness. Materials such as metal, polymer, hydrogels, resin, glass, and ceramic have all been utilised to make 3D printed goods to some extent. (Ngo et al., 2018; Shahrubudin et al., 2020). It is essential that the materials used in 3D printing are filaments (such as wire and filament), powder, paste, and sheets (Ngo et al., 2018). It is possible to make extremely detailed and precise specimens using a wide range of materials with variable qualities utilising 3D printing, however the physical properties of 3D prints are fundamentally different from cadaveric sources (Lim et al., 2016). Anatomical printing presents several obstacles because of the intricacy of each tissue and its composite material, which mandates a multimodal printer, as mentioned in Ratinam et al. (2019). It is possible to improve the realism and efficiency of simulation by modifying the material characteristics of various tissue representations (Ryan et al., 2016). Mechanically improving printed models by altering their materials is a possible future strategy for improving surgical education tools (Garcia et al., 2018)

Since polymers are widely available and often used in 3D printing, this is a good place to start. Medical models and biodegradable scaffolds have been made from polymer materials, including natural and synthetic biomaterials (Cheng and Chen, 2017; Yan et al., 2018). Polymers have a number of advantages, including being resistant to weather and chemical elements, being able to be moulded easily, and being relatively inexpensive to produce (Turek et al., 2020). Acrylonitrile-butadiene-styrene (ABS) copolymers, polyamide (PA), polycarbonate (PC), and polylactic acid (PLA) are the most frequent polymers used in 3D printing, as are thermosetting powders including polyamides, and photopolymer resin (Ngo et al., 2018). In 3D printing composites, PLA and ABS are two of the most used polymers (Ngo et al., 2018). According to some, Polycaprolactone (PCL) has superior viscoelasticity, cost effectiveness, and mix compatibility to other polymers (Cheng & Chen, 2017). To further enhance its mechanical characteristics, the 3D printed composite was reinforced with fibres and nanoparticles, which resulted in a more useful material (Ngo et al., 2018).

2.2.2 Properties of Available 3D Printing Filament

The available 3D printing filament in market such as acrylonitrile-butadiene-styrene (ABS) copolymers, polyamide (PA), polycarbonate (PC) and polylactic acid (PLA) which are widely used in any type of 3D Printing technology. The detail properties of available/commercial filament as shown in Table 2.1.

Table 2.1 The general properties for available/commercial filament

Polymer	Properties
acrylonitrile-butadiene-styrene (ABS)	Possesses an excellent combination of mechanical and chemical resistance, as well as a low melting point.
copolymers, polyamide (PA)	With a temperature tolerance of up to 180 degrees Celsius, the filament is robust, strong, and long-lasting.
polycarbonate (PC)	High impact strength, lightweight, good heat and chemical resistance
polylactic acid (PLA)	Biodegradable, minimal thermal expansion and strong layer adhesion are among the material's many desirable properties.

To get a printed object with increased stiffness and strength, you'll need the above-mentioned commercial filament qualities. There is, however, a lack of elasticity in all filaments. Blending PLA with TPU to create a more flexible printed bone sculpture Nofar, et al., (2020) is an example of how this filament may be made more flexible.

2.2.3 Limitation of Available 3D Printing Filament

The lack of excellent flexibility in commercially available 3D printing filament is the primary constraint of the filament that is currently available for use. The soft filament requires fabricating the flexible printed product. Thermoplastic polyurethane, often known as TPU, is one of the flexible filaments that are employed in commercial applications; nevertheless, the cost of this material is rather expensive. Therefore, the purpose of this research study was to investigate the mixing of TPU with several additional soft components that made use of rubber. When the appropriate parameter settings for 3D printing are utilised, it is possible to successfully create the anatomical model that has the greatest degree of flexibility. The present studies will overcome the limitation of available filament which considered has more rigid and brittle. Research study expected the more ductile material for filament will be fabricate using TPU blends with soft component (EPDM and SBR)

2.3 Overview Compatibility of Thermoplastic Polyurethane (TPU) Blends

In a broad sense, thermoplastic urethane (TPU) is understood to be a block copolymer that is composed of alternating hard and soft segments. Its adaptability can be attributed to the fact that its chemical structure contains both tough and pliable components in equal measure. A wide range of hardness may be achieved by varying the proportion of hard to soft segments in the composite material. When there is a greater proportion of hard segments to soft segments, the resulting TPU is more rigid (Lubrizol.com, 2022). The fact that TPU's hard segment plays such a key role is one of the reasons why it is the polymer of choice for usage in the blending process. This is due to the fact that the hard segment of TPU comprises NH and C=O groups, both of which are able to create interactions with the second component and intermolecular bonds.

2.3.1 The Blending of TPU with EPDM and SBR

The blending of Thermoplastic polyurethane (TPU) with the second component of Ethylene-propylene-diene (EPDM) and Styrene-butadiene rubber (SBR) were explored in the recent study. From the finding of the TPU with EPDM, the addition of EPDM has a great impact on the performance of TPU which is EPDM enhance the mechanical properties and flexibility of blending material (Jing Tan, 2008). Whereas, in the study of blending for TPU with SBR state that it can enhance the properties of the blending material but there has several limitations which are relates to the miscibility. Thus, the study are focusing on the surface modification using the acrylic acid. In my study, the improvement of toward immiscibility are focusing on the physical modification which proceed in two stage of mixing which referring to stage one is internal mixer process and second mixing is single screw extruder.

2.3.1(a) Thermoplastic Polyurethane (TPU)

Thermoplastic polyurethane, often known as TPU, is a kind of elastomeric polymer that has a unique mix of desirable properties, including high ductility, toughness, durability, flexibility, biocompatibility, and biostability (Wang, X., 2004). One of the reasons why thermoplastic elastomer (TPE) was selected as the material for the polymer matrix in the process of fabricating flexible filament was because TPE has a higher degree of flexibility than other thermoplastic elastomer materials. In most cases, TPU materials are used for medical product applications because of their superior flexibility and biocompatibility. TPU polymer is well-known for being an outstanding biocompatible material that may be used for a wide variety of applications in the medical industry (Ajili et al., 2003). TPU is a kind of TPE, and it is this type that may give the finest qualities, particularly for items that are soft. This particular polymer has become a more desirable and essential polymer as a result of the mixture of polymer chain sections that include both hard and soft domains.

2.3.1(b) Ethylene-propylene-diene (EPDM)

Due to the excellent performance, it provides, ethylene-propylene-diene (EPDM) rubber has become increasingly in demand. This is especially true in the automotive industry, where it is used for applications such as weatherstripping, tubes, mounts, building and construction sheeting and gasket, as well as in mechanical goods such as seals, O-rings, and others. The fact that EPDM has excellent characteristics is due to the presence of a saturated polymer chain, which is responsible for the material's high resistance to oxygen, heat, and ozone (Ismail, 2017). EPDM, often known as rubber, has a larger molecular weight and, when combined with another polymer, has the ability to generate strong interactions. This interaction occurs when the hydrogen bond formed between the EPDM linear backbone with the soft segment of TPU95A. Because a larger molecular weight results in a polymer chain that is closer together, this factor contributes to an increased capacity for the polymer chain to bond. In addition to this, the long molecular chain of EPDM helps improve flexibility, making it appropriate for use as a soft component filler. This research project, the purpose of which is to produce flexible filament, is an ideal type for using this filler.

2.3.1(c) Styrene-butadiene rubber (SBR)

The copolymer styrene butadiene rubber (SBR) is one of the synthetic rubbers that is used more frequently than any other. Because of its excellent resistance to cracking and the elements, this polymer is most commonly used in the production of tyres. This material, on the other hand, has a wide variety of other applications in the industrial sector. Some of these applications include membranes, wire and cable insulation, adhesives, rubber toys, moulded rubber goods, shoe soling, and various pharmaceutical, surgical, and sanitary products (Diez, 2010). It is possible that the use of this SBR rubber, which is the rubber that is considered to be the cheaper rubber, is the reason for the price reduction of the product. In addition, the suitability of SBR to act as a soft component (filler) for this research study is because of its properties, which have low viscous, which can enhance the chain mobility due to the increase in the area free volume. This is one of the reasons why SBR is a good candidate.

2.3.2 The Common Challenges in Blending TPU

2.3.2(a) Phase Separation

When a polymer mix is cooled from the one-phase to the two-phase unstable region, phase separation occurs. Concentration fluctuations become significant in this case cause unstable and expand (Henderson & Clarke, 2004). The phase separation is essential because polymer blends often have better properties than individual homopolymers. Unfortunately, most blend components are incompatible with one another and will demix. In this part, it can be said that the phase separation occurs when the polymer blend incompatible phase also can be related to the immiscibility of blend. The phase separation is the problem occurs when the presence of immiscible blends which has an unstable molecular force. This can cause problem in the formation of hydrogen bond and covalent bond to occur between polymer blending. The degree of separation in blends has a significant impact on the ensuing morphology, which may have a negative impact on the mechanical and electrical characteristics (Ncsu.edu, 2022).

2.3.2(b) Reduction of Mechanical Properties

Plain homopolymers are hardly used nowadays. In many applications, polymer blends are used instead. Polymer blends come in a wide variety of materials, including matrix and dispersed phase components. The reduction of mechanical properties is the one of common challenge that need to face during the blending the polymer. The main factor that contributes to the reduction of mechanical properties is the polymer blend in immiscible condition that are weak in the bonding and reduce the ability of stress transfer between blends (Bartczak, & Galeski, 2014). In general, good mechanical behavior is dependent on adhesion at the interphase for efficient transfer of stress between the component of blends phase (Paul & Barlow, 1980). The presence of strong bonding between blend components ensures that the applied force is transferred into the scattered inclusions. The recovery of macromolecular chain mobility at interfaces, which is linked to changes in the shape of interfacial layers, and the transfer of the brittle-to-ductile transition

2.3.3 The Application of Polymer Blend (TPU Blends)

TPU Polymer blends have been utilized in a variety of applications and have grown in popularity in recent years due to the ability to tailor their characteristics to specific applications. Blending polymers provides an easy way to create novel materials with tailored features and versatility (Utracki & Wilkie, 2014). Some of the example applications are:

2.3.3(a) Medical

In recent study, the application of blood bag for the medical used. the blending of TPU with the Polypropylene (PP) and EVA with the blending ratio (80/20/5) has improvement towards properties of the blood bag material and balance the hydrophilicity and hydrophobicity of the blend which play a vital role of compatibility (Ajili et al., 2003). The other findings for this study are the presence of PP in the blend decreases the concentration of TPU hard-segment domains at the blend surface, making it less attractive to blood platelets.

2.3.3(b) Accessories

In recent study of blending TPU with Silicone has been made for the application of phone casing and bad of smart bracelet (Liu et al., 2022). The finding for this study is the mechanical properties of TPU improve when blending with silicone especially elongation at break. This causes the suitability of application phone casing and band smart bracelet that have high flexibility. The excellent in flexibility is due to and Silicone has very soft that blend with the TPU that already better in flexibility.

2.3.3(c) Smart Material

There has also blending of TPU with Polycaprolactone (PCL) to produce self-healing thermoplastic (Smart material) according to the recent study (Xu et al., 2018). TPU and

PCL blend is a form of thermally sensitive shape memory polymer that has a wide range of applications. According to the findings from the X-ray Powder Diffraction (XRD) and Dynamic Mechanical Analysis (DMA) results, the blending of TPU/PCL has a significant impact on the shape recovery ratio and shape fixed ratio, which is ideal for smart material applications such as self-healing material.

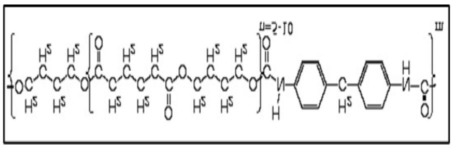
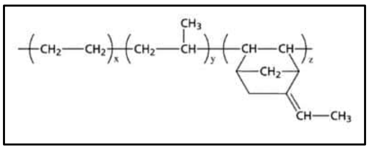
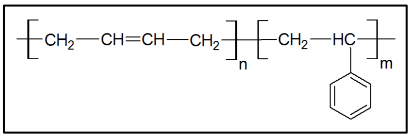
CHAPTER 3

MATERIAL AND METHODOLOGY

3.1 Raw Material

In this research study, the raw material used in the fabrication of flexible filament that is used for the Anatomical model is Thermoplastic urethane (TPU) (85A and 95A), Ethylene propylene diene monomer (EPDM), and Styrene-butadiene rubber (SBR). The general description of raw material is shown in Table 3.1.

Table 3.1 The detail of raw material for the fabrication of flexible filament

Raw Material	Form	Description	Chemical Structure	Founder
Thermoplastic urethane (TPU) (Grade 85A and 95A)	Filament with diameter 1.75mm (need to pelletize for blending)	Function as hard component which consist of hard and soft domains and polymer matrix		ROBOTEDU ENTERPRISE
Ethylene propylene diene monomer (EPDM)	Batch (need to cut into small pieces)	Function as soft component and polymer/rubber filler		ExxonMobil Chemical Asia Pacific
Styrene-butadiene rubber (SBR)	Batch (need to cut into small pieces)	Function as soft component and polymer/rubber filler		Bayer (M) Ltd.