THE STUDY OF SURFACE ROUGHNESS ON LAMINATED TRANSFEMORAL SOCKET

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DISSERTATION SUBMITTED IN FULFILMENT OF
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ABSTRACT

Prosthesis is an artificial limb used by a patient with amputation to replace the original limb. Common material used in Malaysia in fabricating a transfemoral sockets is the polypropylene plastics instead of laminated composite. Polypropylene is known to be weaker and less durable compared to laminated composite. However, discussion of other mechanical characteristics such as surface profile which can contribute to patient's comfort is still very limited. Thus, this research aims to study the surface analysis in laminated transfemoral socket fabricated using different reinforcement materials, type of resin and resin to hardener ratio. In this study, 15 transfemoral sockets were fabricated with different reinforcement materials and different types of resin and ratio. The lateral part of the socket was then cut as a sample for surface testing. A total of 20 trials were done on each surface sample using the Mitutoyo Surftest SJ-210 and the data was recorded in Microsoft Excel. An analysis was done to evaluate the internal surface of the sockets after the samples were tested using the Mitutoyo SurfTest SJ-210 series. Transfemoral socket interface directly to the patient skin without any usage of liner which could lead to skin impairment and inflammation. Fibreglass was shown to be the smoothest surface as the average surface roughness is the lowest at 2.318 µm, followed by Polyester at 2.380 µm, Perlon at 2.682 µm, Elastic Stockinette at 2.722 µm and Dacron felt at 3.750 µm. As for the different types of resin and hardener, the smoothest internal surface was produced by the 3:2 epoxy resin to hardener ratio, followed by 3:1, 2:1 and lastly with value higher than 1, 2:3. The socket made with 1:3 resin to hardener ratio was excluded in surface testing as the composite did not cure and ended up in a liquid state. As for the acrylic resin, the smoothest surface was produced by the ratio of 100:1 resin to hardener, with Ra value of 1.0086 µm. The 100:1 resin to hardener ratio took the longest time to cure at 167 minutes, thus it is expected to produce the smoothest surface. Meanwhile, the cure time for 100:2 resin to hardener ratio was reduced significantly to just 43 minutes, and this also doubled the Ra value to 2.3622 μm as compare to 100:1 ratio. This result suggested that laminated socket using epoxy resin reinforced with fibreglass produces the smoothest socket compare to acrylic and other reinforcement materials.

Keyword: Laminated Prosthesis, Transfemoral Socket, Resin Composite

ABSTRAK

Prostesis ialah anggota badan palsu yang digunakan oleh pesakit yang diamputasi untuk menggantikan anggota badan asal. Bahan yang biasa digunakan di Malaysia dalam membuat soket transfemoral ialah plastik polipropilena dan bukannya komposit berlamina. Polipropilena diketahui lebih lemah dan kurang tahan lama berbanding komposit berlamina. Walau bagaimanapun, dari segi ciri mekanikal lain seperti profil permukaan, sumber rujukan adalah sangat terhad. Oleh itu, penyelidikan ini bertujuan untuk mengkaji analisis permukaan dalam soket transfemoral berlamina yang difabrikasi menggunakan bahan peneguh yang berbeza, jenis resin dan nisbah resin kepada pengeras. Dalam kajian ini, 15 soket transfemoral telah direka dengan bahan peneguh yang berbeza dan dan jenis resin dan nisbah yang berbeza. Bahagian sisi soket kemudiannya dipotong sebagai sampel untuk ujian permukaan. Sebanyak 20 percubaan telah dilakukan pada setiap sampel permukaan menggunakan Mitutoyo Surftest SJ-210 dan data telah direkodkan dalam Microsoft Excel. Analisis dilakukan untuk menilai permukaan dalam soket selepas diuji dengan siri Mitutoyo SurfTest SJ-210. Permukaan soket transfemoral bersentuh terus ke kulit pesakit tanpa sebarang penggunaan pelapik dan ini boleh membawa kepada kerosakan dan keradangan kulit. Keputusan menunjukkan Gentian kaca merupakan permukaan paling licin dengan purata kekasaran permukaan paling rendah iaitu 2.318 µm diikuti oleh Poliester dengan 2.380 µm, Perlon dengan 2.682 µm, Elastic Stockinette dengan 2.722 µm dan Dacron felt dengan 3.750 µm. Sementara itu, bagi jenis resin dan pengeras yang berbeza, permukaan dalam yang paling licin dihasilkan oleh nisbah resin epoksi kepada pengeras 3:2 diikuti dengan 3:1, 2:1 dan terakhir dengan nilai lebih tinggi daripada 1, 2:3. Soket prostetik yang dibuat dengan nisbah resin 1:3 kepada pengeras dikecualikan daripada ujian permukaan kerana komposit tidak terawet dan ia berakhir dalam keadaan cair. Bagi resin akrilik, permukaan paling licin dihasilkan oleh nisbah 100:1 resin kepada pengeras, dengan nilai

Ra 1.0086 µm. Seperti yang dibincangkan, nisbah 100:1 mengambil masa paling lama untuk terawet iaitu 167 minit, justeru ia dijangka menghasilkan permukaan yang paling licin. Nisbah resin kepada pengeras 100:2 mengurangkan masa pengawetan dengan ketara kepada hanya 43 minit dan juga menggandakan nilai Ra kepada 2.3622 µm berbanding nisbah 100:1. Keputusan ini mencadangkan soket berlamina menggunakan resin epoksi yang diperkuat dengan gentian kaca menghasilkan soket paling licin berbanding dengan bahan akrilik dan tetulang lain.

Kata kunci: Prostesis Berlamina, Soket Transfemoral, Komposit Damar

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LIST OF SYMBOLS AND ABBREVIATIONS

PP : Polypropylene

POP : Plaster of Paris

PVA : Polyvinylalcohol

DW : Diabetic Wound

PE : Polyethylene

SPSS : Statistical Package for the Social Sciences

BPEC : Banana Pseudo Epoxy Composite

Ra : Average Surface Roughness

Rq : Root Mean Square Roughness

Rz : Ten points Surface Roughness

CP : Copolymers Socket

CF : Carbon Fibre

ISO : International Organization for Standardization

PETG : Polyethylene terephthalate glycol

ECH : Epichlorohydrin

SEM : Standard Error Mean

CHAPTER 1: INTRODUCTION

This chapter covers the knowledge of prosthetics and orthotics generally to provide a better understanding of the research. This includes the types of prosthesis available, an overview of what a transfemoral prosthesis is, and the difference between a laminated socket and a polypropylene socket. This chapter also states the problems that have led to this study, the scope of work, objectives, and the organization of this thesis.

1.1 Background

Prosthetics is a field that studies the replacement of missing body parts with artificial parts or known as prosthetic devices (Wurdeman et al., 2018). Most parts of the human body currently have prosthetics substitute such as the eyes, tooth and limbs (Murray, 2005; Pibarot & Dumesnil, 2006; Weiland & Humayun, 2008). However, the concerns of prosthetists—practitioner in making of artificial limbs, involve the human limbs (Mackenzie et al., 2018; Mackenzie et al., 2020). Human limbs consist of bone and muscle structure that are unable to regenerate once lost as illustrated in Figure 1.1.

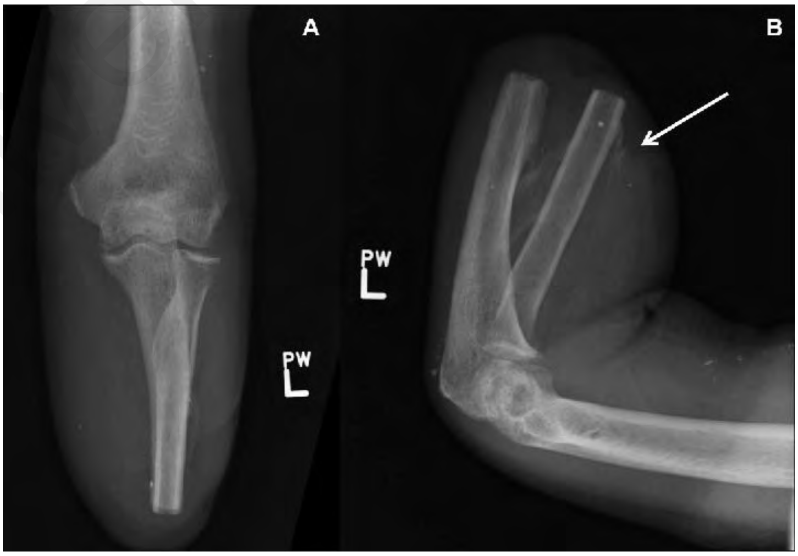


Figure 1.1: Example of residual limb structure

(Retrieved form: https://www.researchgate.net/figure/X-ray-image-of-the-left-residual-limb-A-Anterior-posterior-image-with-no-soft-tissue_fig2_281171253)

Thus, artificial limb is made in order to replace the function of the missing limbs or for cosmetics purposes. Known causes of limb loss are trauma, congenital, and diseases such as diabetes, necrotizing fasciitis and many more (Karim et al., 2020). Prosthesis—the artificial limbs, is classified into two main groups which are the upper limbs prosthesis and lower limbs prosthesis. Lower limbs prosthesis cases are more common compared to upper limbs prosthesis especially in Malaysia due to diabetes cases (Karim et al., 2020). Upper limb prosthesis cases are normally caused by trauma or congenital (Cordella et al., 2016). In fabricating a prosthesis, the first step is to take the shape of the patient's residual limb; this is called casting. The practitioner will cover the residual limb with wetted Plaster of Paris (POP) bandage and wait until it hardens. Once removed, the practitioner will get a negative cast which is the hardened POP bandage with all the information of the residual limb—shape, size and sensitive area marks. Then a POP slurry will be poured into the negative cast to make a positive cast which is a hard so it can be modified and used as a sample in fabricating a socket.

1.2 Types of Prosthesis

Prosthesis comes in many types and characteristics according to patients' needs (Laing et al., 2011). Prosthetic devices are custom made to compensate for patients' limbs and for best functionality. The main classifications are the upper and lower limbs, then it is further classified based on the positions of the residual limb (Cordella et al., 2016; Karim et al., 2020). There are two kinds of nomenclature mainly used in describing the type of prosthesis which are based on the joints and another one is based on the bone's name. For example, upper limbs prosthesis as illustrated in Figure 1.2 types include below elbow or transradial prosthesis, upper elbow or transhumeral prosthesis, shoulder prosthesis or transcapular prosthesis, and lastly the partial hand prosthesis or transmetacarpal or transcarpal prosthesis.

Figure 1.2: Example of Upper Limb Prostheses

(Retrieved from: Upper Limb Prosthetics - Roger Wolfson and Associates upper limb prosth (rwaa.co.za))

For the lower limb, there are hip prosthesis, above knee prosthesis or transfemoral prosthesis, below knee prosthesis or transtibial prosthesis, and partial foot prosthesis or transmetatarsal prosthesis. Example for lower limb prosthesis is shown in Figure 1.3.

Figure 1.3: Example of Lower Limb Prosthesis

(Retrieved from: https://prostheticsolutions.com.au/lower-limb/)

Each of the types also differ in length based on patients’ residual limb length, fabrication technique, type of materials used and the components used in assembling the devices. The two most common fabrication techniques used in making a prosthetic device are thermoforming and lamination. Thermoforming softens a plastic sheet and transfer it to a positive cast. It is then vacuum-suctioned to make sure the plastic takes up the positive cast shape perfectly. The main types of plastic used nowadays are polypropylene (PP) and polyethylene (PE). Lamination technique uses resin and hardener mixture incorporated into reinforcement materials sandwiched between Polyvynilalcohol (PVA) bag on a positive cast.

1.3 Transfemoral Prosthesis components

Transfemoral prosthesis or the above knee prosthesis is an artificial limb used by patients with amputated or missing lower limb between the hip and the knee. This device consists of four main components which are the socket, a knee joint, pylon and foot part.

Figure 1.4: Transfemoral Prosthesis Component

(Retrieved from: https://www.pinterest.com/pin/114067803046019175/)

The socket part as labelled in Figure 1.4 is the interface between the patient and the device. It also provides suspension for the devices. The most common type of suspension for a transfemoral prosthesis is the vacuum suction; where a vacuum condition exists between the prosthetic socket and the patient skin. This will hold the prosthesis in place very firmly. If the residual limb is short, some practitioner will opt for pin and lock suspension system. Lack of surface area from the short residual limb will create less vacuum thus pin and lock is the optimum choice for better suspension and patients' confidence. Suspension belts are sometimes added especially for new users to provide extra security and to build their trust in using the prosthesis. Once the patient is fully confident and fully trusts his new artificial limb, the belt will be removed. The socket is very important in transfemoral prosthesis as slight deviation in size and fit will disrupt the vacuum and it will be impossible to hold the prosthesis. Transfemoral prosthesis socket also interface directly to the patient’s skin; to avoid any skin impairment from donning and utilizing the devices, the surface of the socket must be smooth. The next component is the knee joint. The knee joint comes right after the socket and is attached to the socket. Knee joint mimics the mechanic and function of a real knee to allow a prosthetic user to walk and sit normally. A basic knee joint operates mechanically; it uses the force exerted by the user and normal force from the ground to flex (bend) and extend (straighten). An advanced knee joint, on the other hand, has complex electronic system which incorporates microcontroller and sensors in controlling the knee joint. Detection of motion mimics a knee movement better and lets the user walk as close as possible to a biological leg. Some high-end advanced knee joint is also used in controlling the ankle movement of a transfemoral prosthesis. A pylon attaches the knee joint to the foot part. The pylon is also used to adjust the length of lower limb prosthesis devices. The foot part is used in transfemoral prosthesis to provide stability and normal force from the ground.

1.4 Polypropylene Socket vs Laminated Socket

Polypropylene is the main type of plastic used in thermoforming technique in fabricating a prosthesis especially in lower limbs (Abbas, 2018; Me et al., 2012; Neama et al., 2007) Not only is it hard and sturdy enough to support human weight, polypropylene is also easier to work with as compared to lamination materials in fabricating a prosthesis socket (Neama et al., 2007). In terms of cost, the PP socket value is less than laminated socket, which can be as low as a third of the price for laminated socket. This takes into consideration the materials used in fabricating the PP socket and the expertise needed to in fabricating both sockets. The procedure in fabricating a PP socket is simpler compared to the procedure of lamination. Both sockets need the same positive cast. For PP socket as illustrated in Figure 1.5, the practitioner has to soften a sheet of polypropylene in an oven before transferring the plastic onto the positive cast that is placed on a vacuum platform so that the plastic will stay perfectly in shape according to the positive cast.

Figure 1.5: Polypropylene Transfemoral Prosthesis Socket

(Retrieved from: https://www.researchgate.net/figure/Transtibial-TT-Transfemoral-TF-Test-socket_fig1_325754330)

The laminated socket as illustrated in Figure 1.6 , on the other hand, comes with more steps after the positive cast is obtained. The positive cast is placed on a two-holed vacuum pole before it is covered with a layer of PVA bag. Then, layers of reinforcement materials are laid onto the PVA bag and lastly a second layer of PVA bag is used to cover the reinforcement materials. The point is to sandwich the reinforcement materials in between the PVA bags according to the shape of the positive cast. Then, resin mixture will be poured into the PVA to bind the reinforcement materials, creating a composite. Vacuum suction is switched on to avoid air bubbles formation and to make sure that the composite socket follows the positive cast perfectly.

Figure 1.6: Laminated Transfemoral Prosthesis Socket

(Retrieved from: It RESIN-ates - Standing With Hope)

1.5 Problem Statement

Most high-end prosthesis use laminated socket as their stump-patient interface. This is due to the strength of laminated prosthetic socket is about three times higher as compare to polypropylene socket (Chiad & Hasan, 2009). Many researchers are keen in finding new fibre especially from natural waste or local abundance materials (Campbell et al., 2012; Odusote et al., 2016) for a laminated socket. These studies analyse the physical properties of laminated sockets, but none of the studies touched on the surface properties of laminated prosthetic sockets. Physical properties that are usually examined are flexural strength and tensile strength of the socket when fabricated with different materials.

With the transfemoral socket directly touching the patient skin, it is important to analyse the internal surface of the socket to prevent any skin impairment and discomfort to the prosthetic user. There are differences in surface roughness between epoxy and acrylic resin. Thus, the author is keen to investigate the surface roughness of both types of resin to identify the best fabrication option for a prosthetic socket.

With the progression prosthetic and orthotic technologies, laminated socket will be frequently provided to amputees as their main socket. This thesis serves as guideline and can provide useful information for prosthetist and orthotist in fabricating a laminated socket with regards for surface roughness produced and time taken for different combination of resin and hardener.

1.6 Aim and Objectives of the Study

The purposes of this project are:

1. To determine the best ratio for epoxy and acrylic resin for fabricating a smooth laminated prosthesis socket.
2. To determine the best reinforcement materials between Perlon stockinette, polyester stockinette, elastic stockinette, Dacron felt and glass fibre for fabricating a smooth laminated prosthesis socket.
3. To measure the surface roughness of different combination of laminated prosthetic socket fabricated from different reinforcement materials and type of resin.

1.7 Scope of Study

This research is conducted to study the internal surface roughness of laminated transfemoral socket fabricated using different materials and different types of resin. A total of 15 laminated transfemoral sockets were fabricated using five different materials and five different ratios from two types of resins.

Surface roughness from all different transfemoral sockets were taken using Mitsumoto Surface Tester and values obtained were analysed using SPSS data analysis.

1.8 Organization of Thesis

This thesis consists of five chapters. In the first chapter, the introduction and the basic knowledge about prosthesis are discussed. This includes the types of prosthesis available and most commonly used by patients nowadays. Chapter 2 focuses on the previous studies by past published articles related to the study. This includes the differences in strength between PP and laminated sockets, the materials utilised in laminated prosthesis fabrication, and the skin's reaction to prosthesis use. Next, Chapter 3 discusses the experiment's design and how the data is processed, while Chapter 4 presents the experiment's results. Finally, in Chapter 5, the conclusion of the results provided is included, as well as discussion of the limitations and obstacles, and possible improvements.

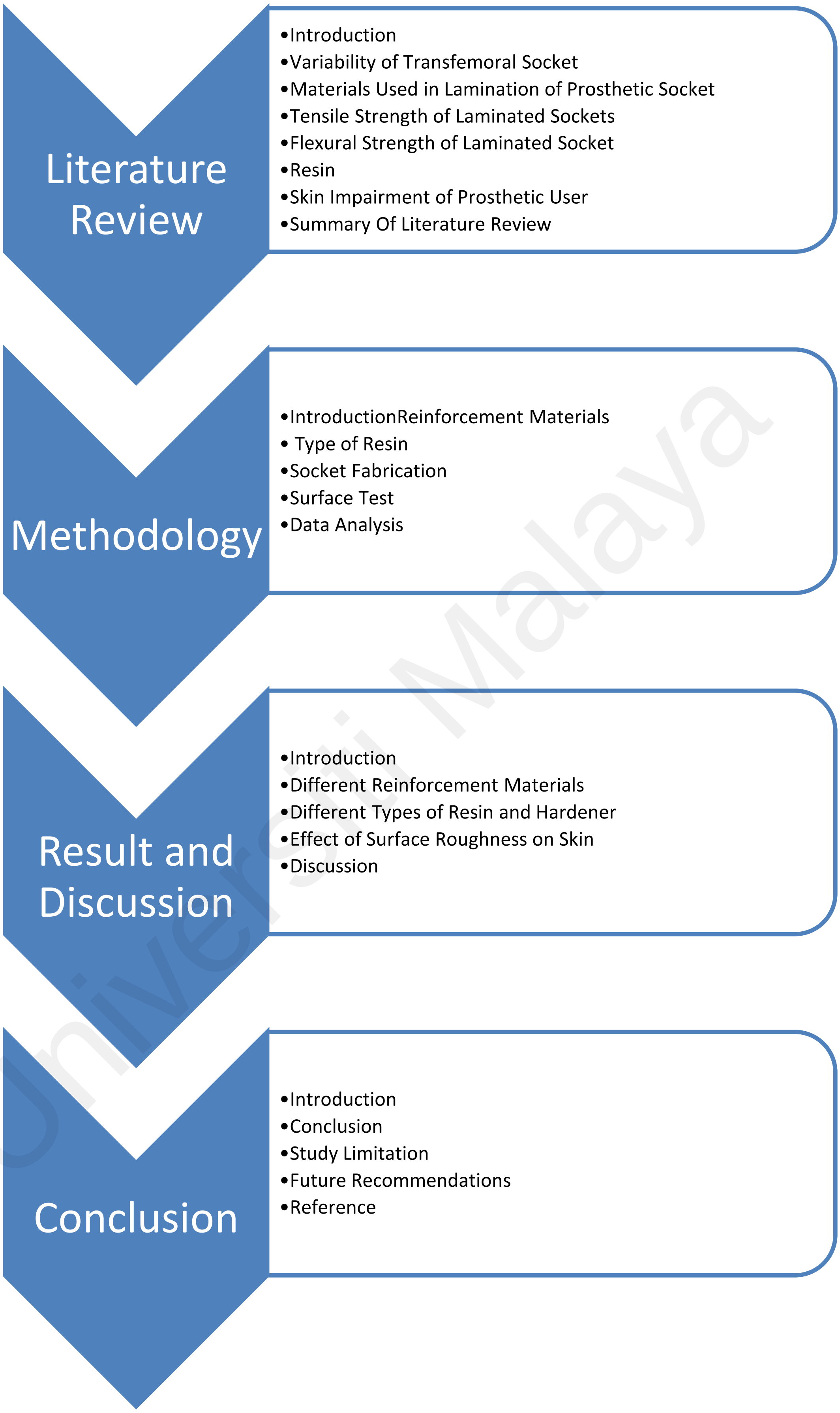


Figure 1.7: Thesis Flowchart

CHAPTER 2: LITERATURE REVIEW

In this chapter the variability of laminated socket as well as the strength of laminated socket that were reported in previous study will be discussed. It also contains discussions on the materials used in fabricating laminated socket which are the reinforcement materials and the resin types. The characteristics of the materials and resin will also be described. Lastly, the impact of roughness of a socket to the patients' skin is mentioned.

2.1 Variability of Transfemoral socket

The fabrication of a laminated prosthetic socket has been found to be more consistent. As comparison to the check socket and copolymer socket, the laminated socket has the least variation in average strength, with just 25% relative standard deviation, compared to 49% for check sockets and 61% for copolymer sockets from various facilities. It also comes second when the sockets come from the same facilities which is only 21% just behind the check socket with 15% while the copolymer socket has 42% relative standard deviation (Gerschutz et al., 2012). During tensile testing, the average standard deviation for all samples was 13% for Epoxyacryl (Foresee), 9% for Lamination Resin 80-20 (IPOS), and 12% for Laminhartz 80-20 (Otto Bock) (Phillips & Craelius, 2005).

2.2 Materials Used in Lamination of Prosthetic Socket

The most common materials used in making laminated prosthetic socket are carbon fibre, fibreglass, Perlon stockinette and Nyglass, where 8 studies out of 16 had used carbon fibre, 6 studies had used fibreglass, 5 studies had used Perlon and 3 studies had used Nyglass.

(A)

(B)

(C)

(D)

(E)

(Retrieved from: (A) Perlon Stockinette (spsco.com), (B) Polyester Fibre Stockinette - Sangyug Online, (C) Polyester Elastic Stockinette | North Coast Medical (ncmedical.com), (D) 27" WIDE DACRON POLYESTER FIBRE BATTING / WADDING Priced per metre - The Foam Shop, (E) CROMAR GRP FIBREGLASS MATTING CSM450GM (APPROX 16.5KG) - GRP Glassfibre Roofing - Flat & Pitched - Roofing | Manningham Concrete)

The strength of these materials were compared in the studies and they are used as a standard when studying new materials. Based on the Ottobock materials catalogue, Perlon is a knitted fabric, is finely meshed, can be stretched based on circumference, has good shaping properties and produce smooth surface after laminating; hence it suitable for surface. Carbon fibre is used for axial reinforcement (bending forces) of thin-walled, high-strength laminates. It is especially designed for use with acrylic resins; the elastic weft thread allows the carbon threads to maintain their 0° orientation, regardless of the diameter, where no elaborate cutting or forming work is required with formed model. The elastic weft thread facilitates forming the stockinette to the model and saves valuable working time. Fibreglass can produce thin-walled laminates, have good braiding and high torsional strength in laminates but the torsion can be influenced by different circumferences (ideal angle is 45°). It also has good draping characteristics. Nyglass has a blend of polyamide (35%) and fibreglass (65%), also knitted fabric, finely meshed, provide high strength but has low resin absorption combined with high stability (Ottobock, 2007). A study by Abbas (Abbas, 2018) showed that sockets that use carbon fibre give the highest ultimate tensile strength followed by fibreglass and lastly Perlon. The eight-layer socket with two carbon fibre in the middle produces the ultimate tensile strength of 175MPa, while the same lay-up replaced by two fibreglass in the middle produces only 50.4MPa,eight-layer socket with only Perlon only produce 44.4MPa and Nyglass produce 43.4MPa of tensile strength. This proves that carbon fibre provides the highest strength-to-weight ratio followed by fibreglass, Perlon and Nyglass. In the effort of producing a biological composite as a new material in laminating, it shows great performance as records show that the new materials are able to perform as well as the existing materials commonly used in the industry. Campbell et al. (Campbell et al., 2012) stated that a ramie composite can withstand 6.5% higher load compare to the standard socket (Nyglass). The banana pseudo epoxy composite (BPEC) used by Odusote et al. (Odusote et al., 2016) shows promise with the results of BPEC shown to be higher than that of fibreglass composite.

2.3 Tensile Strength of Laminated Sockets

Tensile strength is the maximum pressure an object can withstand before breaking. The experiment performed by Gerschutz et al. (Gerschutz et al., 2012) demonstrated great performance strength for industrial laminated prosthetic socket with the highest compression force shown to be 5,713 N while the lowest was at 2,791 N. Relative to the common copolymer prosthetic socket, the average strength of laminated socket is calculated to be about 3.6 times higher than the average of copolymer socket. The highest recorded tensile strength is 422 MPa which was fabricated using three layers of carbon fibre by Aisyah et al. (Aisyah et al., 2018) followed by 175 MPa that was fabricated with 3 Perlon + 2 carbon fibre + 3 Perlon lay-up by Abbas (Abbas, 2018) and the third highest tensile strength recorded is 152.5 MPa fabricated using 10 layers of Perlon and two layers of carbon fibre performed by Jweeg et al. (Jweeg et al., 2018). The banana pseudo epoxy composite experimented by Odusote et al. (Odusote et al., 2016) have the highest tensile strength of 70.05 MPa when the fibre ration is 50% exceeding the 30% glass fibre composite. The tensile strength value is approximately constant at 42 MPa for samples containing between 5 and 12.5 Wt%-graphite. The inclusion of 15% and 30% graphite leads to a further drop in tensile strength, reaching a minimum of 26 MPa for RG 30%. Aisyah et al. (Aisyah et al., 2018) showed that it is among the top socket fabricated as the tensile strength achieved by this socket are above 100MPa with 6x6Kenaf/CF plain (127 MPa), 6x6Kenaf/CF satin (106 MPa), 5x5 kenaf/CF plain (117 MPa), and 5x5 kenaf/CF satin (104 MPa). Jweeg et al. (Jweeg et al., 2018) showed that with the growth of fibreglass layers, the mechanical properties are obviously improved for continuous Perlon layers. Using two layers of fibreglass instead of zero layer with six layers of Perlon leads to an increase in ultimate strength by 30.4%. This indicates that by increasing the number of the same type of fabric or fibre layer, the strength of the composite increases. Campbell et al. (Campbell et al.,

2012) discovered that the ramie composite socket failed at 6,180 N and the standard lay-up socket of Nyglass stockinette fail at 5,800 N at a loading of roughly 6.5% higher than the typical lay-up, where the resin and ramie socket failed. The carbon fibre composite samples have the greatest Young's modulus (8.8 GPa) and ultimate tensile strength of all the samples (127.5 MPa). The acrylic resin and ramie socket failed at 4,650 N. While this is around 20% less than the normal lay-up, it is still more than the 4,025 N that an ISO 10328 socket must bear. (Gerschutz et al., 2011) demonstrated that different resin types also have significance as their study showed that the pigmented resin and nonpigmented resin resulted in different tolerance which are 100.6 MPa and 58.6 MPa respectively. This proves that it is not only fabric or fibre materials that effect the socket fabrication but also the type of resin used.

Table 2.1: Properties of Materials Commonly Used in Fabricating Prosthesis

Materials	Ultimate Strength (MPa)	Stiffness E (GPa)	Strain to failure %
Carbon Fibre	2070-2750	10-380	1.6-2
Fibreglass	1700	68	5-5.5
Nylon	55-83	1.2-2.4	>5
Polyethylene	7-41	0.13-1.3	>5
Polypropylene	28-41	1.3	>5

(Retrieved from: Effects of Lamination Layers on the Mechanical Properties for Above Knee Prosthetic Socket)

2.4 Flexural Strength of Laminated Socket

Flexural strength indicates the flexibility of the prosthetic socket. The tensile strength and the flexural strength may be inversely proportional as shown by Gerschutz et al. (Gerschutz et al., 2011) where the carbon lamination with nonpigmented resin tensile strength at yield is 51.7 ± 29.0 MPa which is higher than the pigmented lamination resin at 43.8 ± 14.0 MPa. However, the tensile strength of nonpigmented lamination resin at break is 58.6 ± 24.0 MPa which is lower than the pigmented lamination resin at 100.6 ± 11.0 MPa. This is also supported by J. Chiad and Hasan (Chiad & Hasan, 2009) that examined below knee prosthetic sockets which consist of a lay-up of 3 Perlon + 1 carbon fibre + 3 Perlon layers. The ranges of the absorbed energy recorded for this lamination were between 74.8%-89.40% for all levels of impact mass and height. The second lamination which consists of 3 Perlon layer + 2 carbon fibre + 3 Perlon layers have the range of absorbed energy of 67.9%-80%. Finally, the third lamination which consists of a lay-up of 4 Perlon + 2 carbon fibre + 4 Perlon layers recorded a range of absorbed energy of 60.9%-68.3% while the tensile strengths are 47, 52.4 and 54.7 MPa respectively.

Nurhanisah et al. stated that composite B which consist of (Helanca stockinette, Kenaf woven, Glass Silk Stokinette, and Helanca Stockinette) has a slightly greater flexural modulus (234.6 MPa) than composite A which consist of (Helanca Stockinette, Kenaf woven, Kenaf Woven, Glass Slik Stockinette, Helanca Stockinette) (229.6 MPa) (Nurhanisah et al., 2018). It indicates that by adding one layer of kenaf fibre to composite B, the flexural modulus improved by 2%, and the flexural strength of composite B (7.11 MPa) is 13.64%t greater than composite type A (6.14 MPa). The flexural strength at 0, 20, 30, 40, and 50% were 29.21 ± 1.14, 44.21 ± 0.21, 55.77 ± 0.21, 72.31 ± 0.03 and 77.02 ± 0.11 MPa, respectively as mentioned by Odusote et al. (Odusote et al., 2016) Both of the studies mentioned show that the composites exhibit better flexural strength with increased number of lay-up materials.

2.5 Resin

As a final material, a resin or plastic composite can be repeatedly softened and hardened by heating and cooling. Thermoplastic materials include acrylic, cellulosic, chlorinated polyether, fluorocarbons, polyamides (nylons), polycarbonate, polyethylene, polypropylene, polystyrene, polyurethanes and vinyl resins. These polymers are made up of long linear chains or long chains with branching. In its end state, a resin or plastic composite is largely infusible and insoluble. At some point during their production or processing, thermosetting resins are liquids that are cured using heat, catalysis or other chemical methods.

Figure 2.1: Polymers crosslink of different plastics

(Retrieved from: http://semesters.in/what-is-elastomer-and-properties-of-elastomer-notes-pdf-ppt/polymer-structures/)

They create a three-dimensional network that is crosslinked. Thermosets cannot be melted when being reheated once they have been properly cured. Crosslinking procedures can be used to convert thermoplastics to thermosets. Alkyd, allyl, amino, epoxy, furane, phenolic, polyacrylic ester, polyester, and silicone resins are examples of thermosetting polymers. The main distinction is in the molecular architecture (Ehrenstein, 2012).

2.5.1 Epoxy Resin

2.5.2 Bisphenol A diglycidyl ether (E-44 and E-51) is the most widely used epoxy resin (>85%). It is manufactured from bisphenol A (DPP) and epichlorohydrin (ECH). The hydroxyl groups in its molecular structure and the epoxy groups at polymer-chain ends offer reactivity, while the DPP skeleton provides strength, toughness and heat resistance to the cured product **(Jin et al., 2015).**

Figure 2.2: Epoxy resin comes with Type A and Type B Parts

(Retrieved from: Epoxy Resin water clear casting Full Kit 7.5kg - Chem Distro)

A hydrogenated bisphenol A epoxy resin (AL-3040) is produced by reacting hydrogenated DPP with ECH. During the hydrogenation reaction, the unsaturated double bonds on the benzene rings become more stable, increasing the epoxy resin's endurance. Its viscosity and hydrolyzed chlorine concentration are lower than E-44 and E-51, making it more in line with the performance requirements of pavement binders. Hydrogenated bisphenol A epoxy resins with superior weatherability can extend the service life of a product while lowering life-cycle costs. And, unlike traditional bisphenol A epoxy resin which is easily broken, its toughness allows it to meet the mechanical needs of the pavement structure, notably the thermal cracking requirements of the pavement surface. Second, the reduced viscosity of the mixture can increase its workability, particularly in the low-temperature construction process. Due to the high cost of typical bisphenol A epoxy resins, AL-3040 costs roughly 2.44 times as much as regular bisphenol A epoxy resin.

2.5.2.1 Curing agent

T31, a phenolic-modified amine curing agent, has low viscosity and can cure epoxy resins at room temperature, but it produces brittle results. Even if toughening chemicals are used, the cured product's hardness cannot be significantly increased. Because room-temperature curing was required, we used polyamide 650, a modified amine curing agent. Polyamide 650 is made from tung oleic acid dimer and diethylenetriamine with a molecular weight of 600–1100. A lengthy fatty acid carbon chain, amino acids, and a rotatable ether bond make up its chemical composition, resulting in a cured product with excellent elasticity, adhesive force, water resistance, and toughness. Polyamide 650 has a moderate viscosity and mechanical qualities at room temperature, and it can react with epoxy resin. Furthermore, this low-molecular-weight polyamide system has low volatility, is non-toxic, and does not irritate the skin.

2.5.3 Acrylic Resin

Acrylics are polymerized by free radical polymerisation, which results in three distinct reactions: (i) Radical peroxides (initiators or catalysts) are commonly used to initiate reactions because they contain unpaired electrons that open double bonds (unsaturation) in the monomers, resulting in the formation of reactive radical sites on the monomers; (ii) unreacted monomer molecules are successively 'caught', and additional unpaired electrons become accessible at increasing chain ends, resulting in the chain propagation process; and (iii) after that, development can be stopped by recombination, usually in the presence of another radical, or by using a termination agent. Variables in the process such as initiator concentration, temperature, and pressure have been demonstrated to have a significant impact on the kinetics of radical polymerisation processes and, subsequently, the molecular weight and molecular weight distribution that occur (Ehrenstein, 2012; McCrum et al., 1997). It's critical to understand how they affect the resulting acrylic polymer system in order to establish a firm foundation of knowledge about the ideal processing conditions. Below is a summary of published research on the polymerization behaviour of acrylics as a function of processing factors.

Figure 2.3: Ottobock Acrylic Resin

(Retrieved from: 617H21 Orthocryl sealing resin - Ottobock)

2.5.3.1 Influence of initiator content

It was discovered that the concentration of the initiator effects the reaction phases of free radical polymerisation using the E 150 grade of liquid acrylic resin and a commercial organic peroxide. Slower initiation and termination reaction rates are promoted by both high (1.6%) and low (0.8%) initiator concentrations than an intermediate concentration (1.2%). The authors concluded that these findings were linked to the availability of the radical species provided by the initiator, based on higher onset temperatures (75 °C) for the high and low concentrations and lower temperatures (58 °C) for the intermediate concentration. It was hypothesised that at a lower radical concentration (0.8 percent), fewer acrylic monomer molecules were launched, resulting in the formation of a few lengthy chains and the observed behaviour. Higher concentrations (1.6%), on the other hand, stimulated the formation of many short chains at the same time. These effects are thus concluded to be combinatory effects of competitive chain expansion and final termination reactions in all situations. Surprisingly, up to the terminal cycle temperature, the lowest initiator content caused an instantaneous, exponential increase in viscosity (rheological study). At all phases of the polymerisation procedure, increasing the initiator content was found to lower viscosity.

Figure 2.4: Ottobock Hardening Powder

(Retrieved from: [Orthocryl Sealing Resin | Lamination Resins | Lamination Technology | Materials & Equipment | Prosthetics | Ottobock US Shop])

2.6 Diabetic Wounds Complication

Diabetic wounds (DW) are a major concern, with leg ulcers and diabetic ulcers being the most common. Diabetes slows wound healing by impairing each step of wound healing, including haemostasis, inflammation, proliferation, and remodelling, resulting in a long-term deleterious impact on quality of life, morbidity, and death. A delayed acute wound or chronic wound with impaired healing due to a postponed, incomplete, or disorganised healing process characterises DWs. A protracted inflammatory phase is seen in DWs, which is accompanied by a delay in the production of mature granulation tissue and a decrease in wound tensile strength. This could be due to ischemia-induced vascular injury (Alavi et al., 2014; Galkowska et al., 2006). Each wound is a medical emergency that requires immediate attention. Wounds are classified into two groups based on their origin: exterior and internal. Cuts, injuries, burns, and bruises are examples of external origin wounds. Because of peripheral neuropathy, these exterior sores may go undiagnosed by diabetic patients. Internal wounds, such as skin ulcers and calluses, destroy the skin and adjacent tissues, increasing the risk of bacterial infection (Patel et al., 2019).

2.7 The Effect of Prosthetic Socket Roughness on Patient

Prosthetic socket surface affects the user in positive and negative ways. Surface roughness help the patient by controlling the unnecessary rotation of a socket (Mak et al., 2001). Study by Quinlan in 2020 reveals that using recently created testing procedures, that various texture patterns greatly enhanced torque in the transverse plane as compared to smooth sockets, particularly for passive suction. (Quinlan et al., 2020).

However, the roughness of the socket also affecting the skin as the pressure on the skin interface is high. The highest-pressure values are clearly associated with devices that transfer a considerable percentage of body weight through the body interface, such as prosthetic sockets with a wide range of peak pressures (34–417 kPa) and the interface beneath the foot (50–250 kPa). New tri-axial pressure and shear sensors based on capacitance design principles revealed substantial shear forces at the socket-skin interface in amputees in a recent study (Laszczak et al., 2015). Internal stresses/strains will be created in the immediate stump tissues as a result of the pressure and shear, increasing their risk of injury (Linder-Ganz & Gefen, 2007; Portnoy et al., 2008).

Interfacial rubbing between scar skin and other external surfaces, such as interfacial rubbing between the scar skin of an amputee residual limb and prosthetic materials, is a common problem in everyday life. The epidermis, subcutaneous tissue, blood vessels, and blood flow of the residual limb are all affected by the pressure and friction created by the movement. Reciprocal sliding friction on the skin surface would tend to degrade the stratum corneum barrier function's efficiency and cause skin damage (Lee et al., 2004; Wei Li et al., 2011). The coefficient of friction and energy dissipation between the prosthetic socket and liner materials are both affected by surface roughness (Schön, 2004; Xie et al., 2021). For a transfemoral patient with suction suspension, the socket interfaces directly on the patient’s skin thus impacting the skin condition.

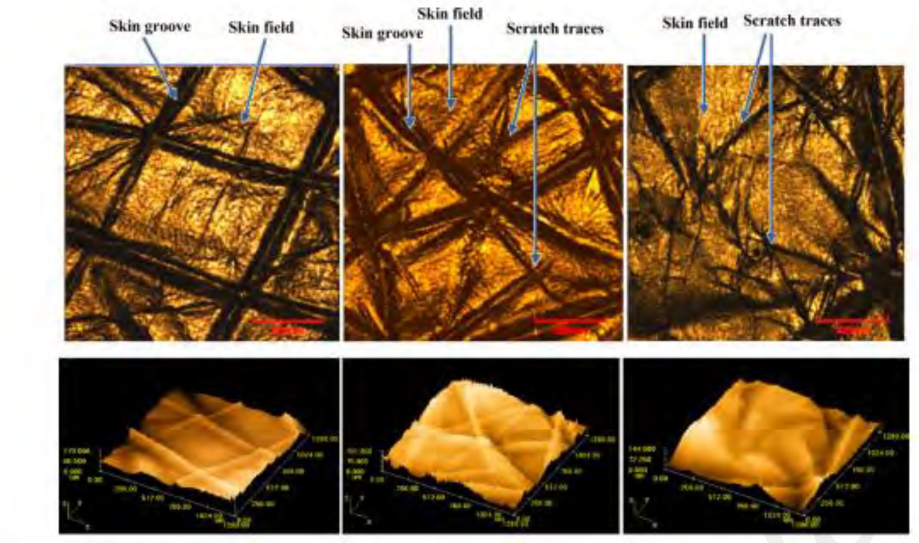


Figure 2.5: Morphologies of residual limb skin measured by laser scanning microscope.

(Retrieved form: Effect of prosthetic socks on the frictional properties of residual limb skin)

Reciprocal sliding friction on the skin surface would tend to break down the stratum corneum barrier function's efficiency and cause skin trauma, especially if the friction behaviours are caused by cyclic mechanical loads with high contact pressures and shear forces that last for long periods of time (Li et al., 2008). The SC layer is avulsed first during the friction course of the prosthetic socket material–rabbit skin interface. The epidermal layer is increasingly ruffled as a result, and tissue fluid and blood begin to extravasate. The lubricant is provided by the avulsed SC layer, exudation, and blood, which lead in the friction coefficient decreasing with time. Various degrees of erythema emerge on the skin surface after 1800 reciprocating cycles. Unlike traditional engineering materials, living organisms have the unique ability to self-repair harm. When living skin is injured, it undergoes a series of complicated changes in shape, biology, physics, and other factors that are split into two phases, namely the inflammation-removal phase and the tissue-rehabilitation phase.

2.8 Summary of Literature Review

By reviewing the performance of laminated composites that were studied by previous researchers, many information were gathered that are very useful in analysing the performance of laminated composites especially techniques that are used to make a prosthetic socket. A brief overview of the socket variabilities, materials used, tensile strength, Young's modulus and flexural strength are reported in this thesis. The author believe that this thesis will give basic knowledge of the work that have been done by previous researchers regarding laminated composite materials and technologies for prosthetic socket. Future work should be focusing on the development and promotion of new materials that are cheaper yet able to deliver the weight-to-strength ratio as the commercially-used carbon fibre. Mechanical properties are widely explored in this laminated prosthetics socket research due to its importance in maintaining and achieving better socket durability and strength. However, patients' comfort is also an important consideration in achieving full rehabilitation goals, thus other aspects such as surface profile, internal pressure and better cosmetic value also need to be considered.

No	Title	Author	Summary	Fabric used	Conclusion
1	Mechanical properties of laminated kenaf woven fabric composites for below-knee prosthesis socket application	(Nurhanisah et al., 2018)	The goal of this research is to make a prosthetic socket made of composite kenaf-glass fibre, as part of an effort to replace prosthetic sockets made of fibreglass polyester composites. The prosthetic socket was fabricated using lamination method. The volumetric and mechanical qualities of a series of kenaf fabric stacking were assessed. The findings suggest that woven kenaf fabric composites might eventually replace glass fabric-based polymer composites	The laminates include woven kenaf, fabric knitted with glass silk and fabric knitted with nylon.	The kenaf fabric is a fantastic solution for creating a laminated prosthetic socket since it is biodegradable, environmentally benign, locally available, lightweight, pleasant, and psychosocially acceptable.
2	*Strength evaluation of prosthetic check sockets, copolymer	(Gerschutz et al., 2012)	The user exerts loading pressures and torques on the prosthesis. Standard 10328 of the International Organization for Standardization (ISO) was created to evaluate the majority of lower-limb prosthetic	There are three types of sockets tested which are check socket (CS), copolymer socket (CP) and laminated socket (DL).	The socket performance from different makers varies significantly. Some insight into alternative pathways to improve

	sockets, and definitive laminated sockets		components. However, prosthetic sockets are not included in this standard. We estimated static failure loads of prosthetic sockets using a modified ISO 10328 and compared them to the criteria given for other components by this standard. CS and CP socket failed the ISO test while for DL socket, most of the sockets failed the brittle loading criterion.		patients' current treatment, and a comparative framework for future technologies was presented.
3	Synthesis and application of epoxy resins: A review	(Jin et al., 2015)	The purpose of this study is to provide an overview of epoxy resin manufacturing, curing, and applications.	The kind of epoxy resin, curing agent, and curing technique all influence the ultimate qualities of cured epoxy resins.	Epoxy resins have been widely employed for coatings, electronic materials, adhesives, and matrices for fibre-reinforced composites, because of its remarkable mechanical qualities, strong adhesion strength, superior heat

					resistance, and high electrical resistance,
4	*Tensile strength and impact resistance properties of materials used in prosthetic check sockets, copolymer sockets, and definitive laminated sockets	(Gerschutz et al., 2011)	The characteristics of materials used in prosthetic socket manufacturing are limited, especially after they have been exposed to fabrication techniques. The current state-of-the-art materials utilised to produce prosthetic check sockets, copolymer sockets, and final laminated sockets were examined for tensile and impact characteristics. The manufacturing procedures were used to sort definitive laminated sockets. Nyglass showed a substantially greater elongation than carbon-based laminations, showing that it is a more ductile material. Nonpigmented carbon sockets showed lower tensile strength and modulus at break	Thermolyn Rigid and Orfitrans polyethylene terephthalate glycol (PETG Nyglass showed a substantially greater elongation than carbon-based laminations, showing that it is a more ductile material.) check socket materials	Thermolyn Rigid and Orfitrans Stiff check socket materials have poorer tensile strength and impact resistance than polyethylene terephthalate glycol (PETG) check socket materials. Copolymer socket materials were more impact resistant than check socket materials, although they had lower tensile strengths than PETG. The hot moulding procedures reduced both tensile strength and elongation at break for the check

			than pigmented carbon sockets. Elongation at yield and elongation at break were the same for both types of carbon-based laminations.		socket and copolymer materials.
5	Mechanical Properties of Banana Pseudo-stem Fibre Reinforced Epoxy Composite as a Replacement for Transtibial Prosthetic Socket	(Odusote et al., 2016)	The goal of this study is to create a synthetic glass fibre transtibial prosthetic socket as a replacement. Epoxy resin was utilised (TKL 121). After treating continuous fibres with 5% NaOH and 2% ascetic acid solution, composite samples were made manually using the hand-lay-up method with fibre ratios of 0, 20, 30, 40, and 50 percent. In this study, the findings of a 30% glass fibre polyester composite (GFPC) were compared to those of a banana pseudo-stem epoxy composite (BPEC).	banana pseudo-stem, a natural fibre abundantly available in Nigeria. Banana pseudo-stem fibres are often considered as waste thus making them relatively cheap. They also have strong and lightweight materials. The goal of this research is to determine the qualities of banana pseudo-stem reinforced with epoxy composite materials in terms of tensile, flexural, and hardness. Banana	The tensile, hardness and impact tests of BPEC at 40 % fibre content were 64.23 ± 4.11 MPa, 63.31 ± 0.03 MPa, 55.23 ± 0.20 BHR, respectively. These were slightly lower than those of the glass fibre composite, which are 65.72 ± 3.30 MPa, 66.10 ± 1.88 MPa, and 61.05 ± 1.77 BHR, respectively. BPEC can also be further produced to act as a possible substitute for composite

				pseudo-stem fibres epoxy composite materials	glass fibre in the application of prosthetic sockets using the normal production process.
6	Glass Fibre Reinforced Polypropylene Mechanical Properties Enhancement by Adhesion Improvement	(Etcheverry & Barbosa, 2012)	Glass fibres (GF) are the most commonly used reinforcing agent in composites based on polypropylene (PP), since they have a strong combination of properties and costs. Their final properties, however, are primarily determined by the strength and stability of the interphase of the polymer-fibre. Fibres do not act as an effective reinforcing material when adhesion is weak. The adhesion between phases can be quickly damaged in harsh climatic circumstances such as high temperatures and/or excessive wetness, as well as by the stress fields to which the material might be	Glass fibres (GF) composites based on polypropylene (PP).	This method entails modifying aluminium alkyl and hydroxy-alpha-olefin fibres to allow for direct metallocenic copolymerization and the growth of PP chains. The fragmentation test, as well as the evaluation of mechanical characteristics, further proved the improvements in adhesion. The strength and durability of PP/GF composites made with in-situ polymerized

			exposed. Many attempts have been made to increase compatibility between polymers and glass fibres in order to enhance adhesion. Glass surface alterations, polymer matrix changes, and/or both are the most often employed approaches. However, the findings show that there is no good correlation between cost and property enhancement. The purpose of this research is to conduct a thorough examination of GF/PP adhesion enhancement approaches and to propose a novel fibre pathway based on PP in-situ polymerization.		fibres are three times higher, and the interfacial strength repeats.
7	Effects of Fabric Counts and Weave Designs on the Properties of	(Aisyah et al., 2018)	The impact of various fabric materials, including weave patterns (plain and satin) and fabric counts (5 X 5 and 6 X 6) on the characteristics of laminated woven kenaf/carbon fibre reinforced	fabric materials, including weave patterns (plain and satin) and fabric counts (5 X 5 and 6 X 6) on the characteristics of	Because of their structure and construction, composites with a fabric count of 5 X 5 have a much greater flexural modulus than

	Laminated Woven Kenaf/Carbon Fibre Reinforced Epoxy Hybrid Composites		epoxy hybrid composites were investigated. Using a vacuum infusion process and epoxy resin as a matrix, the hybrid composites were created from two types of fabric, woven kenaf manufactured from a yarn of 500tex and carbon fibre. Tensile, flexural, and impact strength tests were performed on the panels. According to the findings, plain cloth is better than satin fabric for achieving high tensile and impact strengths.	laminated woven kenaf/carbon fibre reinforced epoxy hybrid composites.	those with a fabric count of 6 X 6. Plain woven fabric composites showed greater adhesion qualities than satin woven fabric composites, as evidenced by the presence of significantly less fibre pull out, according to scanning electron micrographs of the fractured surfaces of the composites.
8	*Effects of Lamination Layers on the Mechanical Properties for Above Knee	(Chiad & Hasan, 2009)	The influence of increasing and decreasing Perlon and fibre glass layers on mechanical and physical qualities was investigated through tensile and flexural testing of 82 manufacturing samples of the various 14 groups of laminations. The	The lamination consisting of three layers of Perlon, two layers of fibreglass, and three layers of Perlon	When comparing this lamination to the standard Baghdad centre lamination of five layers of Perlon plus two layers of fibreglass plus five layers of Perlon, it can be seen

	Prosthetic Socket		lamination consisting of three layers of Perlon, two layers of fibreglass, and three layers of Perlon has the best mechanical qualities, according to the results.		that, despite the reduction in Perlon layers from ten to six, yield stress increased by 14.75%, ultimate strength remained unchanged, and bending stress only decreased by 1.3%. This method of lamination is suggested for the lay-up of an above-knee socket because it fits the requirements of a good socket design for acceptable mechanical qualities while also keeping the cost of socket lamination at a reasonable level.
9	*Study the Impact	(Chiad,	The first part of this work involved	classical laminated materials	Finally, for each set of specimens,

	Behaviour of the Prosthetic Lower Limb Lamination Materials due to Low Velocity Impactor	2014)	manufacturing different types of laminated below knee prosthetic socket materials with different classical laminated materials used in Baghdad centre for prosthetic and orthotic (4Perlon layers+2carbon fibre layer+4Perlon layers), and suggesting two laminated materials (3Perlon layers+2carbon fibre layer+3Perlon layers) in order to choose the perfect laminated socket. While the second portion uses an experimental rig created specifically for this purpose to test (impact test) the laminated materials specimens used in socket manufacture in order to get the impact characteristics for each socket materials group. In addition, using a piezoelectric sensor, the interface pressure between the residual limb and the	used in Baghdad centre for prosthetic and orthotic (4 Perlon layers + 2 carbon fibre layer + 4 Perlon layers), and suggesting two laminated materials (3 Perlon layers + 2 carbon fibre layer + 3 Perlon layers)	a theoretical and analytical model was proposed to determine the absorbed energy behaviour and maximum stress for each laminated B-K prosthetic socket material.

			prosthetic socket is monitored throughout the whole surface area of the B-K prosthetic socket in order to estimate the resultant stress based on loading circumstances. To complete the above-mentioned testing procedures, a 42-year-old guy with a right transtibial amputation was chosen. His age, length, mass, and stump length were 42 years, 164 cm, 67 kg, and 13 cm, respectively.		
10	Effects of Composite Material Layers on the Mechanical Properties for Partial Foot Prosthetic Socket	(Abbas, 2018)	In this study, nine different laminated composite materials were employed to test the tensile and fatigue characteristics of a partial foot prosthesis socket made with a vacuum pressure system. Lamination 80:20 was used to strengthen the composite material matrix, which was reinforced with nine different types of laminations (Perlon, n-	The mechanical properties were improved by using two layers of carbon fibre, fibreglass, and n-glass instead of zero layers with six layers of Perlon, resulting in increased yield strength y, ultimate tensile strength ult, and modules of	The results demonstrate that (3Perlon+2carbon fibre+3Perlon) has the best mechanical qualities and has higher endurance limit stresses (e), extending the socket’s lifespan. This method of lamination is recommended for

			glass, fibreglass, and carbon) with different thicknesses depending on the lamination.	elasticity E with (71%,76%, and 58%) for carbon fibre, (20%, 19%, and 40%) for fibreglass, and (22%, 5.5%, and 29%) for n-glass.	laminating partial foot prosthetic sockets because it satisfies the requirement for lamination layers with adequate mechanical qualities while lowering the cost of socket lamination to a costing value that is acceptable.
11	Natural Based Biocomposite Material For Prosthetic Socket FABRICATION	(Me et al., 2012)	The findings of this study are based on the compatibility of the properties of current and suggested materials, which lead to the development of alternative materials that are more cost-effective, environmentally friendly, and still have the characteristics necessary for prosthetic limbs. The findings are intended to assist patients or wearers who cannot afford to receive this requirement when	This research focuses on the socket section of prosthetic legs, which is frequently altered and replaced with natural-based biocomposites. Natural fibre-based biocomposites, such as natural-based reinforced plastic, have the same properties as current	

			they are young and living independently.	materials and may be employed in a variety of applications, according to our hypothesis.	
12	Optimised Analysis, Design, and Fabrication of Trans-Tibial Prosthetic Sockets	(Jweeg et al., 2018)	The vacuum moulding technology was utilised to make residual limb prosthetic sockets out of two laminated composite materials. Tensile and bending tests were used to determine mechanical properties, and a fatigue test was used to determine socket failure characteristics at room temperature. In two participants with unilateral transtibial amputation, an F-socket equipment was utilised to assess the interface pressure between the remaining leg and the socket. When compared to previous laminations with six layers of Perlon and two layers of carbon, the ultimate stress rose by 12.46	Acrylic was employed as the matrix material, which was reinforced with Perlon and carbon fibres.	A lamination with six layers of Perlon and four layers of carbon had a Young Modulus of 3.66 GPa, which was greater than the Young Modulus of the other laminations studied. A whole contact socket with a high Young's Modulus will provide the highest level of patient comfort. The maximum principles stress and total deformation rose as the length of the stump grew: A long socket's

			percent despite the minor increase in Perlon and carbon layers (from eight to twelve layers).		maximum principal stress rose by 0.3 percent over a medium socket's, although the medium socket's overall deformation was lower than the long socket's.
13	Material Properties of Selected Prosthetic Laminates	(Phillips & Craelius, 2005)	The bending responses of several carbon fibre laminations were studied in addition to composition to assess the influence of layer location on bending strength. The lowest mechanical strengths were found in laminates with Perlon or Nyglass stockinette, Spectralon, nylon, and cotton fibres, ranging between 18 and 42 megapascals (MPa); the midrange was fibreglass, ranging between 67 and 109 MPa; and the highest mechanical strengths were found in carbon fibre	Eight different lay-up materials (fibres) were laminated individually with one of three common resins (matrix), yielding 24 different fibre/resin laminate combinations. Perlon or Nyglass stockinette, Spectralon, nylon, and cotton fibres, fibreglass matte, and fibreglass cloth,	Lamination Resin 80-20 (IPOS, Bauerfeind Prosthetics, USA, Kennesaw, GA) showed better ultimate tensile strength (UTS) than Laminhartz 80-20 (Otto Bock, Healthcare, Minneapolis, MN). In the case of Nyglass, Lamination Resin 80-20 had a greater UTS than epoxyacryl (Foresee, Orthopedic Products, Oakdale,

			laminates, ranging between 236 and 249 MPa. This information gives a preliminary database of common lamination material strengths and suggests that minimal requirements for prosthetic laminations may be useful.		CA). For nylon, cotton, spectrum, and fibreglass fabric, epoxyacryl had a higher UTS than Laminhartz 80-20. Carbon fabric was not found to be significant. Bending studies on carbon fibre lay-ups revealed that strength increased linearly as layer spacing increased, with R2=0.868.
14	COMPARITION OF MECHANICAL BEHAVIOUR OF BASALT AND CARBON FIBRE REINFORCED	(Baptista et al., 2015)	The development of new, more efficient and cheaper high performances prosthesis is very important. In this paper the full development process of Cheetah® type leg prosthesis is described, as well as all the required experimental tests to verify the quality and performance of the	Cheetah® prosthesis were manufactured using both carbon and basalt fibre reinforced composite material	The carbon fibre prosthesis exhibits higher compression loads than basalt ones, however the elasticity is greater in basalt prosthetics, which is not advantageous to the athlete, as

	COMPOSITES APPLIED TO A PROSTHESIS DEVICE		final product. Cheetah® prosthesis were subjected to static and dynamic tests where the load vs. deformation behaviour were evaluated. Dynamic tests, where the materials have been subject to repeated cycles of stress and deformation, shows that the carbon fibre prosthesis releases more energy, which is quite useful for an athlete because it compensates the lack of muscles.		being very elasticity, the prosthesis cannot absorb sufficient energy in order to release after that. In general, and with all the pros and cons, carbon fibre prosthesis is more adequate for a running prosthesis; however, basalt fibre prosthesis is a good candidate for a non-running prosthesis, presenting lower weight, cheaper and very high elasticity.
15	An experimental study on mechanical properties of epoxy-matrix composites	(Baptista et al., 2016)	The impact of various volumes of graphite filler on the mechanical characteristics of epoxy resin and carbon fibre reinforced epoxy composites Following cure, the materials were put through	With graphite fractions ranging from 5 to 30 wt%, graphite-reinforced epoxy-matrix composites were created. The	Increased graphite filler content improves the epoxy matrix's tensile modulus. The ultimate stress value increased with

	containing graphite filler		tensile and flexural three-point bending tests. Optical microscopy and scanning electron microscopy were used to examine the microstructural characteristics of fracture surfaces.	carbon-fibre reinforced graphite/epoxy hybrids were made with a set quantity of carbon fibre and 7.5, 10, and 11.5 wt% graphite incorporation in the epoxy.	increasing filler in the 7.5, 10 and 11.5 wt percent -graphite composites. Tensile modulus is improved by adding reinforcement carbon fibres. The bigger the quantity of graphite filler in the matrix, the greater the rise. The results of this study reveal that graphite/epoxy composites reinforced with carbon fibre have better mechanical properties than traditional carbon fibre reinforced epoxy matrix composites.
16	An open socket technique for through–	(Otter et al., 1999)	When a prosthesis is worn, the skin is encased in a tight-fitting socket, which can cause issues owing to a lack of air circulation, increased sweating, and increased pressure on certain places. The bacterial flora is more plentiful and the danger of		

	knee amputations in relation to skin problems of the stump: an explorative study		infection is raised since the air within the socket cannot move freely.		
17	Modeling and Characterization of Fatigue Strength of Laminated Composites with Knitted Fabric Reinforcement	(Huang et al., 2002)	This study presents the findings of theoretical and practical studies on a stress ratio of R=0.1 and a cycle frequency of 5 Hz, tensile fatigue with stress control was applied to the laminates as well as the monolithic matrix material. A generic technique was used to provide a theoretical prediction for laminate fatigue strength, which is a mix of classical lamination theory and the bridging micromechanics model. The internal fatigue stresses created in the fibre and matrix materials of the laminate were computed using the bridging	Laminated epoxy composites reinforced with plain weft-knitted carbon fibre textiles of various configurations exposed to fatigue stresses. The stacking sequences used are [0/0/0/0], [0/45/- 45/0], [90/90/90/90], [0/90/90/0], and [90/45/- 45/90] where 0 refers to the fabric wale direction and 90 to the course direction.	As a result, only the constituent fatigue data and the laminate geometric characteristics, which were measured/determined independently, were used to forecast the laminate fatigue strength. The anticipated and actual S–N curves of all five laminates were found to be in reasonable agreement.

			model, whereas the stresses sustained by each lamina layer in the laminate were determined using the classical lamination theory. Internal stresses were measured against constituent fatigue strengths under loading levels identical to those used on the laminate.		
18	Prosthetic limb sockets from plant-based composite materials	(Campbell et al., 2012)	Lower limb prosthesis are in high demand across the world owing to vascular disease, war, violence, land mines, and natural calamities. Acrylic resins, glass, and carbon fibres are common composite materials used for prosthetic limb sockets, however their production emits toxic gases and dust. In order to enhance the safety and accessibility of prosthetic limb manufacturing, this study will examine the feasibility of employing a	sustainable plant oil-based polycarbonate-polyurethane copolymer resin and plant fibre composite conventional composite material socket and the plant resin with ramie composite socket failed, surpassing the ISO 10328	High tensile strengths were achieved by combining plant resin with either banana or ramie fibres. At a comparable stress, the conventional composite material socket and the plant resin with ramie composite socket failed, surpassing the ISO 10328 requirement. Socket strength was

			sustainable plant oil-based polycarbonate-polyurethane copolymer resin and plant fibre composite instead of standard materials. Experimental, bench research, test pieces of the resin with a range of plant fibres (10.0% by volume) were prepared and tensile strengths were tested. Both traditional composite materials and plant resin containing plant fibres were used to make test sockets, which were then destroyed.	requirement. Socket strength	influenced by both wall thickness and fibre-matrix adhesion. The plant resin and ramie fibre composite socket have the potential to replace the traditional lay-up, according to this research. Additional mechanical and biocompatibility testing, as well as a comprehensive economic analysis, are needed.
19	The development of a rapid prototyping prosthetic socket coated with a resin layer for transtibial	(Hsu et al., 2010)	This paper presents a transtibial socket made up of an inner layer made with a fast-prototyping machine and an exterior layer coated with unsaturated polyester resin. This project uses cutting-edge technology, such as a portable scanner	The current study coatings the preliminary RP socket with an unsaturated polyester resin layer.	The findings of the experiments show that the resin-reinforced RP socket may be used by transtibial amputees. This work not only strengthens the FDM socket and

	amputees		and CAD tools, to create a tiny main socket form, which is subsequently manufactured using a fused deposition-modelling machine. This work assembles and aligns a shank and a prosthetic foot to produce a prosthesis set after moulding the proximal brim of the resin-reinforced RP socket to match the individual stump. This study analyses interface pressures between the stump and the resin reinforced RP socket after the amputee and a registered prosthetist complete a trial safety walk wearing the prosthesis that is satisfactory to the amputee and a qualified prosthetist.		produces consistent socket fit, but it also illustrates a practical technique for designing and manufacturing transtibial sockets without the need of plaster moulds.
20	Polymeric materials: structure, properties, applications	(Ehrenstein, 2012)	Polymers are twentieth-century materials. Because of their broad range of properties, they have largely replaced other materials in most applications. Polymers now make up the majority of the items we use in our daily lives, including carry bags, packaging materials, pencils, beverage bottles, containers, clothes, furnishings, adhesives, and syringes. Polymers are also used		

			in engineering applications such as gears and structural components in appropriate synthetic route or circumstances, as well as the introduction of additives throughout the production process. When compared to other types of materials, most polymers are fairly easy to process. This allows the producer to generate a greater number of things while using less energy. Despite the fact that there are several worries about the disposal of polymeric waste, there is no class of materials that can replace them. Polymer comes from two Greek words: poly, which means many, and meros, which means pieces.		
21	Tribological behaviour of scar skin and prosthetic skin in vivo	(Li et al., 2008)	Interfacial rubs between scar skin and other external surfaces are a common occurrence in daily life. To date, there is a scarcity of literature on the tribological behaviour of scar skin. The tribological behaviour and comfort sensations of residual limb scar skin, prosthetic-wearing skin, and healthy limb skin were investigated in vivo using the UMT-II multi-specimen Micro-Tribometer under simulated rubbing conditions between the residual limb skin and prosthetic socket in this study.		
22	Materials Components & Systems	(Ottobock, 2007)	This brochure lists the materials and components for prosthesis from Ottobock with specifications and suggestion from the company.		
23	Skin self-adaptation to friction trauma under reciprocal	(Wei Li et al., 2011)	In this work, friction testing, histological analysis, and animal experiments were used to evaluate skin self-rehabilitation and self-adaptation		The results revealed that after the skin underwent numerous cycles of stress and rehabilitation,

	sliding conditions.		to friction injuries in vivo under the simulated prosthetic socket rubbing scenario. Rabbits' denuded dorsal skin was utilised to mimic stump skin.		keratinization developed on the skin surface, lowering the friction coefficient and reducing skin injuries.
24	Finite element modelling of the contact interface between transtibial residual limb and prosthetic socket	(Lee et al., 2004)	A relevant technique for understanding the load transfer mechanics between a residual limb and its prosthetic socket has been discovered as the finite element approach. This research offered a new method for simulating the contact interface that takes into account the friction/slip conditions as well as the pre-stresses imparted to the limb within a rectified socket. The residual limb and socket were modelled as two independent components, with automated contact methods used to mimic their interactions. Because of the socket alteration,		Comparisons were done between the model that used the suggested technique and the model that assumed the limb and socket shapes were identical and ignored pre-stress. In the model with the simplifying assumption, peak normal and shear stresses over the locations where socket undercuts were produced decreased, whereas stress values over other regions

			certain parts of the limb pierced it. The penetrated limb surface was transferred onto the inner surface of the socket in the first stage of the simulation, and the pre-stresses were calculated. Pre-stresses were preserved in the next loading step, and loadings were delivered to the knee joint to imitate loading during the stance phase of gait.		increased.
25	Study on friction behaviour at the interface between prosthetic socket and liner.	(Xie et al., 2021)	Amputees' walking function and wearing comfort are influenced by the friction properties at the contact between the prosthetic socket and liner. The frictional behaviour at the socket/liner contact of prosthetics can give theoretical assistance for prosthetic material design and selection. As a result, studying the friction behaviour at the prosthetic socket/liner contact is crucial. Methods:		The silicon rubber fabric's coefficient of friction is much lower than that of the foam liner materials. The liner/acrylic socket contact has the least frictional energy dissipation, whereas 3D-printed socket materials have the most. Meanwhile, the coefficient

			A laser confocal microscope was used to assess the surface roughness of the prosthetic socket and liner materials. By modelling the reciprocating sliding contact mode on a UMT TriboLab Tribometer, the frictional behaviour at the prosthetic socket/liner interface was investigated. Thermal pictures were taken with an infrared camera, and the temperature rise at the socket/liner contact was estimated.		of friction and frictional energy dissipation grow in lockstep with temperature.
26	Coefficient of friction and wear of a carbon fibre epoxy matrix composite	(Schön, 2004)	The goal is to determine the coefficient of friction for composites in contact with composites in reciprocal sliding, which is critical for modelling bolted joints and forecasting failure loads. SEM was used to investigate wear processes, and contact surfaces from a fatigue-loaded joint were investigated.	HTA-6376, a carbon fibre/epoxy matrix composite.	While the initial coefficient of friction was 0.65, the peak after wear in was 0.74, indicating that friction force will transmit a large portion of the applied load to a joint at quasi-static failure. The measured coefficient of friction

					from the friction specimens may be used on the joints since all wear processes detected in the friction specimen were also found in the joint specimen. Slow wear of the matrix on the original surface and breaking of the fibre–matrix interface were the predominant wear processes, resulting in fracture of both the matrix and the fibres.

CHAPTER 3: METHODOLOGY

The methodology including the selection of materials, fabrication procedure, surface testing, and data analysis are described in this chapter. All steps are explained thoroughly with specific parameters and measurements used in the experiment. The socket types are also tabulated for better visualization and understanding.

3.1 Overview of Transfemoral Prosthesis Fabrication

A transfemoral prosthesis fabrication starts with the assessment of a patient's stump. This is done by a certified prosthetist and orthotist to evaluate muscles strength, pressure tolerance area, stump shape, ambulation category, and skin impairment. This will help a prosthetist to prescribe the components that will benefit the patient best. The next step is casting where the prosthetist will measure the stump and take a cast using a POP bandage. The bandages are wetted then wrapped around the stump and pressure points are pressed until the bandage is hard enough to maintain shape before it is pulled from the stump and a negative cast is obtained. The negative cast is then filled with POP slurry; a mixture of POP powder and water. When the POP slurry is hard, the negative cast is removed and this will give a positive cast; model of the stump. The positive cast is then modified accordingly and then is draped or laminated to fabricate a socket. The socket is then cut according its trimline and assembled with a knee joint, pylon and foot part. During fitting, assessment of the socket is taken to identify any possible adjustment to prevent pain and minimize gait deviations.

3.2 Socket Modification

The positive cast was obtained by copying a polypropylene transfemoral socket provided from Centre for Prosthetic and Orthotic Engineering (CPOE) into a negative cast as shown in Figure 3.1.

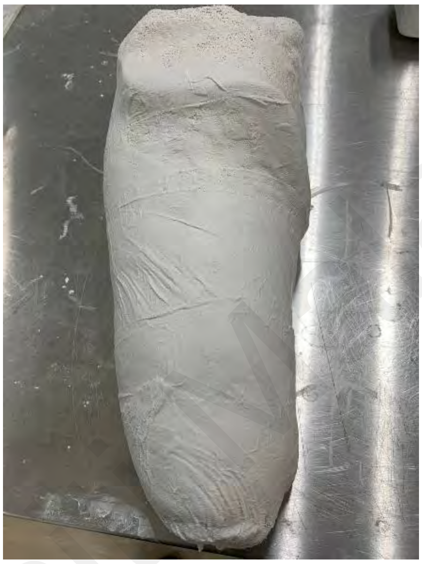
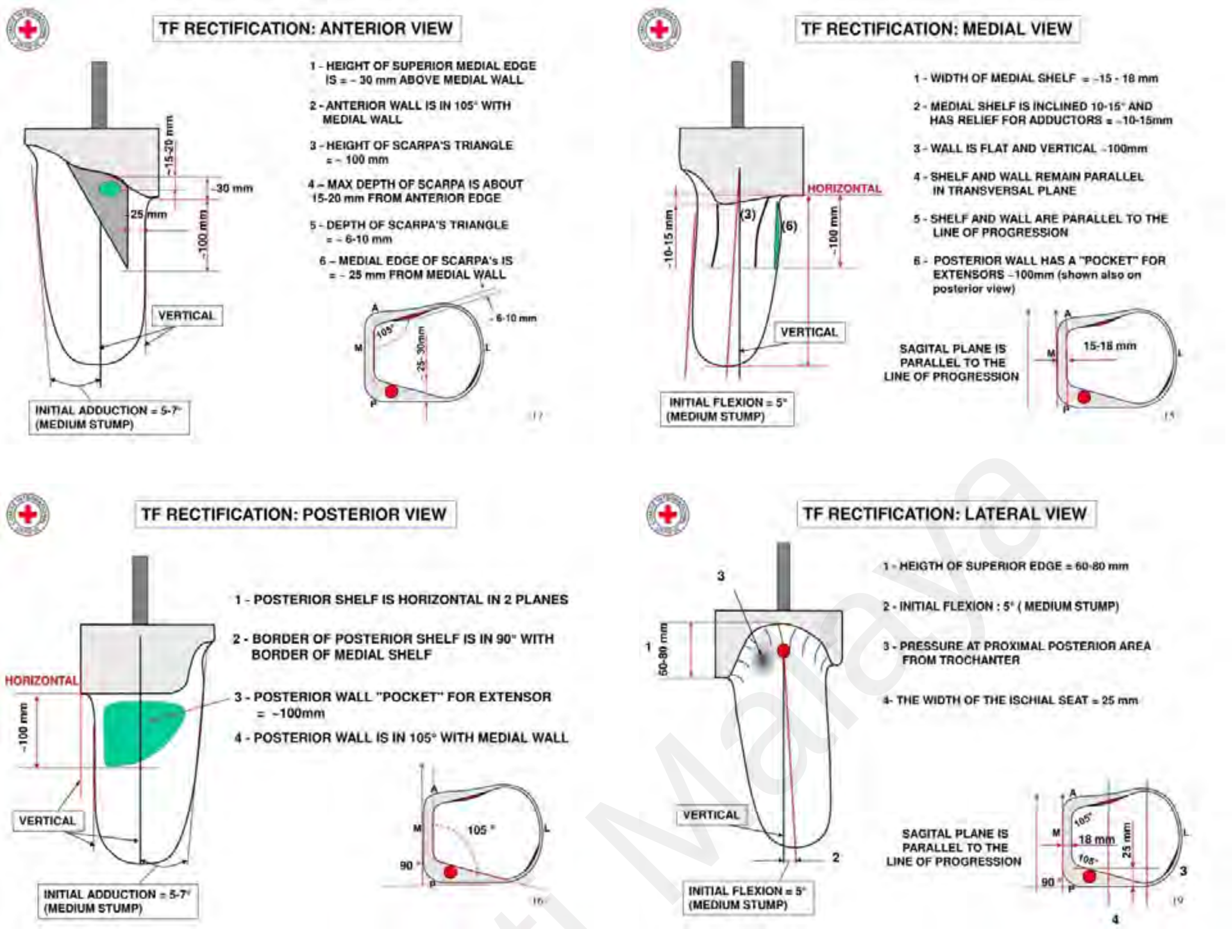


Figure 3.1: Transfemoral Socket Negative Cast

The negative cast was then filled with Plaster of Paris (POP) slurry made by mixing POP powder and water. As the POP slurry hardened, the negative cast was removed and the positive cast was modified. The modifications of the socket are as follows:



TF RECTIFICATION: ANTERIOR VIEW

1 - HEIGHT OF SUPERIOR MEDIAL EDGE IS = ~ 30 mm ABOVE MEDIAL WALL

2 - ANTERIOR WALL IS IN 105° WITH MEDIAL WALL

3 - HEIGHT OF SCARPA'S TRIANGLE = ~ 100 mm

4 – MAX DEPTH OF SCARPA IS ABOUT 15-20 mm FROM ANTERIOR EDGE

5 - DEPTH OF SCARPA'S TRIANGLE = ~ 6-10 mm

6 – MEDIAL EDGE OF SCARPA's IS = ~ 25 mm FROM MEDIAL WALL

TF RECTIFICATION: MEDIAL VIEW

1 - WIDTH OF MEDIAL SHELF = ~15 - 18 mm

2 - MEDIAL SHELF IS INCLINED 10-15° AND HAS RELIEF FOR ADDUCTORS = ~10-15mm

3 - WALL IS FLAT AND VERTICAL ~100mm

4 - SHELF AND WALL REMAIN PARALLEL IN TRANSVERSAL PLANE

5 - SHELF AND WALL ARE PARALLEL TO THE LINE OF PROGRESSION

6 - POSTERIOR WALL HAS A "POCKET" FOR EXTENSORS ~100mm (shown also on posterior view)

SAGITAL PLANE IS PARALLEL TO THE LINE OF PROGRESSION

TF RECTIFICATION: POSTERIOR VIEW

1 - POSTERIOR SHELF IS HORIZONTAL IN 2 PLANES

2 - BORDER OF POSTERIOR SHELF IS IN 90° WITH BORDER OF MEDIAL SHELF

3 - POSTERIOR WALL "POCKET" FOR EXTENSOR = ~100mm

4 - POSTERIOR WALL IS IN 105° WITH MEDIAL WALL

TF RECTIFICATION: LATERAL VIEW

1 - HEIGTH OF SUPERIOR EDGE = 60-80 mm

2 - INITIAL FLEXION : 5° (MEDIUM STUMP)

3 - PRESSURE AT PROXIMAL POSTERIOR AREA FROM TROCHANTER

4- THE WIDTH OF THE ISCHIAL SEAT = 25 mm

SAGITAL PLANE IS PARALLEL TO THE LINE OF PROGRESSION

Figure 3.2: Quadrilateral Transfemoral Socket Modification

(Retrieved from: PPT - MEASUREMENTS, CASTING & RECTIFICATION FOR TRANS-FEMORAL (TF) QUADRILATERAL SOCKET PowerPoint Presentation - ID:5969895 (slideserve.com))

After all the steps were done, the positive cast was smoothened as shown in Figure 3.3.

Figure 3.3: Transfemoral Socket Positive cast

3.3 Socket Fabrication

Lamination technique began by preparing two polyvinylalcohol (PVA) bag according to the size of the positive cast as shown in Figure 3.4. The bag was then sealed using sealing iron with the seam set at 2 cm wide as shown in Figure 3.5. A total of two PVA were made for each laminated socket.

Figure 3.4: PVA Sheet cut according to the size of positive cast

Figure 3.5: Sealing Process in PVA Bag Making

The positive cast was the covered by the PVA bag. Lay-up of eight layers of reinforcement material which was elastic stockinette were put in between the PVA bags.

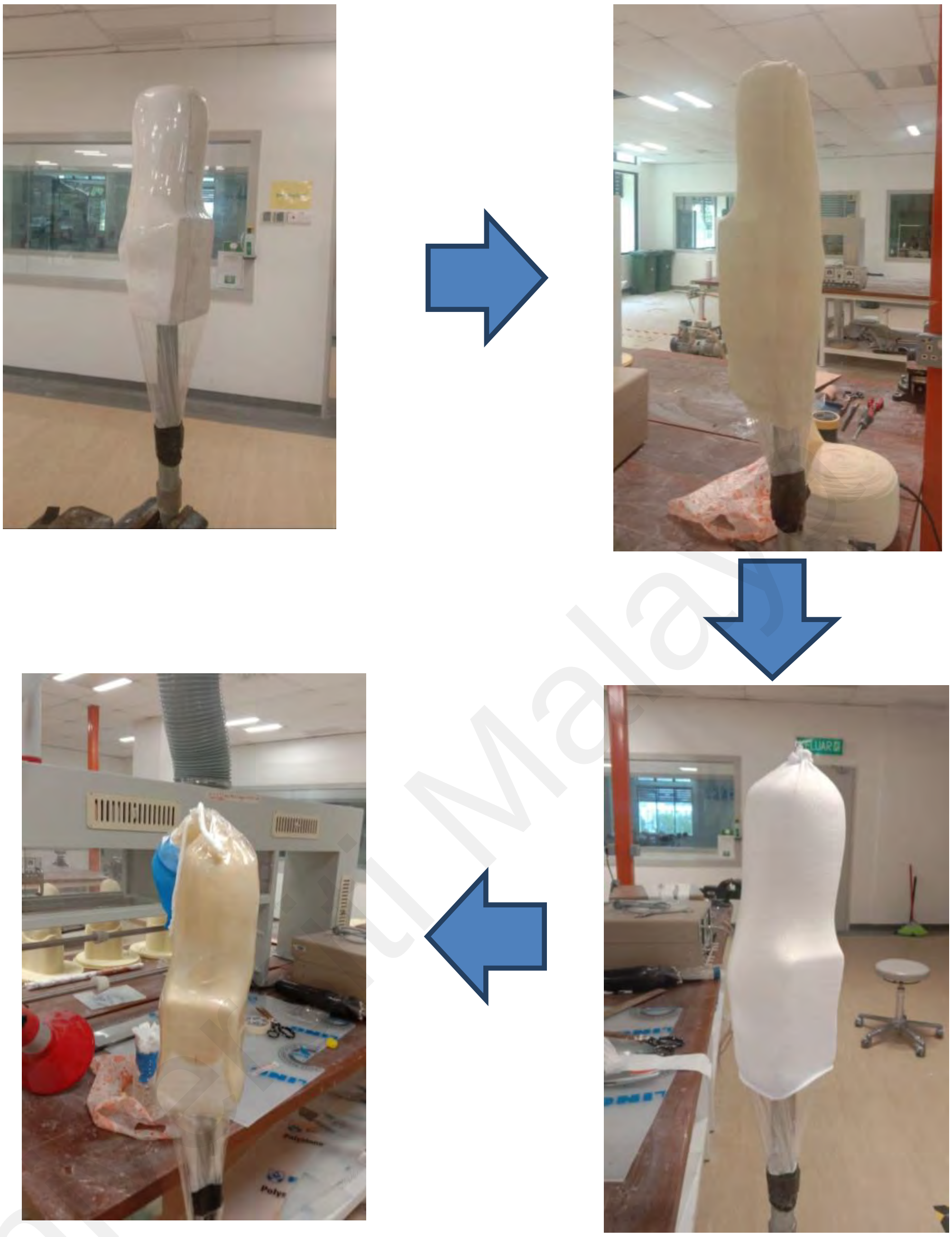


Figure 3.6: Lamination process

Figure 3.6 shows the sequence of lamination process where the positive cast was covered with PVA bag as in the first picture. Then the PVA bag was top with reinforcement materials which is the elastic stockinette as in the second picture and third sequence, then the second PVA bag where the resin was poured in and vacuum action took place in fabricating the laminated socket as shown in last picture.

A mixture of resin and hardener ranging from 600 g to 610 g was made in a cup with different combination ratio as shown in Table 3.1.

Table 3.1: Resin to Hardener ratio

Transfemoral socket	1	2	3	4	5
Epoxy Resin (Resin : hardener)	2:1	3:2	2:3	3:1	3:1
Acrylic Resin (Resin : hardener)	100:1	100:2	100:3	100:4	100:5

The solution was then poured into the PVA bag-reinforcement materials sandwich. Each socket was made using acrylic resin and epoxy resin under vacuum suction of less than 20% non-inductive until it is hot, indicating it has cured. The cure time of different combinations of resin was recorded using stopwatch. The laminated composite was then left overnight before finishing the socket by smoothening the edge of the socket trimline.

Figure 3.7: Samples from Transfemoral Laminated Socket

The next socket fabrication step was to repeat the same process but using eight lay-up of reinforcement materials which are listed in the Table 3.2 using Acrylic resin with fix ratio of 100:3.

Table 3.2: Lay-up of Different Reinforcement Materials

Prosthetic Socket	1	2	3	4	5
Materials	4 Perlon + 4 elastic stockinette	4 fibreglass + 4 elastic stockinette	4 Dacron felt + 4 elastic stockinette	8 elastic stockinette	4 polyester + 4 elastic stockinette

3.4 Reinforcement Materials

Reinforcement materials are used to strengthen the binding of resins. These materials commonly come as fabrics and fibres. In this experiment, five types of materials were chosen which are the Perlon Stockinette, Elastic Stockinette, Polyester Stockinette, Dacron Felt, and Glass Fibre.

(a)Da (b)

(c) (d)

(e)

Figure 3.8: (a) Glass Fibre, (b) Dacron Felt, (c) Perlon Stockinette, (d) Polyester Stockinette, (e) Elastic Stockinette

The materials were chosen based on information from previous studies which reported the strength of said materials (Abbas et al., 2020; L. Alimi et al., 2020; Chiad & Hasan, 2009). The materials were supplied from Centre for Prosthetics and Orthotics Engineering (CPOE), Universiti Malaya (UM).

The Perlon, Polyester and Elastic Stockinette came in stretchable stockinette while Dacron Felt and the Glass Fibre came in long rectangular sheet.

3.5 Type of Resin

Materials used in this study were acrylic resin; Orthocryl Laminierharz 80:20 (617H19) with Ottobock hardening powder (617P37) as hardener, epoxy resin; Epoxen CP362 part A with hardener CP362 part B. The polyvinylalcohol (PVA) bag was made using Ottobock PVA sheeting (616F4). Stockinette used was also obtained from Ottobock which was Perlon elastic stockinette, white (623T5=15) with width of 15 cm. Elastic stockinette was provided by Centre for Prosthetic and Orthotic Engineering (CPOE) with its width also 15 cm.

3.5.1 Surface Test

Laminated transfemoral sockets surfaces sample cut outs of around 2 cm x 6 cm (benchmark samples) as shown in Figure 3.7 were prepared. The samples were taken out from the lateral side of the transfemoral prosthetic socket at 3 cm below the greater trochanter. This area is chosen as it is the pressure tolerance area and high pressure was applied.

Figure 3.9: Area of sample cut out

A table-top contact profilometer was used to assess the surface roughness of the Pe-Lite samples (Mitutoyo SurfTest SJ-210 series) (Baltsavias et al., 2008; Bhushan, 2000). A retractable probe with a diamond tip stylus was included with the profilometer. The stylus had a 2.5 µm radius and was fitted with a 5 mN measuring force. A stylus tip directly contacts a sample's surface when using contact-type surface roughness instruments. The detector tip has a stylus tip that tracks the sample's surface and electronically detects the stylus's vertical motion. In order to be recorded, electrical impulses are amplified and converted to digital form. The radius of the stylus tip must be as narrow as feasible with little contact pressure in order to correctly assess fine forms and roughness with a contact-type surface roughness tester.

The stylus on contact-type surface roughness testers has to be polished since the tip will eventually corrode. Depending on the material and shape of the measurement target item, the stylus tip may become flat or rounded as a result of varying modes of wear. Naturally, different wave profiles will be produced by various stylus shapes.

One method for determining stylus wear is to use a commercially available wear-inspection test piece. Wear is determined by comparing the data profile (groove width) of the test piece before and after the wear of the stylus. Because the tip of the stylus is spherical, the stylus cannot trace the shape properly if the width of the groove is narrower than the radius of the stylus tip.

For each surface, twenty trials were conducted. The topographical analysis was carried out with the use of a portable gadget connected to a communication software program that enabled real-time inspection to be recorded and shown as a Microsoft Excel spreadsheet. Average surface roughness (Ra), root mean square roughness (Rq), and ten-point mean roughness (Rz) were chosen as roughness parameters. These parameters were derived from the measurements as illustrated in figures below.

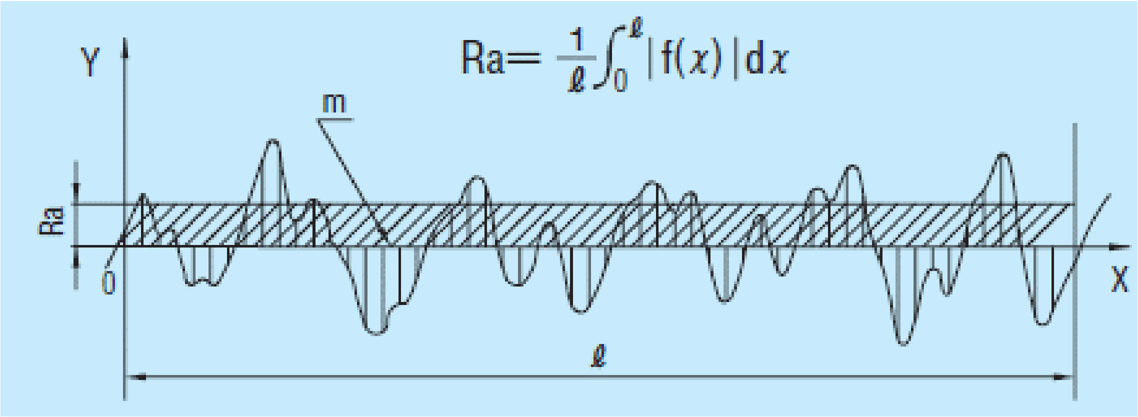


Figure 3.10: Ra and Rq measurements illustration.

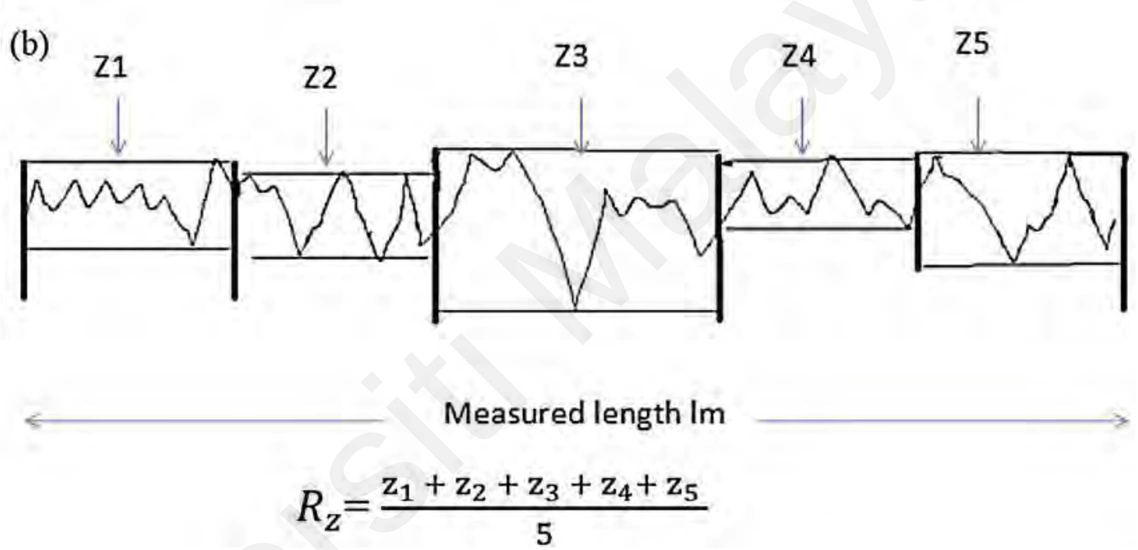


Figure 3.11: Rz measurements illustration.

Figure 3.12: Surface testing using Mitutoyo Surftest SJ-210

Twenty trials were conducted by running the stylus onto the samples. As the stylus of the profilometer cannot be place on the same spot, the location of the stylus was shifted to the side approximately 0.5cm between each reading. As the location of reading is different, the samples were divided into four equal segments, and five trial were conducted on each segment. The sequences of the trials are shown in Figure 3.13. The trials started from the anterior-distal segment and ended on the anterior-proximal segment. These segments were divided to investigate the differences of the surface roughness along the anterior to posterior and along the distal to proximal.

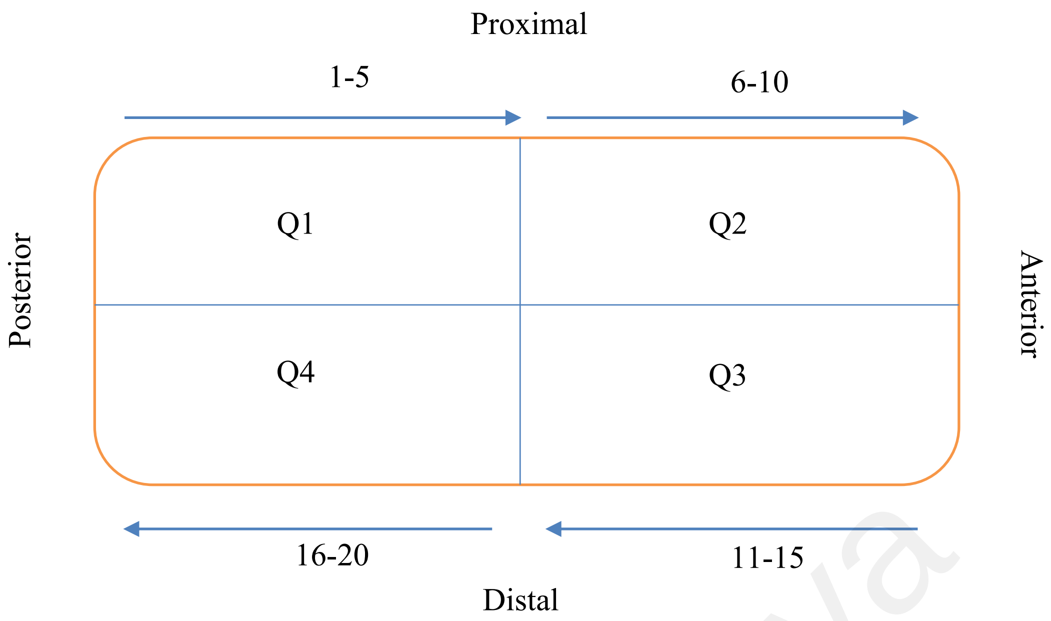


Figure 3.13: Sequences of surface testing

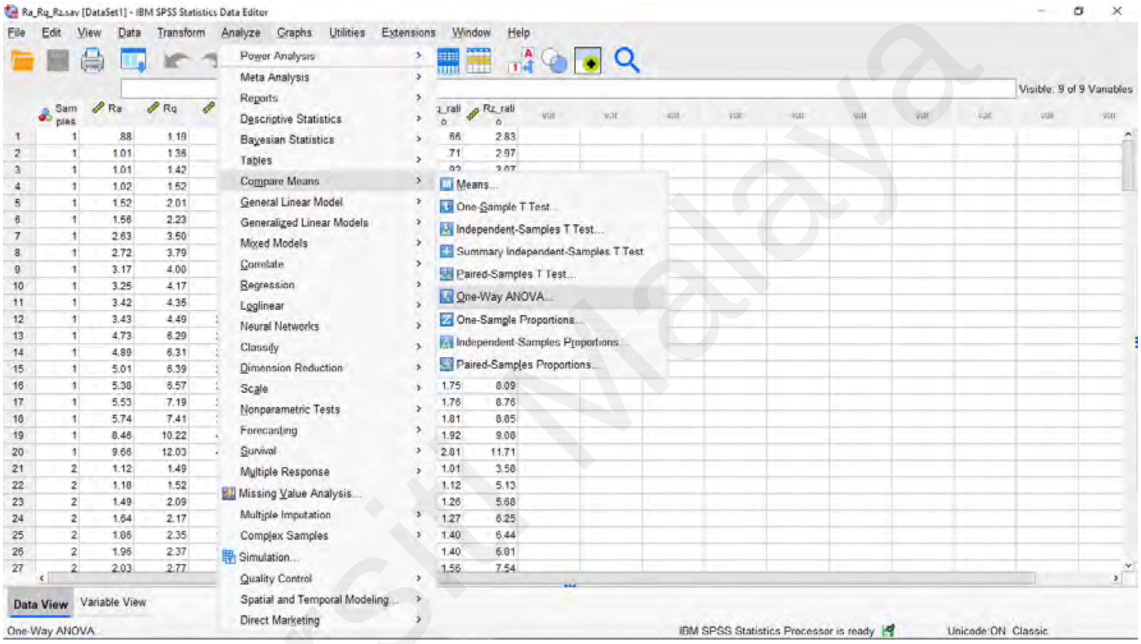
Lastly, to obtain the comparison data, means of all twenty trials were conducted for all five surface roughness parameters of the laminated socket.

3.6 SPSS Analysis

The one-way analysis of variance (ANOVA) is performed to see if any statistically significant differences exist between the means of two or more independent variables (unrelated). A one-way ANOVA, for example, is used to see if exam performance varies based on test anxiety levels among students, with students divided into three groups (e.g., low-, medium-, and high-stressed students). The one-way ANOVA is an omnibus test statistic that cannot tell which specific groups were statistically significantly different from each other; it can only say that at least two of them were. Because certain study design may have three, four, five, or more groups, it is critical to figure out how they differ from one another.

Descriptive Test of One-Way ANOVA was done to see the standard error mean for every sample trials. Post Hoc Test was done to see the significance of difference of each sample as there are more than two groups of data involved. These two tests were done by keying in the trials values as the dependent list and the ratios or the materials as the factor.

To run a One-Way ANOVA in SPSS, click **Analyze** > **Compare Means** > **One-Way ANOVA**.

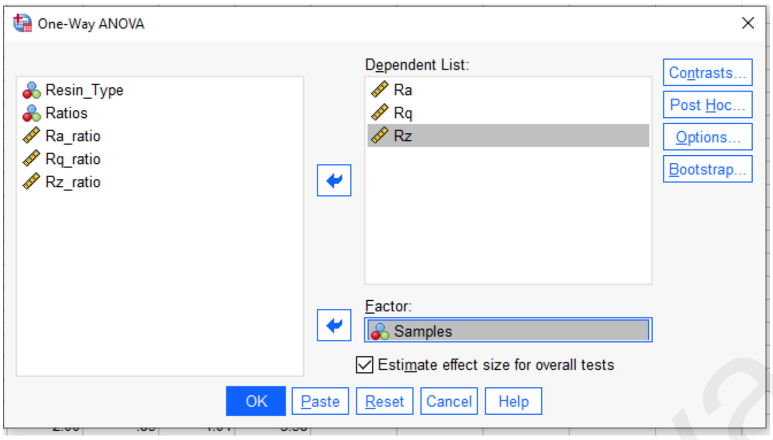


	Samples	Ra	Rq
1	1	.88	1.19
2	1	1.01	1.36
3	1	1.01	1.42
4	1	1.02	1.52
5	1	1.52	2.01
6	1	1.56	2.23
7	1	2.63	3.50
8	1	2.72	3.79
9	1	3.17	4.00
10	1	3.25	4.17
11	1	3.42	4.35
12	1	3.43	4.49
13	1	4.73	6.29
14	1	4.89	6.31
15	1	5.01	6.39
16	1	5.30	6.57
17	1	5.53	7.19
18	1	5.74	7.41
19	1	8.46	10.22
20	1	9.66	12.03
21	2	1.12	1.49
22	2	1.18	1.52
23	2	1.49	2.09
24	2	1.64	2.17
25	2	1.86	2.35
26	2	1.96	2.37
27	2	2.03	2.77

Figure 3.14: One-Way ANOVA selection

When One-Way ANOVA window appears, the variables for the study were specified. The list on the left side shows all of the variables in the dataset. Variables were selected in the list and the blue arrow buttons were clicked to move them to the right. A variable(s) can be moved to one of two areas: Dependent List or Factor.

The dependent variable was listed in the dependent list which are the parameters. The mean of this variable was compared against the samples (groups). By selecting more than one dependent variable, it ran several means comparisons at the same time, as shown in Figure 3.15.



Resin_Type
Ratios
Ra_ratio
Rq_ratio
Rz_ratio

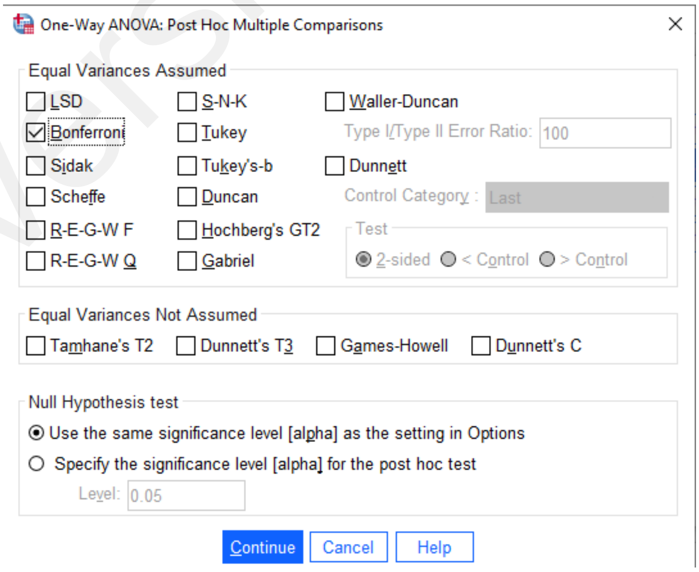
Dependent List:
Ra
Rq
Rz

Factor:
Samples

☑ Estimate effect size for overall tests

Figure 3.15: Variables selections

Factors are the variables that are not controlled which are the samples cut out. The independent variable's categories (or groups) will determine which samples will be compared. When using a One-Way ANOVA, the independent variable must have at least two categories (groups).



Equal Variances Assumed

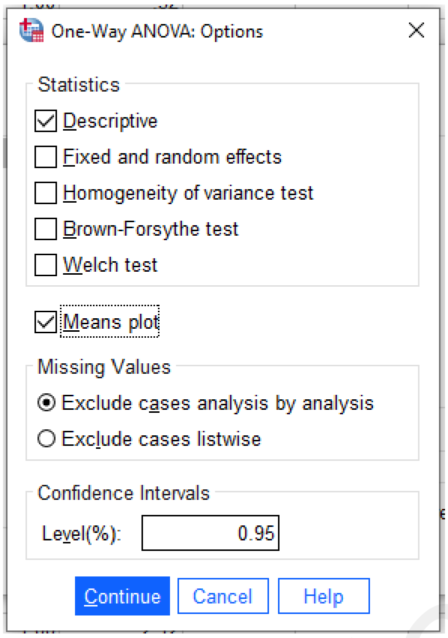
☐ LSD ☐ S-N-K ☐ Waller-Duncan
☑ Bonferroni ☐ Tukey Type I/Type II Error Ratio: 100
☐ Sidak ☐ Tukey's-b ☐ Dunnett
☐ Scheffe ☐ Duncan Control Category : Last
☐ R-E-G-W F ☐ Hochberg's GT2 Test
☐ R-E-G-W Q ☐ Gabriel ● 2-sided ○ < Control ○ > Control

Equal Variances Not Assumed

☐ Tamhane's T2 ☐ Dunnett's T3 ☐ Games-Howell ☐ Dunnett's C

Null Hypothesis test

● Use the same significance level [alpha] as the setting in Options
○ Specify the significance level [alpha] for the post hoc test
Level: 0.05


One-Way ANOVA: Options

Statistics

☑ Descriptive

☐ Fixed and random effects

☐ Homogeneity of variance test

☐ Brown-Forsythe test

☐ Welch test

☑ Means plot

Missing Values

● Exclude cases analysis by analysis

○ Exclude cases listwise

Confidence Intervals

Level(%): 0.95

Post hoc Bonferroni test option was selected in order to make multiple comparison among the samples cut-out.

CHAPTER 4: RESULT AND DISCUSSION

In this chapter, the results of surface roughness from 14 surfaces of laminated transfemoral socket is presented. The discussion on the obtained result is also presented. Here, the comparison for surfaces from different materials are made and another comparison between different ratios and different types of resin are also made.

4.1 Different Reinforcement Materials

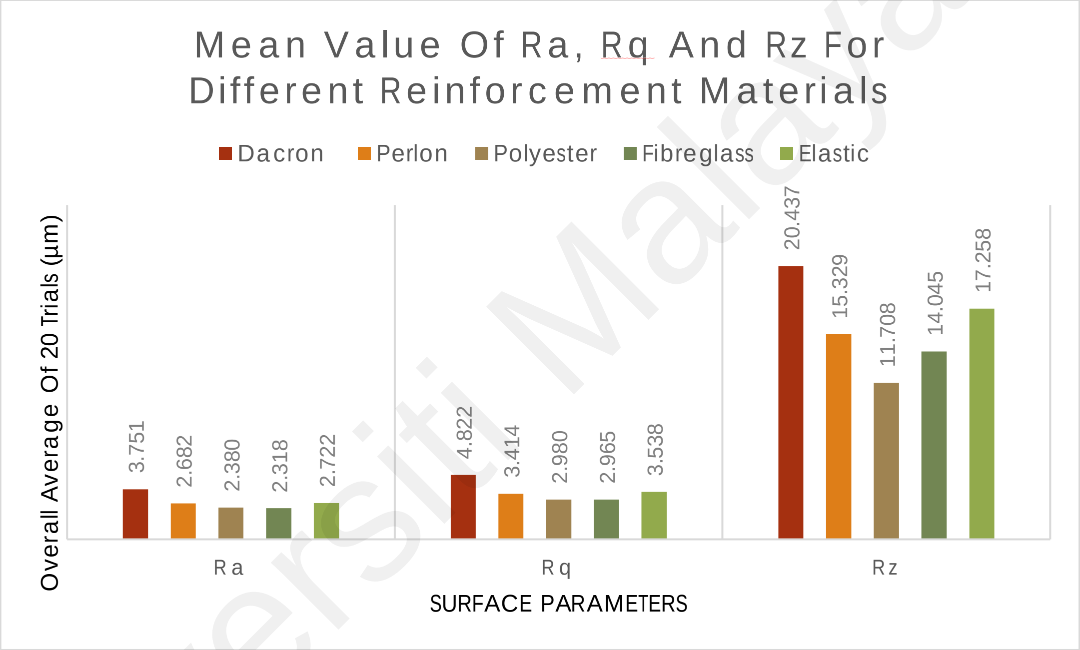


Figure 4.1: Overall average surface profile for laminated sockets using different materials

A total of five lamination socket were made and tested for their surface profiles. Fibreglass gives the best values for Ra (2.318µm) and Rq (2.965 µm) but comes second after Polyester stockinette for Rz (14.045µm). Polyester Stockinette come in second with Ra value of 2.380 µm and Rq of 2.980 µm and the best Rz with 11.708 µm followed by Perlon stokinette (Ra of 2.682 µm, Rq of 3.414 µm and Rz of 15.329 µm), Elastic Stockinette (Ra of 2.722 µm, Rq of 3.538 µm and Rz of 17.258 µm) and lastly Dacron Felt with Ra of 3.751 µm, Rq of 4.822 µm and Rz of 20.437 µm.

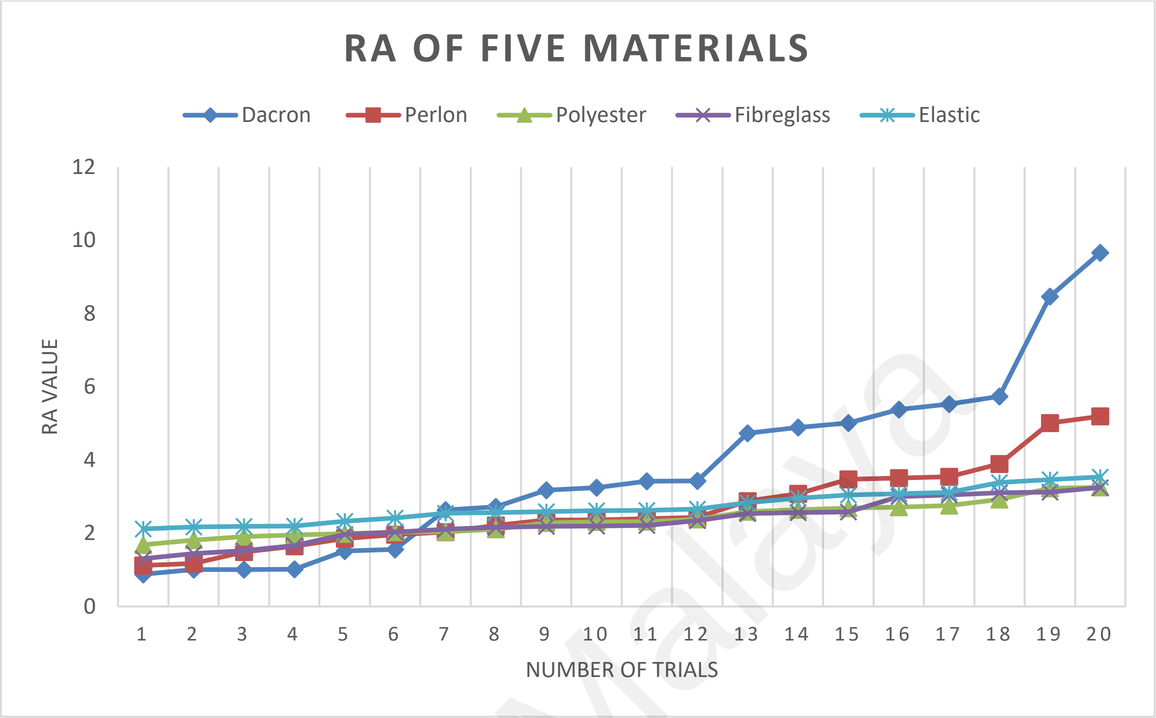


Figure 4.2: Graph of Ra values for different materials sorted from lowest to highest

From the chart in Figure 4.2, we can see value of each trial for all five materials. Dacron has the lowest and highest value compared to the other four materials and shows the highest inconsistency. This contributes to the high standard deviation of 2.453. Perlon stockinette comes second in terms of inconsistency with 1.143, and the chart also shows a huge difference from the lowest to highest Ra value. Perlon has the second lowest Ra value after Dacron felt, so it has a lower overall surface average than elastic stockinette. Elastic stockinette gave the most consistent Ra values for all twenty trials with standard deviation of 0.441. However, with high Ra values across all trials, it has the second roughest overall surface after Dacron. Fibreglass proof has the smoothest overall surface with high consistency across all trials and low Ra value followed by polyester stockinette which shows a similar performance.

Fibreglass has the smoothest overall surface compared to the other four materials. This is due to consistency for all the 20 surface tests across the samples. This shows that fibreglass is easy to handle in fabricating a prosthetic or orthotic devices (Hamad et al., 2021). Fibreglass lamination comes third in standard deviation; however due to the lower Ra, Rq and Rz values compared to polyester and elastic stockinette, its overall surface average remains the lowest. As mentioned in the Ottobock catalogue, fibreglass can produce thin-walled laminates, has good braiding, high torsional strength in laminates but the torsion can be influenced by different circumferences (ideal angle is 45°) and it has good draping characteristics (Ottobock, 2007). Another factor is that fibreglass are distributed evenly in the matrix, contributing to the structure's homogeneity and the quality of its mechanical qualities (Latifa Alimi et al., 2020).

Dacron felt has the lowest Ra value with 0.881 μm, but has the highest overall surface roughness due to its inconsistency and having the highest Ra value with 9.66 μm. This problem arises due to the difficulty in fabricating the socket as the Dacron felt is not in stockinette form. The sheet form of Dacron felt will fold as it is circled to cover the positive cast as a cast is not fully cylindrical with the existence of body compensation area. This produces overlapping and void in random area. With four lowest points, Dacron felt can still be the best material for lamination socket. Dacron felt is used for filling reinforcements, having good bleeding properties when laminating and has the best good absorption of all Ottobock lamination resins (Ottobock, 2007). Dacron felt gives a smooth surface after laminating thus it is suitable for surface. However high skill and the correct technique is required as it proves to be the worst with the wrong fabricating technique.

Base on the Ottobock materials catalogue, Perlon, Polyester and Elastic stockinette are knitted fabrics and have finely meshed property. Perlon can be stretched based on circumference, has good shaping and produces a smooth surface after laminating thus it is suitable for surface. This contributes to the consistency of Ra value for 14 points but with six points being much higher compared to the rest, Perlon comes second in terms of standard deviation. Perlon comes in stockinette form but still comes second in terms of inconsistency, even with easier handling. The catalogue mentioned that elastic stockinette is particularly suitable for viscous resins and is often used for silicone lamination, made with 100% polyamide. The products will have high strength and have low tendency to wrinkle and are suitable for surfaces. However, the results show that elastic stockinette may be the last option compared to the other four materials. Elastic stockinette comes in stockinette form and shows the highest overall Ra value compared to other stockinettes. However, ignoring the difficulty in handling the Dacron felt, the elastic stockinette may be the worst material among the five that are being compared. Polyester has high strength, good stretching properties, low tendency to wrinkle, and is suitable for surfaces (Ottobock, 2007; Sülar et al., 2013). Easy to handle and having the lowest Ra values, polyester proves to be the best material as the internal surface for a laminated prosthetic socket.

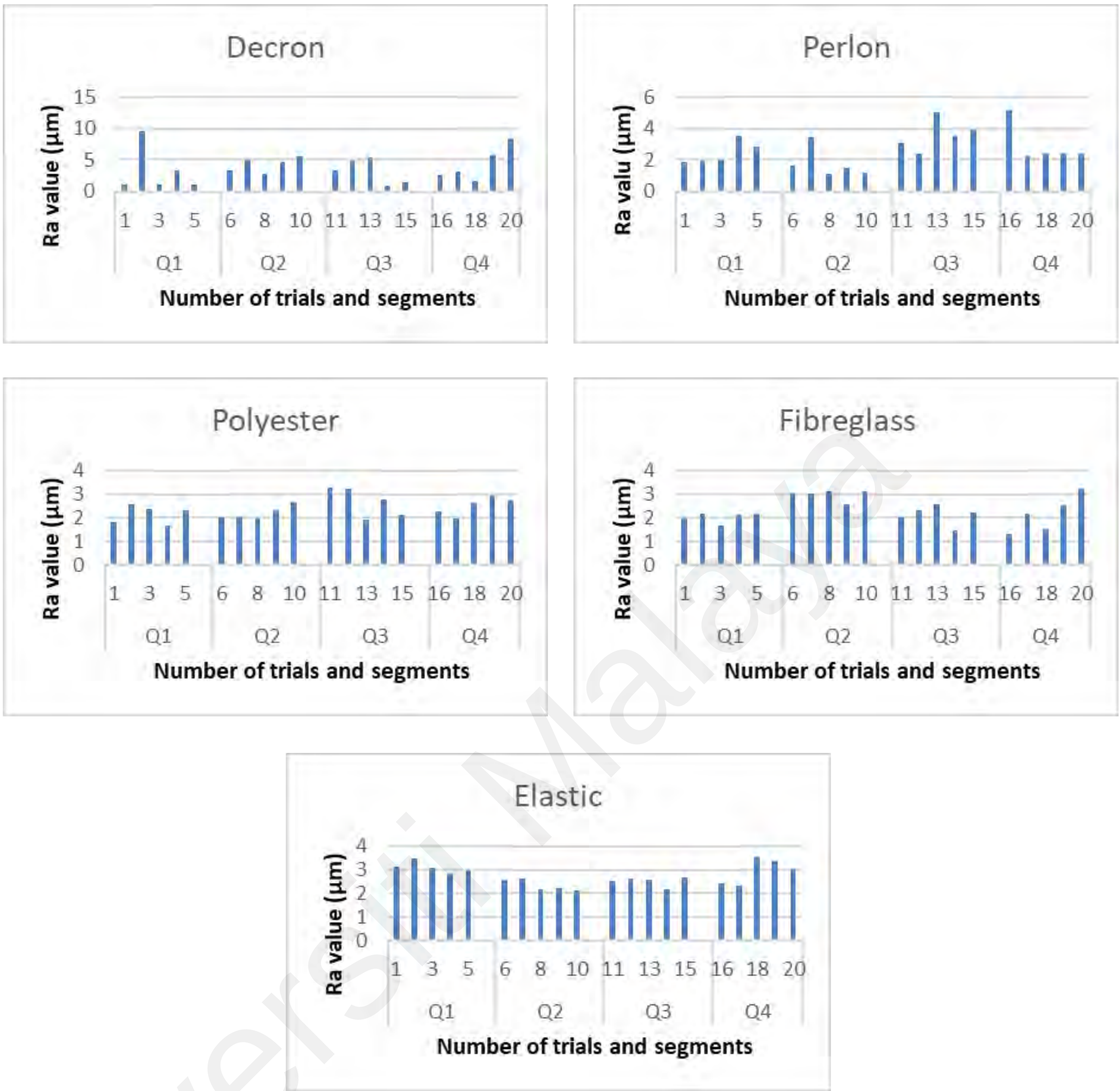


Figure 4.3: a) Ra values by segments for Dacron felt, b) Ra values by segments for Perlon Stockinette, c) Ra values by segments for Polyester Stockinette , d) Ra values by segments for Fibreglass , e) Ra values by segments for Elastic Stockinette

For Dacron felt, we can clearly see in Figure 4.3 a low Ra values at the centre of the samples. The high Ra values are located at the end of the samples. This suggests that the high Ra values is caused by the folding of the Dacron felt (Aisyah et al., 2018). Dacron felt comes in sheet form and needs to be wrapped around the positive cast, unlike the stockinette form which can easily cover the positive cast. Folding will occur as the sheet tries to compensate the area at the edges (Kapp, 2000). This will also slightly deform the central area which causes the high Ra values in the samples.

In contrast with the Dacron felt graph, the Perlon graph in Figure 4.3 shows high values at the centre of the sample. This indicates uneven resin distribution at the centre compare to the sides of the sample. A theory on this occurrence is that it may be caused by the stretching of the stockinette. The knitted fabric will create larger pores at the stretched area allowing the resin-hardener mixture to penetrate better (He et al., 2021).

Polyester stockinette shows similar profile with Dacron felt where the central area is smoother compared to the sides. Although having the same form as Perlon, polyester has good stretching properties. However, the edges of the positive cast may alter the stretching, leading to a rougher surface just like in Dacron felt (Kapp, 2000; Ottobock, 2007; Salman et al., 2015).

Fibreglass shows no particular pattern in its Ra values across the sample. But it is visible that there are higher Ra values at distal segment compare to proximal segment. As the resin is distributed from distal to proximal, the resin-fibre homogeneity may be altered when the resin is flowing down.

Elastic stockinette shows even distribution of the Ra values except at the anterior side of the sample. The posterior wall of a transfemoral socket consists of ishcial seat (Carroll, 2006). This may have stretched the stockinette greater at the posterior side, therefore making larger pores. Resin-hardener mixture will easily penetrate the pores and produce more even surface along the posterior side (He et al., 2021).

4.2 Different Types of Resin and Hardener

Table 4.1: Cure time at different ratios for Acrylic Resin

Acrylic Resin			
Ratio (resin:hardener)	Mix time (hh: mm)	Cure time (hh: mm)	Time taken (minutes)
100:1	11:33	14:20	167
100:2	12:11	12:54	43
100:3	13:37	14:17	40
100:4	13:27	13:57	30
100:5	14:37	15:11	34

Table 4.2: Cure time at different ratio for Epoxy Resin

Epoxy Resin	
Ratio (resin:hardener)	Time taken (minutes)
2:1	570
3:1	660
3:2	480
2:3	1440
1:3	-

Result shows that cure time depends on the amount of hardener used. Curing time is the time taken for a resin to harden. More hardener will cure the composite faster. As we can see, the cure time for the composite increases as the amount of hardener decreases, as shown in Table 4.2. However, the amount of hardener must not exceed the resin, or this would produce an uncured composite as we can see with epoxy resin to hardener ratio of 1:3. The same case also happened with the ratio of 2:3 where the socket takes a day to cure and the composite remained soft. Thus, these ratios need to be avoided. The cure time for acrylic resin shows clearer pattern as the time taken for the composite to cure decreases as the hardener increases. The last ratio combination however, exceeds the previous one by 4 minutes as displayed in Table 4.1. This pattern illustrates the behaviour of acrylic resin where intermediate amount of hardener has different onset temperature compared to low amount and high amount of hardener (Raponi et al., 2018). Acrylic shows faster curing time as it is a thermoplastic materials whereas epoxy resin is a thermoset materials (de Andrade Raponi et al., 2018; Wu & Hoa, 2006).

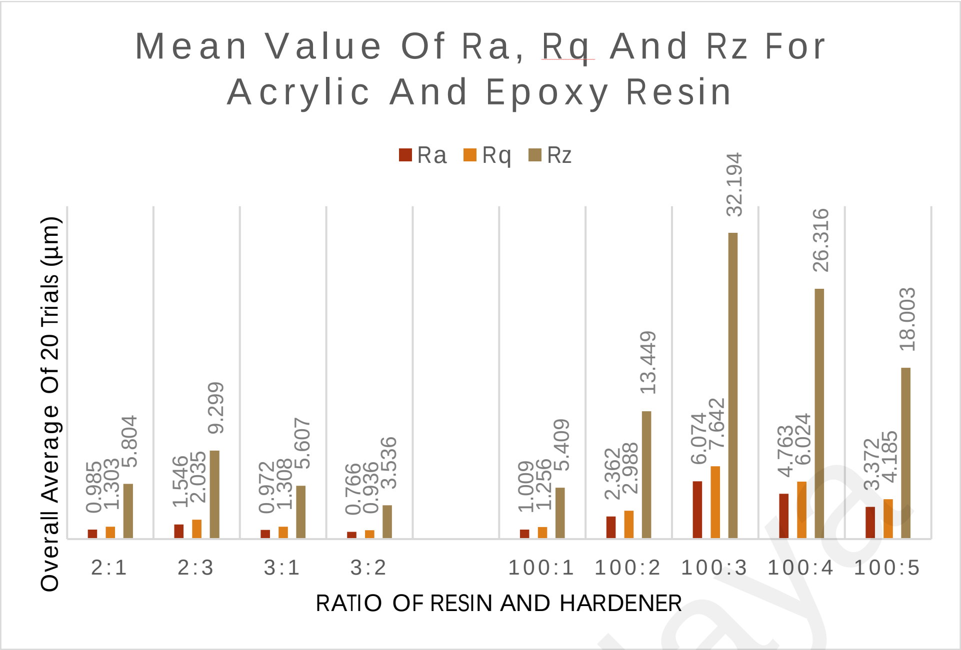


Figure 4.4: Mean Ra, Rq, Rz value of different resin and ratios

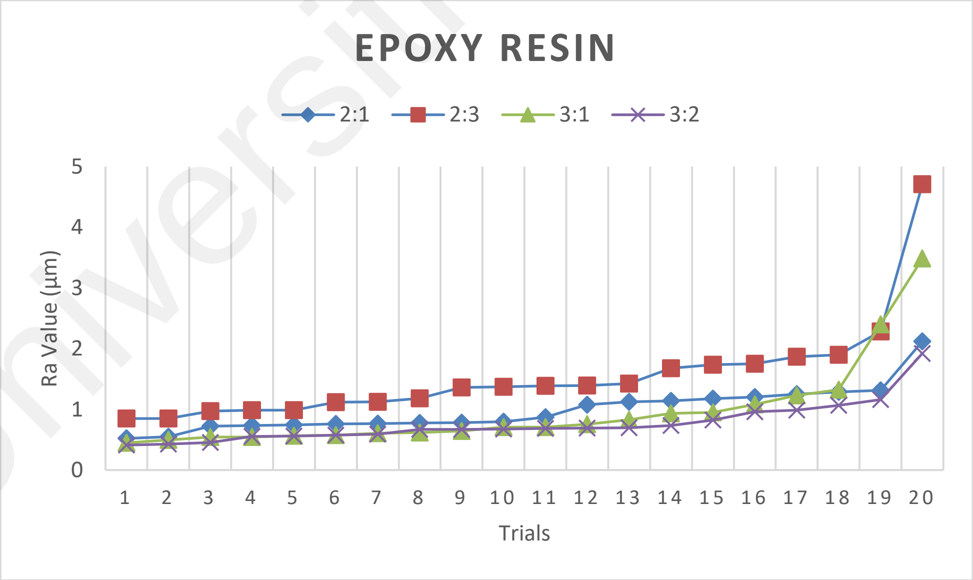


Figure 4.5: Ra values of internal surface with different ratios of epoxy resin to hardener sorted in ascending order

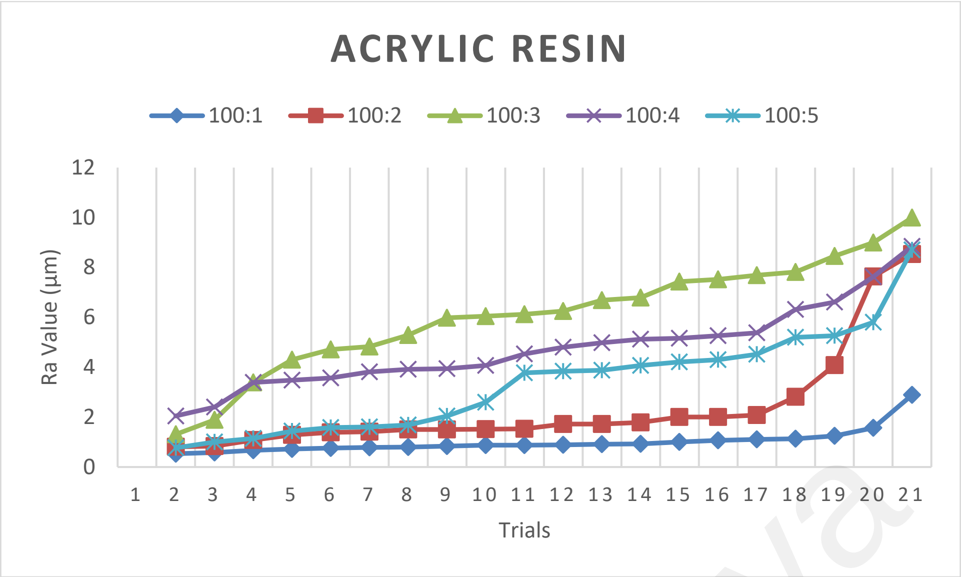
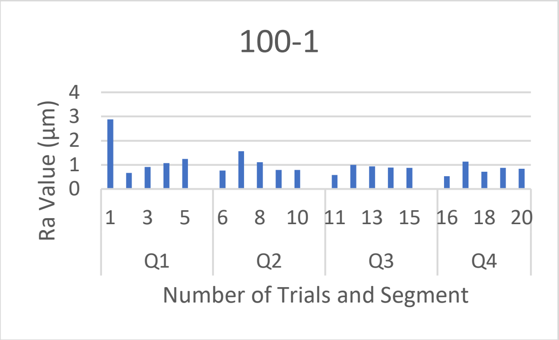
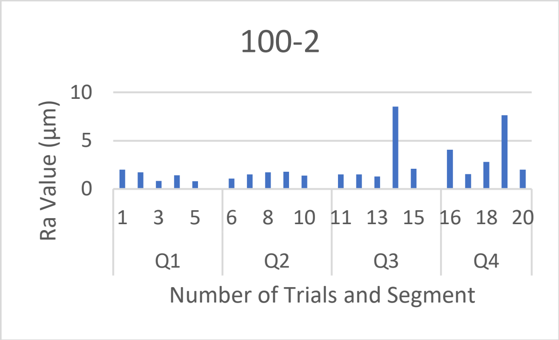


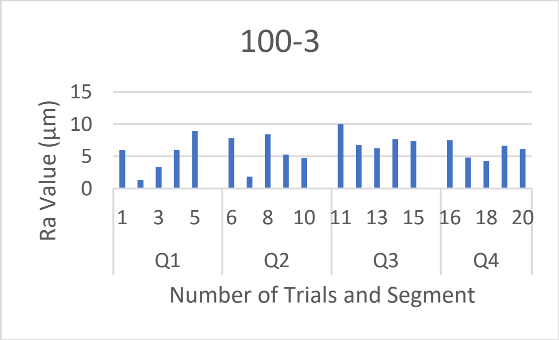
Figure 4.6: Ra values of internal surface with different ratios of acrylic resin to hardener sorted in ascending order

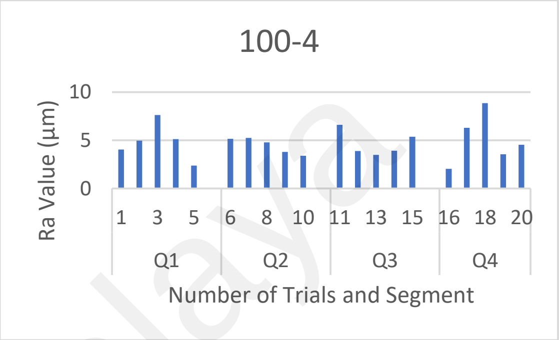
For epoxy resin, the smoothest internal surface was produced by the 3:2 resin to hardener ratio followed by 3:1, 2:1 and lastly with value higher than 1, 2:3. The socket made with 1:3 resin to hardener ratio was excluded in surface testing as the composite did not cure and ended up in a liquid state. This is due to the amount of epoxide molecules which had fully reacted with the hardener molecules leaving extra hardener molecules free (Cañavate et al., 2000; Wu & Hoa, 2006). The socket made with 2:3 resin to hardener ratio has the highest Ra, Rq, and Rz values compared to other epoxy socket because the socket is soft and produce visible wrinkles as shown in Figure 6 which are invisible in other sockets. The epoxy groups are prone to reaction with primary amines with an increase of hardener amount. The epoxy with a large excess of hardener has a looser epoxy network (d'Almeida & Monteiro, 1998; Wu & Hoa, 2006).

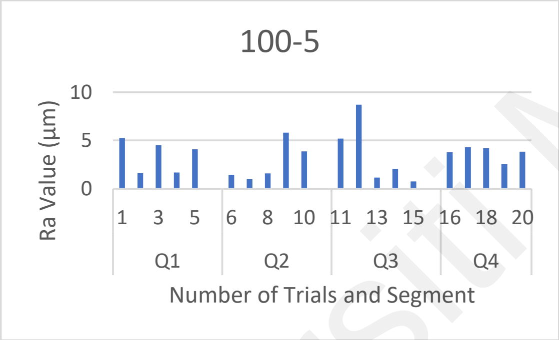
As for acrylic resin, the smoothness of the internal surfaces is related to the amount of hardener used. This may be affected by the cure time of the composite. As the composite was slowly curing, the resin-hardener mixture was allowed to flow more freely creating less void as compared to other ratios that have faster cure time. The smoothest surface was given by the ratio of 100:1 resin to hardener, with Ra value of 1.0086 µm. As discussed, the 100:1 ratio took the longest time to cure at 167 minutes, thus it was expected to produce the smoothest surface. Meanwhile, 100:2 resin to hardener ratio reduced the cure time significantly to just 43 minutes, and it also doubled the Ra value to 2.3622 µm as compared to 100:1 ratio. Ratio of 100:3 shows the highest value of all three parameters Ra, Rq and Rz. This is a bit peculiar as the next ratios which are 100:4 and 100:5 have lower parameters values. This is because the initiator contents are associated with a small number of free radicals that were disrupting monomers and, therefore, also responsible for a propagation based on a lower number of growing chains with greater length (de Andrade Raponi et al., 2018; Raponi et al., 2018). High initiator content sample, on the other hand, the propagation is based on the competitive growth of many short-forming chains because of the greater number of free radicals available. Consequently, the polymer content is increased and can promote the so-called gel effect (Obande et al., 2021; Raponi et al., 2018) This suggests the instability with the 100:3 ratio but the mixture becomes more stable with low and high amount of hardener.

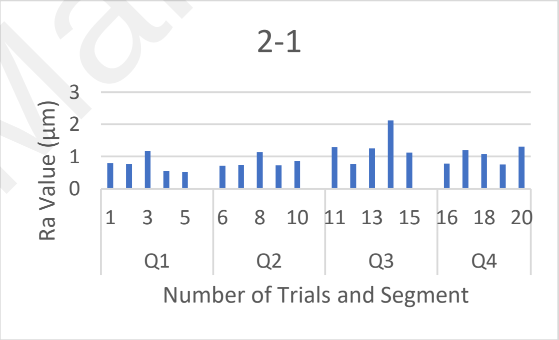

100-1
Ra Value (µm)
0
1
2
3
4
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment

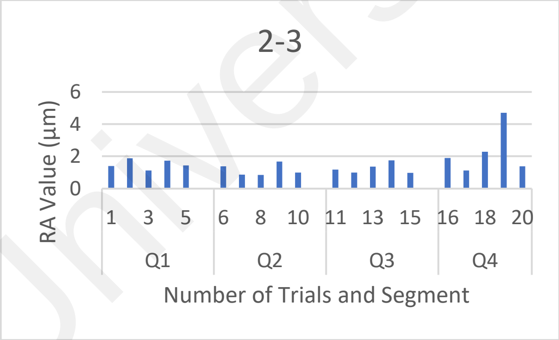

100-2
Ra Value (µm)
0
5
10
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment

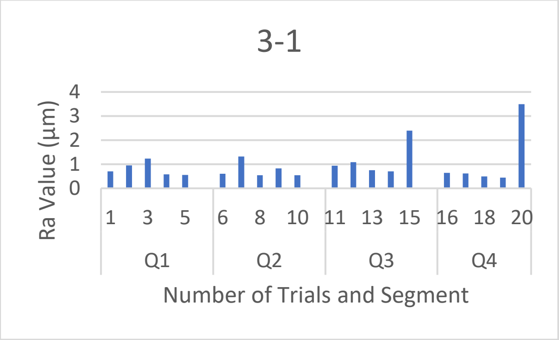

100-3
Ra Value (µm)
0
5
10
15
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment


100-4
Ra Value (µm)
0
5
10
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment


100-5
Ra Value (µm)
0
5
10
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment


2-1
Ra Value (µm)
0
1
2
3
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment


2-3
RA Value (µm)
0
2
4
6
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment


3-1
Ra Value (µm)
0
1
2
3
4
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment

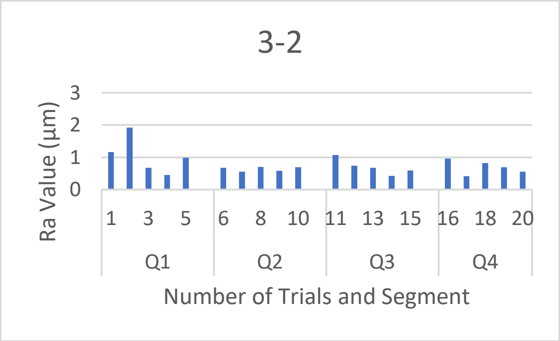

3-2
Ra Value (µm)
0
1
2
3
1
3
5
6
8
10
11
13
15
16
18
20
Q1
Q2
Q3
Q4
Number of Trials and Segment

Figure 4.7: Figure 4.8: a) Ra values by segments for Acrylic 100:1, b) Ra values by segments for Acrylic 100:2, c) Ra values by segments for Acrylic 100:3, d) Ra values by segments for Acrylic 100:4, e) Ra values by segments for Acrylic 100:5, f) Ra values by segments for Epoxy 2:1, g) Ra values by segments for Epoxy 2:3, h) Ra values by segments for Epoxy 3:1, i) Ra values by segments for Epoxy 3:2

From Figure 4.7,the surface roughness of the samples depends directly with the amount of hardener used. Lower amount of hardener produce smoother surface as the Ra values are smaller. This can be clearly seen in graph of acrylic resin 100:1 and 100:2 as compared to 100:3, 100:4 and 100:5. The same behaviour also shown for epoxy resin as the most hardener contains is the 3:2 and the graph presented of Ra values of almost 2 for every trials

There are no distinguish pattern seen in every graph as respect to quadrant and area of the sample as the Ra values distributed evenly with a few extraordinary values which can considered as outliers. This is due to the same materials used for every socket which is the elastic stockinette and the pattern of Elastic Stockinette from the different materials study.

4.3 Statistical Analysis of Surface roughness

The statistical analysis was done to determine the Standard Error Mean (SEM) and the p-value to determine the significance of the surface roughness. From the ANOVA one-way test, we can see that from overall parameters the only significant difference is between Dacron felt and polyester stockinette with p-value less than 0.05 which is 0.023 whereas the other four materials have insignificant difference in surface roughness between each other. However, when parameters were analysed as shown in Table 4.3, Dacron felt indicates weak significance ($0.1 > p > 0.05$) with Perlon stockinette for average surface roughness (Ra) and ten-point surface roughness (Rz) but strong significance for root mean square roughness (Rq). Dacron felt have very strong significance ($p < 0.01$) with polyester (0.009 for Ra, 0.003 for Rq and <0.001 for Rz) and with fibreglass (0.006 for Ra, 0.003 for Rq and 0.012 for Rz). Meanwhile, for the Perlon, polyester, fibreglass, and elastic stockinette, there are insignificant differences between Ra values and Rq values but strong significant difference between polyester and elastic stockinette for Rz value with p=0.047.

Table 4.3: p value between parameters of different reinforcement materials.

(I) Samples	(J) Samples	Ra Sig.	Rq Sig.	Rz Sig.
Dacron	Perlon	0.091	0.048	0.091
	Polyester	0.009	0.003	<.001
	Fibreglass	0.006	0.003	0.012
	Elastic	0.12	0.099	1
Perlon	Dacron	0.091	0.048	0.091
	Polyester	1	1	0.622
	Fibreglass	1	1	1
	Elastic	1	1	1
Polyester	Dacron	0.009	0.003	<.001
	Perlon	1	1	0.622
	Fibreglass	1	1	1
	Elastic	1	1	0.047
Fibreglass	Dacron	0.006	0.003	0.012
	Perlon	1	1	1
	Polyester	1	1	1
	Elastic	1	1	0.973
Elastic	Dacron	0.12	0.099	1
	Perlon	1	1	1
	Polyester	1	1	0.047
	Fibreglass	1	1	0.973

As for socket fabricated with different ratios, Anova one-way test revealed that the difference between epoxy resin is insignificant with all the ratios resulting with p=1.00 but there is a very strong significance between epoxy and acrylic resin. The socket made from epoxy resin is statistically similar to the socket made from acrylic resin with ratio 100:1 and 100:2. Meanwhile, 100:3 to 100:5 acrylic resin ratio shows a very strong significance as p value is calculated to be less than 0.001. In between the acrylic resin socket, a few ratios are statistically similar to the other such as 100:1 with 100:2, 100:2

with 100:1 and 100:5, 100:3 with 100:4, 100:4 with 100:3 and 100:5, and lastly 100:5 with 100:2 and 100:4

Table 4.4: p value between parameters of different ratios of resin and hardener

(I) Samples_Ratio	(J) Samples_Ratio	Sig.	(I) Samples_Ratio	(J) Samples_Ratio	Sig.
2:1	2:3	1.000	100:1	2:1	1.000
	3:1	1.000		3:1	1.000
	3:2	1.000		3:2	1.000
	100:1	1.000		100:2	.231
	100:2	.312		100:3	<.001
	100:3	<.001		100:4	<.001
	100:4	<.001		100:5	<.001
	100:5	<.001	100:2	2:1	.312
2:3	2:1	1.000		2:3	1.000
	3:1	1.000		3:1	.270
	3:2	1.000		3:2	.033
	100:1	1.000		100:1	.231
	100:2	1.000		100:3	<.001
	100:3	<.001		100:4	<.001
	100:4	<.001		100:5	1.000
	100:5	.069	100:3	2:1	<.001
3:1	2:1	1.000		2:3	<.001
	2:3	1.000		3:1	<.001
	3:2	1.000		3:2	<.001
	100:1	1.000		100:1	<.001
	100:2	.270		100:2	<.001
	100:3	<.001		100:4	1.000

	100:4	<.001		100:5	<.001
	100:5	<.001	100:4	2:1	<.001
3:2	2:1	1.000		2:3	<.001
	2:3	1.000		3:1	<.001
	3:1	1.000		3:2	<.001
	100:1	1.000		100:1	<.001
	100:2	.033		100:2	<.001
	100:3	<.001		100:3	1.000
	100:4	<.001		100:5	.169
	100:5	<.001	100:5	2:1	<.001
				2:3	.069
				3:1	<.001
				3:2	<.001
				100:1	<.001
				100:2	1.000
				100:3	<.001
				100:4	.169

Table 4.5: Tests of Between-Subjects Effects

Dependent Variable: Results					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	509.771^a	12	42.481	18.703	>.001
Intercept	530.468	1	530.468	233.552	>.001
Samples	96.077	4	24.019	10.575	>.001
Ratios	477.206	8	59.651	26.263	>.001

Samples * Ratios	.000	0	.	.	.
Error	606.439	267	2.271		
Total	2937.119	280			
Corrected Total	1116.210	279			
a. R Squared = .457 (Adjusted R Squared = .432)					

The Table 4.5 shows the result of the Two-way ANOVA test. The table suggest that there are significance difference between samples of different reinforcement materials and different type of resin and ratios. However, between the two variables, materials and ratios. The result shows to be irrelevant as there are no values on the Samples*Ratio. This is due to the violation of one of the six assumptions for a valid Two-Way ANOVA which is independence of observations, which means that there is no relationship between the observations in each group or between the groups themselves.

4.4 Effects surface roughness on the skin

In the prosthetization process, the friction behaviour of the surface’s contacts involved is crucial. In determining friction, surface roughness plays important roles as these values are in accordance to each other (Gadelmawla et al., 2002). Friction study shows important details about how the skin interacts with other surfaces. In the case of a prosthetic socket, the reduction areas of a positive cast will contribute the most pressure (Dakhil et al., 2020) as these areas are responsible to control residual limb movement in the socket. Also, the walking speed will have different effect on the friction as the patients are walking (Bonnet et al., 2014). For a transfemoral socket, reduction areas are wide across the circumference of the cast as the residual limb consists of more muscle compared to other prosthesis.

As a result, the friction between surfaces, which is commonly measured by the COF, is determined by a combination of the adhesion component and deformation (Unal &

Mimaroglu, 2003). The elastic-plastic response and energy dissipation in the contact region are involved in the deformation (Cavaco et al., 2016). Friction causes skin irritation and skin sensation. The physical features of the penetrating material are mostly responsible for the cause of irritation. Under friction, the long and rough projecting textile fibres may penetrate into the cell membranes of the skin, causing considerable irritation, but the soft and smooth surface generates only minor discomfort. The coarse weave surfaces and rough projecting textile fibres of nylon and wool generate more acute discomfort and drag, similar to the skin irritation described above. Skin sensations can be utilized to determine when injury begins and progresses. They also related with the surface character of a materials interact with the skin on the surface (W Li et al., 2011).

The result and discussion above mention on few factors in determining the best combination for a laminated transfemoral socket. A prosthetic device is a subjective matter where different patient requires different specifications as adjusted to their conditions. Few factors have to be considered and others factors may be tolerated in making the best socket for the patients. A skin-sensitive or skin-related clinical conditions patient like diabetic may require smoother surface as compared to a normal patient. While normal patient may be given a tolerable-rougher surfaces which will enhance gripping. With the results presented above, Prosthetist and orthotist will be able to refer to the materials and resin best use for their patients depending on their conditions.

CHAPTER 5: CONCLUSION

In this chapter, the research is concluded and what is discovered from this research will be presented. Plus, further development of the design is discussed to improve the device for better application.

5.1 Conclusion

The first objective which is to determine the best combination of ratio for epoxy and acrylic resin, material and fabric between Perlon stockinette, polyester stockinette, elastic stockinette, Dacron felt, and glass fibre for a laminated prosthesis socket was achieved. The best combination is using the acrylic resin with ratio of 100:1 or 100:2 with fibreglass as the reinforcement material. The curing time for acrylic resin is faster compared to epoxy resin by a significant amount and the statistical analysis showed that epoxy and acrylic 100:1 and 100:2 is similar. Fibreglass produced the smoothest surfaces compare to Perlon, polyester, elastic stockinette, and Dacron felt.

The second objective which is to evaluate the surface analysis of different combination of laminated prosthesis was achieved. Epoxy resin gave the smoothest surface in terms of type of resin and as for the reinforcement materials, fibreglass is the best material to use followed by polyester stockinette.

5.2 Study Limitation

There are limitations in this study. First, the materials selection was limited to five materials. Many other materials are being used in industries nowadays and researches on new materials are actively ongoing.

Second, the study highlights the impact on the patient skin and not the liner. The effect on the liner should also be studied to see the correlations of the impact of direct skin contact and liner-mediated contact.

5.3 Future Recommendations

There are some recommendations to improve this study in the future. First and foremost, all materials used as reinforcement should be analysed to determine the best for laminated prosthesis. This includes newly-discovered materials and the ones that are commonly used in the industries.

Next, the direct impact of surface roughness for transfemoral sockets to a patient’s skin was not observed as it requires different experimental set up including finding the subjects for the experiment. Biomechanical factor should be included in analysing the effect of surface roughness to a patient’s skin. Patients should use the laminated socket to evaluate if the impact will be general or only on certain areas.

Lastly, different materials fabricated with both types of resin should be examined, too. This will show the effect of different resins on different materials.

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