FABRICATION OF UNIAXIALLY ALIGNED ELECTROSPUN NANOFIBRE USING A ROTATING COLLECTOR

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DECLARATION

I declare that this project report entitled “Fabrication of Uniaxially Aligned Electrospun Nanofibre Using A Rotating Collector” is the result of my own work except as cited in the references.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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DEDICATION

To my beloved mother, father and the loves one.

ABSTRACT

Due to the development of nanofiber in medical application, military equipment and many more, the aligned nanofiber required intensive knowledge and information in electrospinning process and rotating drum as collector of nanofiber. Yet, the normal process of electrospinning using flat plate as collector produced random of nanofiber due to whipping instability that occur when the electrostatic force is induced to the polymeric solution. Thus, formation of aligned nanofiber can be generated by using rotary collector with suitable speed. Therefore, this research aims to obtain the uniaxially aligned electrospun nanofiber by using collector and identify the suitable speed of rotating collector. Polyvinyl Alcohol (PVA) electrospun nanofiber was produced by using electrospinning machine fabricated by UTeM students. The speed of rotating collector was set up at 100, 200, 300, 400, 500 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500 and 1600 RPM for 7 minutes with 10 cm distance needle tip with rotating collector and set up feed rate at 0.5 ml/h. The voltage was set at 15kv. Scanning Electron Microscope (SEM) was used to examine the morphology of the fiber. While ImageJ software was used to analyze the characteristic of nanofiber. Alignment of electrospun nanofibers were fabricated but there were still random nanofiber were obtain. This is because the speed of rotating collector need to get alignment approximately 24 m/s but the speed of rotating collector that can that use for this study only can rotate at 8.46 m/s. Generally, to get aligned eelctrospun nanofiber, the speed of rotating collector must be same or higher with speed of whipping instability.

ABSTRAK

Oleh kerana pembangunan seratnano dalam aplikasi peruatan, peralatan ketenteraan dan banyak lagi, seratnano yang sejajar memerlukan pengetahuan dan maklumat yang intensif dalam proses pemintalan elektrik dengan dram yang berputar dalam pengumpulan seratnano. Namun, proses pemintalan elektrik yang biasa digunakan adalah plat rata sebagai pengumpulan serat dan ia menghasilkan serat yang rawak. Ini disebabkan, ketidakstabilan sebat yang berlaku apabila daya electrostatik diinduksi pada larutan polimer. Oleh itu, pembetukan seratnano sejajar boleh dihasilkan dengan menggunakan dram berputar sebagai pemungut serat dengan kadar kelajuan yang sesuai. Objektif kajian ini adalah untuk mendapatkan sejajar seratnano yang telah dipintal oleh elektrik dengan menggunakan pemgungut dram dan mengenal pasti kelajuan pemungut berputar yang sesuai. Polyvinyl Alcohol (PVA) yang telah dipintal, seratnano dihasilkan dengan menggunakan mesin pemintalan elektrik yang direka oleh pelajar UTeM. Kelajuan dram ditetapkan pada 100, 200, 300, 400, 500 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, dan 1600 RPM selama 7 minit dengan 10 cm jarak antara hujung jarum dengan pemungut dram dengan kadar sesuapan di tetapkan pada 05 ml/j. Voltan juga ditetapkan pada 15 kV. Scanning Electron Microscope (SEM) digunakan untuk mengkaji morfologi serat. Perisian ImageJ digunakan untuk menganilisa sifat seratnano. Penjajaran seratnano telah dibuat tetapi masih terdapat seratnano dalam kedudukan secara rawak. Ini kerana kelajuan dram perlu berputar dalam 24 m/s tetapi kelajuan dram berputar yang boleh digunakan untuk kajian ini hanya boleh berputar pada 8.46 m/s. Secara amnya, untuk mendapatkan sejajar seratnano, kelajuan dram berputar mestilah sama atau leih tinggi dengan kelajuan ketidakstabilan serat.

ACKNOWLEGDEMENT

In the name of God, the most kind and merciful, first, I am grateful to Allah S.W.T for blessing me with a good health and well-being, opportunities and courage to complete my research and especially throughout all eight semesters in Universiti Teknikal Malaysia Melaka.

Next, I would like to express my deepest gratitude to my supervisor, Dr. Nurfaizey bin Abdul Hamid for giving me chances and trust to finish this project. Thank you for his time, guidance and willingness to share his ideas and views to make this research a reality. The encouragement and under supervise of Dr. Nurfaizey bin Abdul Hamid, I manage to understand and complete my final year project successfully.

Lastly, my gratitude goes to my lovely families for their encouragement, constant support and emotional understanding throughout my studies here. Their sacrifices and caring towards me are priceless. They are my source of strength to face all the obstacles in finishing this dissertation.

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LIST OF ABBREVIATION

DMF	Dimethylformamide
kV	Kilo Volts
PVA	Polyvinyl Alcohol
Wt.%	Weight Percentage
PVP	Polyvinylpyrrolidine
THF	Tetrahydrofuran

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Nanofibers have a small size of structure and light of weight. The characteristics of nanofiber are enormous specific area, high porosity and small pore size. Nanofiber can create a new product with new properties by using various chemical or physical processes as nanofibers are able to modify the nanofibrous layer. In 1930, electrospinning was first discovered as simple technique making nanofiber from polymer solution with diameter between 50 to 500 nanometers (Katta *et al.*, 2004).. Nowadays, nanofiber have been used as chemical sensors for detecting biological species, in high-performance filtration, as a drug delivery system, and as a scaffold for tissue engineering (Kim and Kim, 2006). There has been globally production and fabrication of nano-size structure for used optical and electrical feedback. Electrospun nanofiber also used in military and civilian in filtration application as the nanofiber has small pore of surface tension.

Electrospinning is a nanofiber production using High Voltage Direct Current (HVDC) from polymer solution. Nanofibers can be produced in many ways, such as electrospinning, melt spinning, solution spinning and gel state spinning (Katta *et al.*, 2004). The advantage of electrospinning process is it has a greater porous structure that could allow drug molecule to disperse out from the matrix efficiently (Taepaiboon, Rungsardthong and Supaphol, no date). Other than that, the high surface area of nanofiber with small pore size are good for certain application.

Alignment of electrospun nanofiber can be determine by using rotating collector that fixed with alternating current (AC) electric field and spinning nozzle that connected to with cylindrical electrode (Lee, Yoon and Kim, 2009). Various frequency can be tested to form an align of nanofiber electrospun such as 20 Hz, 100 Hz, and 500 Hz. Moreover, to produce the alignment

nanofiber, the collector speed need to modify or adjust until the aligned structure of nanofiber is obtained. As example, the speed rotating collector can be adjusted from 3.1 m/s to 8.4 m/s (Lee, Yoon and Kim, 2009). This is due whipping instability of polymer that stretch out by rotating collector. There various type of rotating collector was use to generate aligned nanofiber.

The type of collector used will gives different results for nanofiber either is random nanofiber or an align nanofiber Based on a study from (Safaeijavan *et al.*, 2014) shows that the rate of human Adipose-derived Stem Cell (ASC) is higher on aligned nanofiber compare to random nanofiber. ASC is the best cell stem cell-based in biomedical. The comparison between random nanofiber and aligned nanofiber as shown Figure 1.1 and Figure 1.2

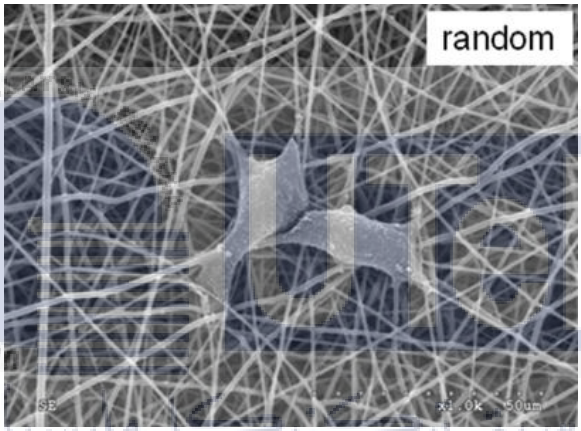


Figure 1.1 : Random nanofiber (Shin *et al.*, 2012)

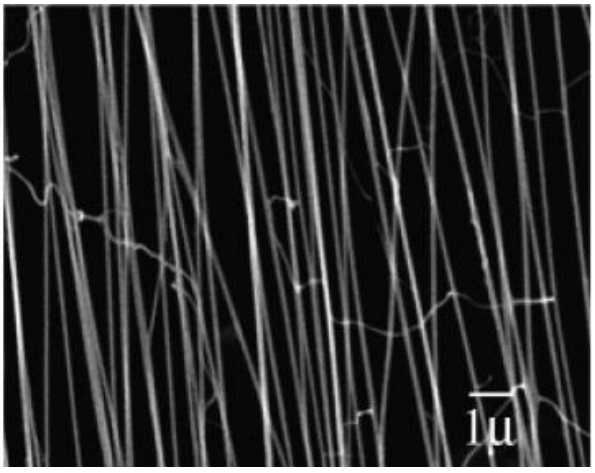


Figure 1.2 : Aligned nanofiber (Katta *et al.*, 2004)

1.2 Problem Statement

The problem that occur in common electrospinning with flat plate collector is formation of random nanofiber. This is because whipping instability cause from electrostatic interaction of the charge. The behavior of whipping instability is unpredictable because the behavior is affected by the viscosity of solution, induced of high voltage power supply and distance between collector. The uses of rotating collector to stretch the electrospun nanofiber once its reach the rotating collector. However, in flat plate collector only obtained random electrospun nanofiber as the collector static in one place. Thus, formation of aligned nanofiber can be generated by using rotating collector but the speed of rotating collector must be equal or more than of speed whipping instability in order to eliminates the accumulation of fiber at the collector. If the speed of the rotating collector is low, the accumulation of fiber at the collector occur and random nanofiber is obtained. Use of aligned nanofiber in engineering application is to hold promising potential as efficient cardio-inductive implants for cardiac tissue (Safaeijavan *et al.*, 2014). In some study, cell growth has shown improving in aligned formation of nanofiber and rapid oxygen exchange to heal wound. In this research will undergo uniaxially aligned nanofiber by using electrospinning process and observe the nanofiber under Scanning Electron Microscopy (SEM). Only the uniaxially aligned nanofiber will be fabricated in this study.

1.3 Objective

The objectives of this project are as follows:

1. To obtain the uniaxially aligned electrospun nanofiber by using a rotating collector.
2. To identify the suitable speed of rotating collector to get aligned nanofibers.

1.4 Scope of Project

The scopes of this project are:

1. To produce aligned polyvinyl alcohol (PVA) electrospun nanofiber by using electrospinning process with rotating collector.

2. To analyse morphology of nanofiber by using Scanning Electron Microscope (SEM)
3. To measure the fiber diameter and degree of oriented of electrospun nanofiber by using ImageJ software

1.5 Report Overview

The study begins with literature review on Chapter 2 that covers the historical background of electrospinning, an introduction to the electrospinning process, electrospinning parameter, application of nanofiber and current development. The basic experimental procedures are then presented in Chapter 3, to describe the process preparation of solution, preparation of electrospinning and analyse of electrospinning. Then, analysis of the result and discussion of the nanofiber was explained in Chapter 4. Finally, implication of the results and future research directions are also presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 History of Electrospinning

The term of electrospinning was taken or derived from electrostatic spinning and the term has rapidly used in around 1994 (Bhardwaj and Kundu, 2010). Electrospinning is a process depend on electrostatic force to produce continues fibre from polymeric solution and polymer melt (Casasola and Raffaella, 2016). Electrohydrodynamic phenomenon (EDH) is one of example of electrospinning, EDH is that the charge an electric field that induces in fluid motion (Collins *et al.*, 2012).

The reactions between fluid motion and electric field were explored and documented the process of electrospray by William Gilbert in 1600 (Tucker *et al.*, 2012). The first patent the process of electrospinning were John Francis Cooley and William James Morton (Casasola and Raffaella, 2016). In 1934, Anthony Formhals was the first pioneer of western world who patent the procedure of electrospinning (Casasola and Raffaella, 2016). Between 1934 to 1944, Formhals issues several of patents that explained procedure of fabrication of polymers filaments using an electrostatic force (Huang *et al.*, 2003). Fabrication of yarn that made from cellulose acetate (CA) electro spun nanofibre using rotating collector that produced by Formhals (Casasola and Raffaella, 2016). Fabrication of yarns by Formhals is using CA with of monomethyl either ethylene glycol and a voltage of 57 KV (Bhardwaj and Kundu, 2010). Movable thread collection machine to collect threads in stretched condition was consist in Formhals'spinning method (Subbiah *et al.*, 2005).

Over 60 years, there were 50 patents for electrospinning polymer melts and solutions had been filed. In 1952, Vonnegut and Neubauer designed simple apparatus for electrical atomization and could produces droplet about 0.1 mm droplets with sources of variable Direct Current (DC)

or Alternating Current (AC) voltage. In the early 1964, Taylor produced a study on behaviour of initial fluid droplet (cone) at needle tip when applied high electrical field. The studied shows that the droplet of cone with angle of 49.3º is produce when the surface tension is equilibrium with electrostatic force. Later in 1969, Taylor predict the critical electric potential required to change a cone of conducting fluid into an equilibrated cone by deriving a mathematical model.

In the 1971, Baumgarten produces an apparatus than can electrospun solution of polyacrylonitrile (PAN) into dimethyl formamide (DMF) with diameter range 0.05 – 1.1 µm and used various parameter such as solution viscosity , flow rates and distances to review the effect on nanofiber. The result shown that the viscosity of the solution is affected by the concentration of the solution itself thus it produced bigger nanofiber.

In the 1980, electrospinning method had regained more attention to among researchers as the fibre can be ultrafine fibre or fibrous structures from various polymer solution with diameter down to nanometres (Huang *et al.*, 2003). Over 200 colleges and research institutions all over the world are studying various parameter of electrospinning process and patent the electrospinning process has grown rapidly over years (Bhardwaj and Kundu, 2010). The companies such as eSpin Technologies, NanoTechnics and KATO Tech have close the gap of the advantages that offer from electrospinning while for air filtration product, company from Donaldson Company and Freudenberg has been using over two decades. Figure 2.1 show that increasing of publication of electrospinning over the years between 1967 to 2017.

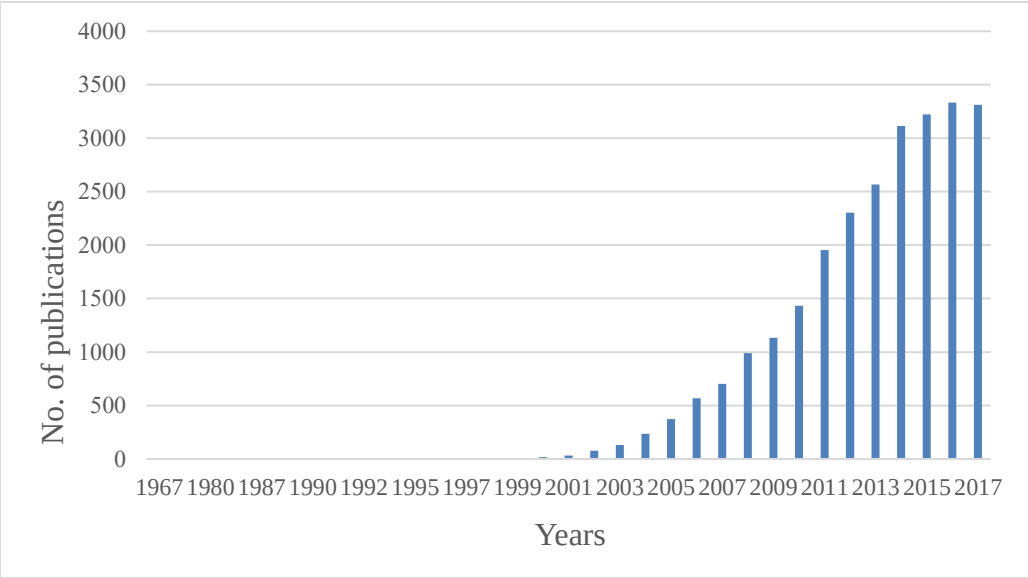


Figure 2.1: Publication of electrospinning over 50 years (Scopus, 19/11/2017. Search using keyword 'electrospinning')

2.2 Process of Electrospinning

Electrospinning is a spinning method that using electrostatic force to form small diameter of fibre (micrometre to nanometre) from a polymeric solution (Bhardwaj and Kundu, 2010). The fundamental setups of electrospinning involve with two electrodes which are source of electrode that connected with high voltage power supply and grounded conductive electrode (Nurfaizey, 2014). Basically, procedures of electrospinning involve with common apparatus consists of high voltage power supply, syringe, needle, syringe pump, conducting collector. The material of syringe can be plastic or metal to store the polymeric solution before inducing with high voltage power supply. The voltage can be in various voltage, between 5 to 39 kV (Casasola and Raffaella, 2016).

There are two types for set up the electrospinning which are horizontal and vertical as in Figure 2.2(a) and 2.2(b). Thus, researchers can fabricate nanofiber in more vigorous and complex way formation of nanofiber because development of electrospinning systems. Usually process of electrospinning take place in close chamber with good ventilation system because some solvent of polymer is hazardous and toxic to human being. Most fabrication of nanofiber are in room temperature. Furthermore, there also two types of set up of feed rate that sell in the market of

electrospinning machine which are, constant pressure using gravity and constant flow rate using syringe pump as shown in Figure 2.3(a) and 2.3(b).

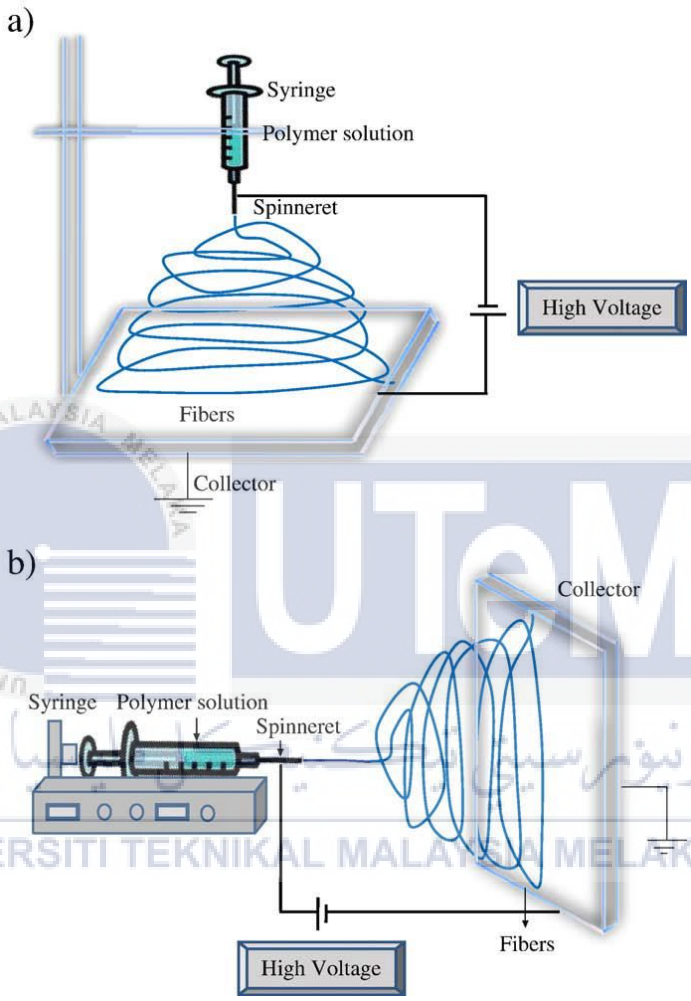


Figure 2.2: Set up of process electrospinning process (a) vertical set up of electrospinning (b) horizontal set up of electrospinning (Bhardwaj and Kundu, 2010)

At the end of spinneret, polymer droplet will form when applying suitable feed rate. Deformation of semi-spherical shape of droplet at the end of spinneret is deform when electrostatic force and molecules have same charges. However, the surface tension will not break up and deform a conical shape as known as Taylor Cone. Inducing a proper voltage will help braking down the surface tensions droplets due to high electrostatic forces. Then, at the summit of conical shape it will accelerating toward collector when the surface breaks up and emit by straight jet polymer as shown in Figure 2.3(a) and 2.3(b) (Nurfaizey, 2014).

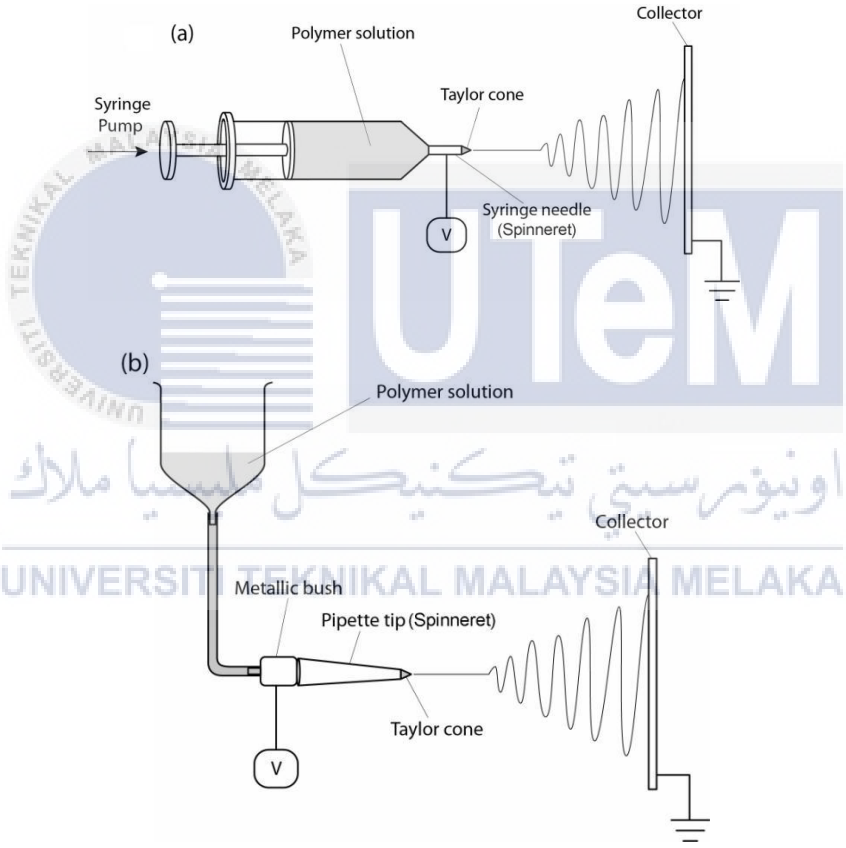


Figure 2.3 :Schematic drawing of feed rate system (a) constant flow rate using syringe pump (b) constant pressure by using gravity (Nurfaizey, 2014)

At the end of spinneret, polymer droplet will form when applying suitable feed rate. Deformation of semi-spherical shape of droplet at the end of spinneret is deform when

electrostatic force and molecules have same charges. However, the surface tension will not break up and deform a conical shape as known as Taylor Cone. Inducing a proper voltage will help braking down the surface tensions droplets due to high electrostatic forces. Then, at the summit of conical shape it will accelerating toward collector when the surface breaks up and emit by straight jet polymer (Nurfaizey, 2014).

There are three stages of polymeric jet act which is the development droplet at the end of spinneret, straight jet and unstable whipping jet region as shown in Figure 2.4. The formation of these three stages of polymeric jet due to several forces are present such as gravity, drag force, surface tension of the polymeric solution electrostatic force, viscosity of the solution, and coulomb repulsive force on the jet surface (Casasola and Raffaella, 2016). When started the electrospinning process the droplet of polymeric solution are present at the end of needle because the effect of the surface tension of polymeric solution. The polymeric solution elongates and formed Taylor cone shape due to increasing of voltage power supply. The electrostatic forces overcome the surface tension and effect a small electric charge jet from the tip of the Taylor cones when the voltages reach a critical value V_c as shown in Figure 2.5

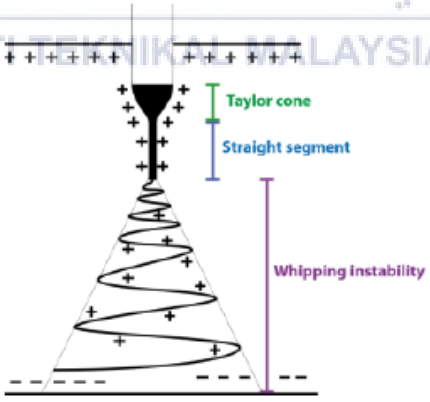


Figure 2.4: Schematic diagram of polymeric behaviour (Casasola and Raffaella, 2016)

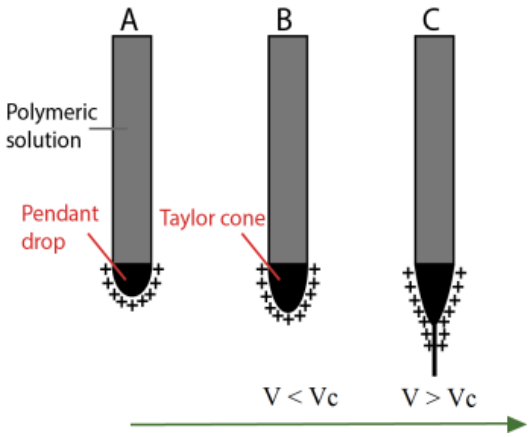


Figure 2.5: Schematic drawing a Taylor cone and jet formation (Casasola and Raffaella, 2016)

2.3 Electrospinning Parameter

Electrospinning process can be manipulated by various parameter such as process parameters, solution parameter and ambient parameter (Bhardwaj and Kundu, 2010). Bhardwaj and Kundu categorized variable on each these parameters. For this study are focus on process parameter:

- Process parameter
  - Applied voltage, tip to collector distance, type of collector and speed.

2.3.1 Applied Voltage

Applied voltage to the polymeric solution are the important step in the electrospinning process. Voltage are crucial to determine diameter and morphology of electrospun nanofiber. Applied voltage to the polymeric solution are also affected by distance between needle and collector and type solution are use. The applied voltage (V) and the distance between the needle and the collector (d) affect the electric field (E) which is well-defined as the ratio V/d.

Megelski *et al.* (2002) state that increment of spinning voltage (5-12 kV) will decrease the fiber diameter from 20 to 10 µm. Formation of thinner nanofibre are effected by increasing the

voltage that also increasing the electrostatic repulsive force on the end of spinneret (Zhang *et al.*, 2005). In other hand, increment of voltage will help broadening of the solution due to higher columbic forces. Other than that, it also leads to fast evaporation of the solvent from the fiber formations. Probability of beads development are increase as the voltage increase (Bhardwaj and Kundu, 2010). Researchers, Liu *et al.* (2009) have made a comparison between the applied voltage with the mean diameter of fiber. For example, electrospun solution PLGA in THF/DMF had conducted by Lie et al. The result that gained from the electrsopun of fiber show that increase of nanofiber diameter from 412 to 751 nm is detected as the voltage in increase from 14 to 20 kV. The research continue until 22 kV and the diameter of fiber are reduce to 636 nm. This phenomena cause by unstable whipping; the straight jet become more unstable as increasing the voltage.(Casasola and Raffaella, 2016). Electrospinning setup, distance between needle and collector, temperature, humidity and type of polymer-solvent are use can cause different result and finding.

2.3.2 Tip to Collector Distance

Many researchers have studied about the distance from needle tip to collector. The studied found that there are changes on fiber characteristic and its morphology. Observation show that, a suitable distance is required to ensure the fiber have enough time to dry before reaching the collector (Bhardwaj and Kundu, 2010). Furthermore, if the collector distance with needle tip too far or too close can cause formation of bead is occurred. Huang *et al.* (2003) stated that incomplete evaporation can cause the electrospun fiber stick to collector due to distance between needle tip and collector are to short. In other studied from Lee *et al.* (2004) show that non-linear graph was obtained in average diameter of fiber polyvinyl alcohol over distance between needle tip to collector. The result show lowest diameter of fiber at 7 cm of distance between needle to collector for both cases; 1700 and 4000 number-average degree of polymerization (P_n) of vinyl acetate at constant voltage of 20 kV as shown in Figure 2.6.

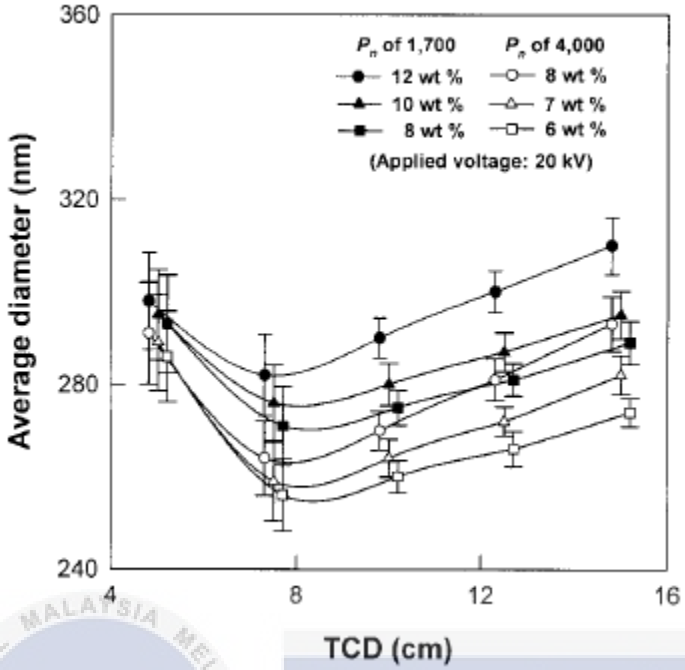


Figure 2.6: Average diameter of PVA nanofiber as function of needle tip to collector (Lee *et al.*, 2004)

2.3.3 Fiber Alignment

The common fabrication of nanofiber is non-woven nanofiber which use for certain applications such as filtration, tissue scaffolding and drug delivery system. However, aligned nanofiber or axially nanofiber are limited of publications due to difficulty of three-dimensional of whipping. The following are the possible technique to obtain align nanofiber.

2.3.3.1 Type of Collector and Speed

Types of collector are using is one most significant aspect on electrospinning process. The role of collector in electrospinning act as conductive material connected to ground that collect electrospun nanofiber. Basically, aluminum foil with static plat is used to collect electropsun nanofiber (collector) but due to difficulty in transferring the electrospun nanofiber and aligned

nanofiber, several researchers have come out with various type of collector in its application such as wire mesh(Wang *et al.*, 2005), pin (Sundaray *et al.*, 2004), parallel or gridded bar , rotating wheel, rotating drum and many more.

In Wang et al. (2005b) study on two different collector which is wire screen and aluminum foil in the blowing -assisted electrospinning of hyaluronic acid and found that in aluminum foil was problematic to detached the membrane from the collector (Wang *et al.*, 2005). Even though the formation of nanofiber are good in wire drum but still form some bead as seen in SEM image and it became worst as increase the collection time.

Alignment of nanofiber can be carried by using rotating collector and suitable rotation speed (Kumbar *et al.*, 2008). Lee, Yoon and Kim (2009) show that the apparatus of electrospinning by using (a) rotating collector with field controllable electrode and (b) normal electrospinning to get aligned nanofiber as shown in Figure 2.7 . The studied was carried with two different speed; 3.1 m/s and 8.4 m/s with three different method; normal electrospinning, modified electrospinning (5 kV, 20 Hz) and modified electrospinning (5 kV, 500 Hz). The result show most aligned nanofiber under SEM micrograph at 8.4 m/s for modified electrospinning (5 kV, 20 Hz) as shown in Figure 2.8. These results most related to the apply frequency and induced induces polarization moment and anisotropy due to shape factor by field-controllable electrode.

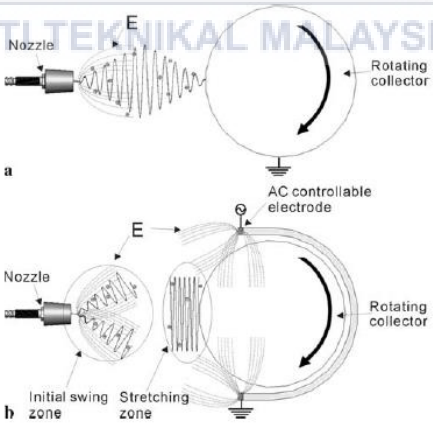


Figure 2.7: Schematic diagram of electrospun fibre alignment mechanism (a) normal electrospinning (b) modified electrospinning process with a field-controllable electrode ((Lee, Yoon and Kim, 2009)

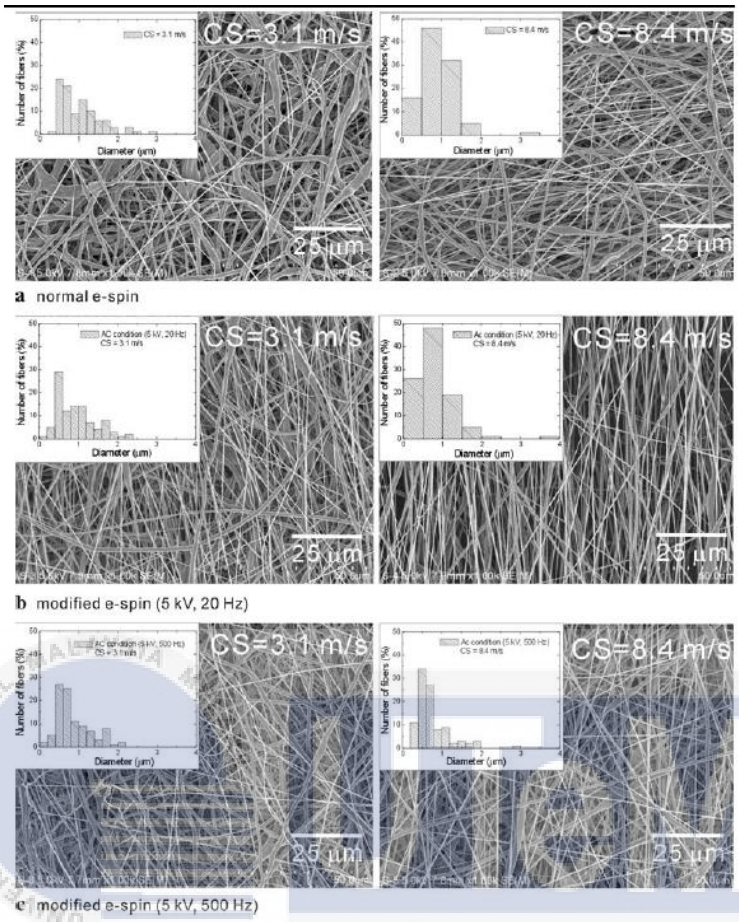


Figure 2.8: SEM micrographs of electrospun fibres fabricated with two different collector speed for (a) normal electrospinning (b) modified electrospinning process with 5kV, 20Hz (c) modified electrospinning with 5 kV, 500 Hz (Lee, Yoon and Kim, 2009)

Pan *et al.* (2006) studied about aligned nanofiber with different parameter as shown in Table 2.1. The result of nanofiber under SEM microscopic shown PVP (12 wt%) fiber well aligned at velocity of 14.9 m/s. It shows that alignment of nanofiber can be determined in high velocity as shown in Figure 2.9. In the other hand, nanofiber below 14.9 m/s of velocity still become aligned nanofiber but some of the nanofiber have curly pattern or not align well at certain area. Thus, the alignment nanofiber also depends of other parameter such as type of polymers and solvent, the molecular weight of the polymer and polymer concentration which need to be further investigation.

Table 2.1: Parameter study (Pan *et al.*, 2006)

Polymer	Concentration (wt%)	Spinning voltage (kV)	Flow rate (µl/min)	Velocity (m/s)
PVA	10	±3.3k	5	3
PVA	13	±4.5k	5	4.3
PVP	6	±3.8k	16	1.4
PVP	8	±3.8k	14	2.8
PVP	10	±4k	14	6.4
PVP	12	±4k	14	14.9

Figure 2.9: Well-aligned PVP (12wt%) fibres collected at the surface velocity of 14.9 m/s (Pan *et al.*, 2006)

2.4 Application Nanofiber

Electrospinning process is a process fabricate nanofibrous structure that claim various range of application to science application, such as water and air filtration, in protective clothing, in biomedical application as tissue engineered scaffolds dressing, wound healing and as drug delivery system (Casasola and Raffaella, 2016).

2.4.1 Tissues engineered scaffolds dressing for wound healing

Tissue engineering is design of synthetic matrices that can mimic the structure and biological function of the natural extracellular matrix (ECM) (Huang *et al.*, 2003). The current method to replace damage tissue is by using autografting allografting method (Casasola and Raffaella, 2016). Allografting method is transplanted tissue from human body to the part is damaged but disadvantage of this method is continuing pain affect from the procedure of surgery. Other than that, if the organ from the donor it might rejection of the recipient body and risk from infection.

In recent years, electrospun nanofiber have increased attention among researchers in production of scaffolds due to smaller diameter and stronger structure of nanofiber. Furthermore, high surface area with volume ratio permit nutrient and waste products to exchange more vigorous (Liu, Xia and Czernuszka, 2007). The type of tissue can be fabricated depend on the material or polymer that had been used to gain the best mimic to ECM.

The most common natural material that has been used were collagen (Ma and Zhang, 1999), gelatin (Huang *et al.*, 2004) and cellulose acetate (Liu and Hsieh, 2002). These natural material they have better cell adhesion and proliferation of large surface area and better biocompatibility than synthetic polymer (Casasola and Raffaella, 2016). However, there are disadvantages on these types of material which is electrospun nanofiber have weak mechanical properties. Moreover, the main disadvantage is loss of properties of the material when dissolve with solvent.

2.4.2 Dressing for wound healing

Dressing for wound healing is the most common people used when injured or burn of human skin. The purpose of dressing is to protect from bacterial infection and speed up the rate of healing without leaving a scar to human skin. However, the material of the dressing depends on the type of wound or burn. Nowadays, there are several type of dressing that had been developed such ass hydrocolloid dressing, alginates dressing, hydrogel dressing, semi-permeable adhesive film dressing, foam dressing and biological dressing (Boateng, 2008).

High porosity of nanofiber make it good for dressing because it good exchange white blood cell and absorption of oxygen from surrounding to the wound (Casasola and Raffaella, 2016). The preferable of material of dressing is hydrophilic material because it give moist wound environment that increase of rate of healing and improve migration of epithelial cell (Kocbek *et al.*, 2013). The material of polymer that most common in dressing wound application are polyvinyl alcohol (PVA) (Jannesari *et al.*, 2011), chitosan (Homayoni, Ravandi and Valizadeh, 2009) collagen (Rho *et al.*, 2006), hyaluronic acid (Uppal *et al.*, 2011) and polyurethane (Khil *et al.*, 2003). Synthetic polymers also can be used as wound dressing membrane. In another study show that alignment of nanofiber increases the cell infiltration compare to randomly nanofiber

2.4.3 Protective clothing

Protective clothing in military to provide in survivability, sustainability and combat effectiveness to overcome bad weather conditions, and nuclear, biological and chemical warfare. The function of breathing aid and protective clothing to protect soldier and civilian from inhalation and absorption to the skin by hazardous chemical warfare such as sarin, soman, tabun and mustard gas (Huang *et al.*, 2003). The current protective clothing containing charcoal absorbents that has limitation on water permeability and more weight of the protective clothing. Thus, electrospun nanofiber has high porosity but the size of porosity is small and it desirable that can block the deadly chemical agent in spray form (Gibson, Schreuder-Gibson and Rivin, 1999).

2.5 Current Development

2.5.1 Aligned Nanofiber of Polyvinyl Alcohol (PVA)

In 2012, Kumar studied that aligned nanofiber by using polyvinyl alcohol as polymer at 8 wt.% and distilled water as solvent. The solution was prepared by weighting 0.4 gm of PVA by using electronic weighing machine and 5 mL of distilled water. The fabrication was held at flow rate 0.2 mL/hr and the applied voltage was 19 kV. The distance between needle tip to collector was 10 cm. The rotating drum as collector was connected to the ground. The result from this study were shows that formation beads were present due to complete evaporation of nanofiber before reaching the rotating drum as shown Figure 2.10. The diameter of nanofiber was found that 192 nm to 286 nm.

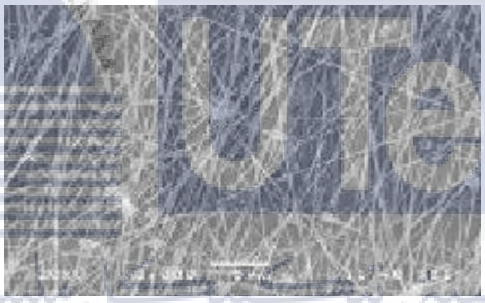


Figure 2.10: Structural of nanofiber under SEM (Kumar, 2012)

In 2016, Aphale *et al* studied on axially oriented on nanofiber in various wt.% of solution which are 10 wt.%, 15 wt.% and 0.1 wt.% of multi-walled nanotubes (MWNT) in 10wt.% PVA by using rotating plate (Aphale *et al.*, 2016). Electrospinning of each PVA solution was prepared at 15 kV across 15cm distance at flow rate of 1.5 ml/hr. The result from the studied show the average diameter of 10wt.%, 15wt% and 0.1 wt.% MWNT in 10 wt.% PVA were 80 nm to 170 nm, 100 nm to 270 nm and 250 nm respectively as shown in Figure 2.11. The increase of concentration nanofiber lead to increase of viscosity of the solution. Hence, the diameter of nanofiber was as increase as the viscosity increase due to less

stretching of each nanofiber. While for PVA-MWNT was observed that have uniform diameter nanofiber due the composition of the solution.

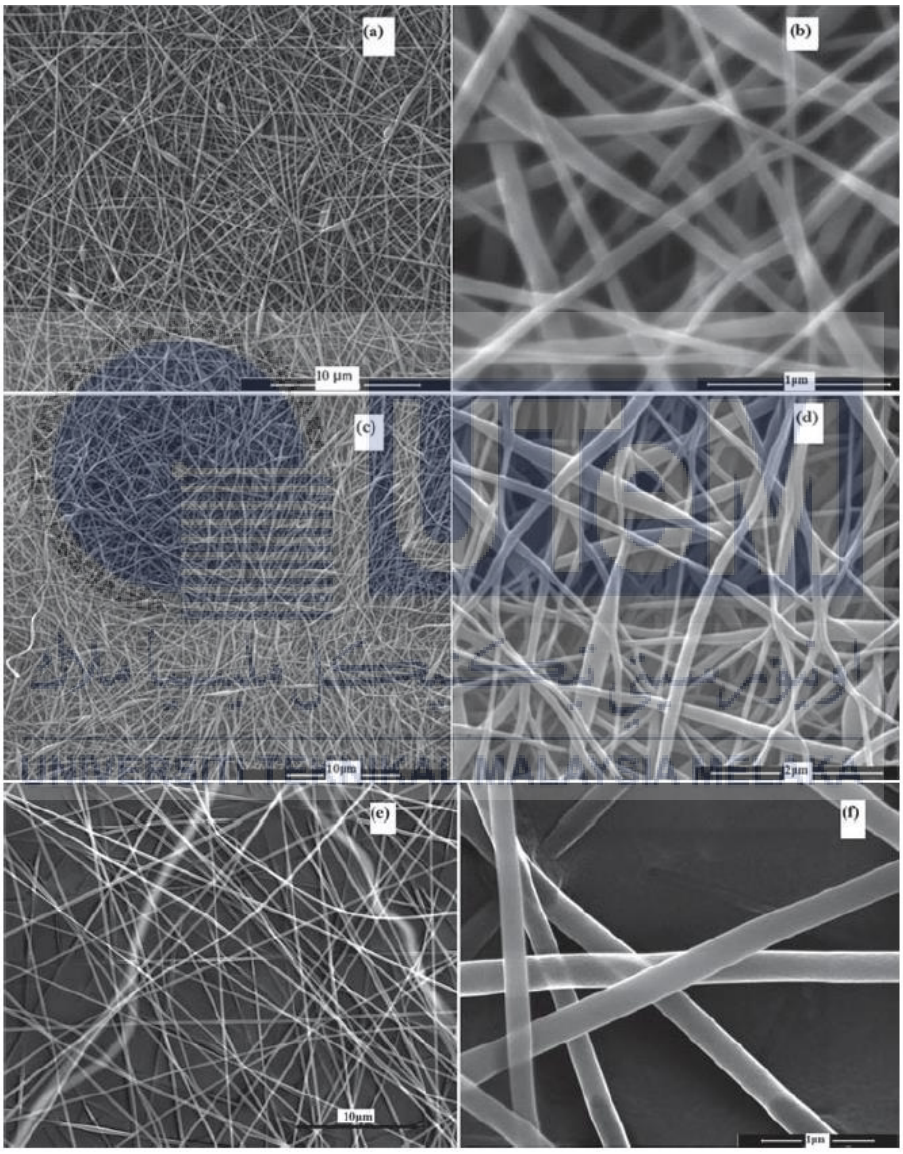


Figure 2.11: SEM images of randomly oriented nanofiber (a), (b) 10 PVA, (c), (d) 15%, (e), (f) 10% PVA-0.1 wt.% MWNTs (Aphale *et al.*, 2016)

CHAPTER 3

METHODOLOGY

There several types and standard are used to conduct electrospinning process and fabricate nanofiber. In this chapter, step by step from preparation of solution, fabrication of nanofiber and analysis the nanofiber. The information and theory regarding to the solution of the polymer and standard use to conduct the experiment will be explain further in methodology. The flow chart to complete this project is included to show the flow process as shown in Figure 3.1.

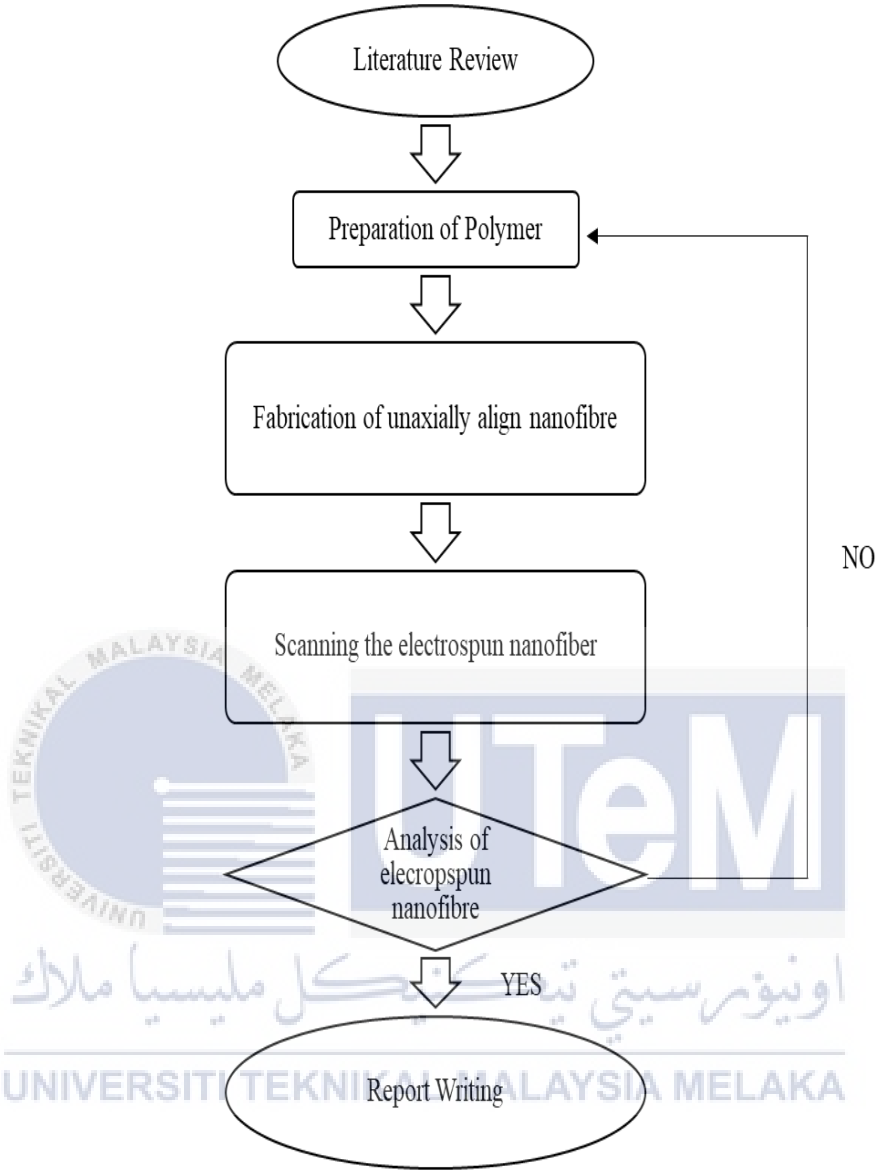


Figure 3.1 Flow chart

Table 3.1: Gantt Chart

GANTT CHART FOR FINAL YEAR PROJECT SEMESTER 1														
No.	**Task**	**Week**												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Search related topics from journal articles and other material														
2	Literature Study 2.1 Objective and scope 2.2 Method and procedure 2.3 Electrospinning 2.4 Polyvinyl alcohol														
3	Experiment 3.1 Preparation of polyvinyl alcohol 3.2 Fabrication nanofibre by using electrospinning														
4	Observation 4.1 Scanning the nanofibre														

3.1 Preparation of Polymer

3.1.1 Weighting Process

Weighting process of solution are the crucial step before entering electrospinning process. Polyvinyl Alcohol (PVA) only polymer will be cover in the experiment. Digital analytical balance from Mettler-Toledo Group with model Dragon 204 shown in Figure 3.2 was used to weight the solution. The specification of the solution was used in this experiment was 8 wt. % of PVA with 92% of distilled water as solvent. Before weight the solute and solvent, place a beaker in the digital analytical balance and set zero. This will help get exact value of the solution without including the weight of the beaker. Next, place 8 gram of polyvinyl alcohol into the beaker by using spatula. Then, insert 92 grams of distilled water carefully to the beaker. Every time place the solute or solvent, close the clear glass to get exact value needed.

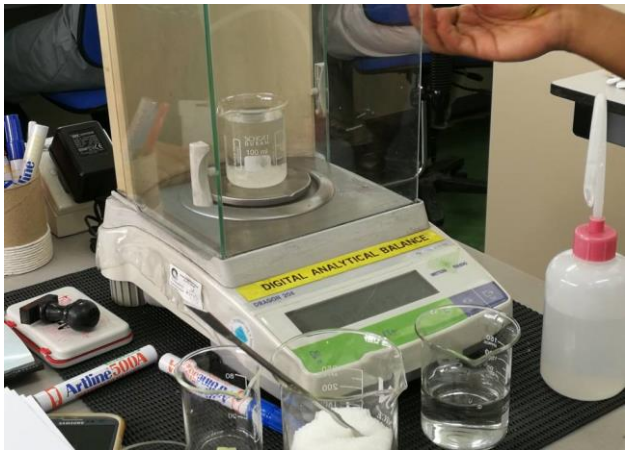


Figure 3.2: Digital Analytical Balance

3.1.2 Stirring Process

Stirring process need to be done after weighting process. This is because to mix component between solid and liquid to get homogeneous liquid mixture. In this experiment a mechanical stirrer IRA RW 20 digital model was used to speed up the mixture as show in Figure 3.3. The stirrer process takes up to three hours for PVA-distilled water solution.

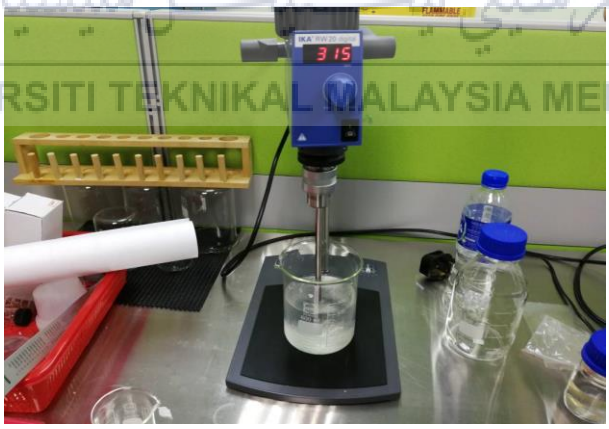


Figure 3.3: Mechanical Stirrer for PVA-distilled water solution

3.2 Fabrication of Nanofiber

3.2.1 Electrospinning Process

The electrospinning machine with rotating collector at Advance Material Characterization Laboratory Centre (AMCHAL) was used to process aligned nanofiber as shown in Figure 3.4. The electrospinning machine was fabricated by previous PSM student whose supervise under Dr. Nurfaizey. The high voltage power supply and syringe pump are using machine from company name, NLI while motor for rotate the collector is from Orientalmotor with model number US2D40 – EC.

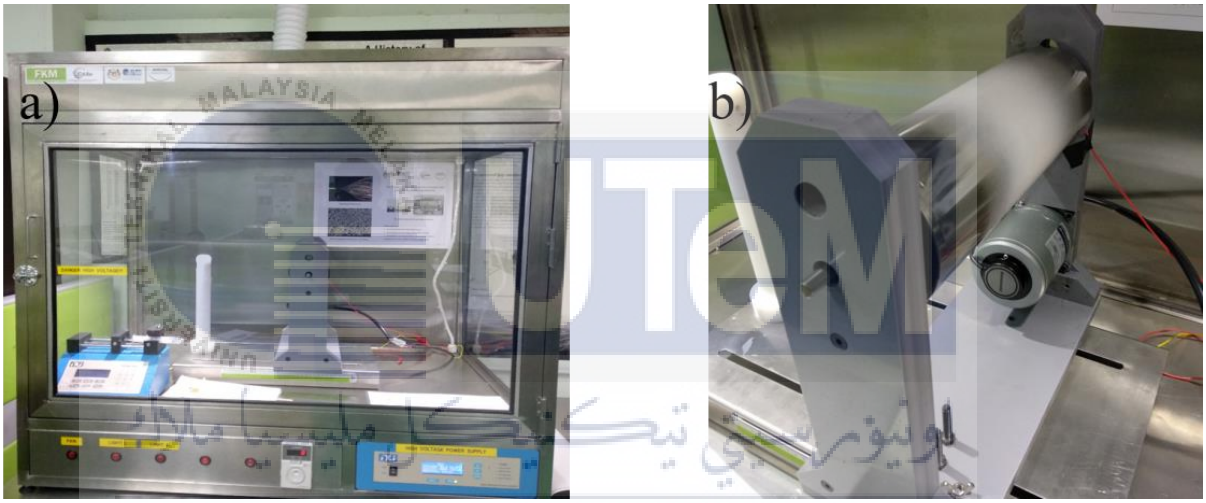


Figure 3.4: a) Electrospinning machine b) Rotating Collector

The setup of the electrospinning process by placing syringe at syringe pump machine with feed rate of 0.5 ml/hour. Next, the syringe was connected to the needle via capillary tube. The distances between needle tips to rotating collector was set 10 cm apart and the voltage was set 15 kV. The experiment was conduct at different speeds of rotating collector which were 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600 RPM.

3.3 Analysis of Nanofiber

3.3.1 Sputtering

Before preparing nanofiber for Scanning Electron Microscope (SEM) observation, Auto Fine Coater model JEOL JEC-3000FC as shown in Figure 3.5 was used to sputter the sample of nanofiber. This process will help improve imaging under SEM. In this experiment, it coated with ultra-thin silver to the surface of the sample and the coated duration was set up for 300 seconds. Efficient glow discharge for sputtering can be obtained due to permanent magnet in the cathode. The vacuum machine helps get ultrafine coating and result shadows free of coating.

Figure 3.5: Auto Fine Coating (JEOL JEC-3000FC

3.3.2 Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) Model JEOL JSM-6010PLUS/LV as shown in Figure 3.6 was used to examine the morphology of the fiber. The machine was scans a focused electron beam over a surface to create an image. To obtain information about the morphology and surface fiber, the electrons in the beams cooperate with the sample to producing several signals. There were 16 samples examined under SEM. Each sample were conducted with two different image magnifications which were SEI 12 kV WD10mm SS49 ×5,000 5 µm and SEI 12 kV WD10mm SS49 ×10,000 1 µm.

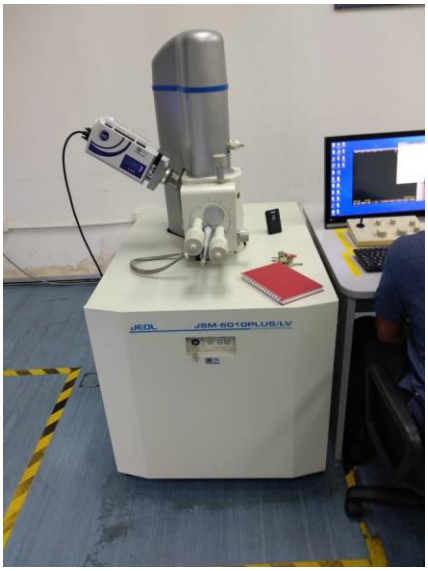


Figure 3.6: Scanning Electron Microscopy machine (JEOL JSM-6010PLUS/LV)

3.3.3 Analyse the SEM

To analyze the SEM micrograph ImageJ version 1.8.0_112 software from National Institutes of Health, USA was used as shown Figure 3.7. The degree orientation and diameter of the fibre for each RPM were analyzed in this experiment.

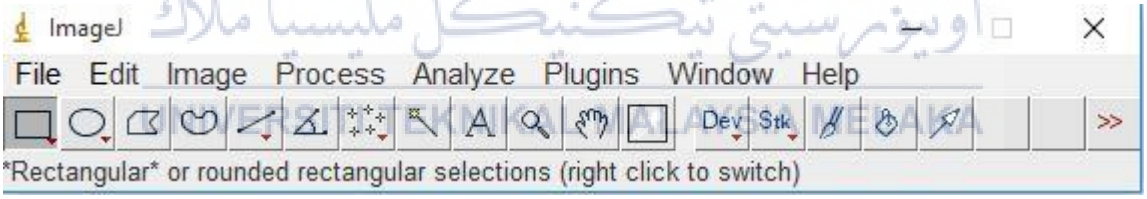


Figure 3.7: ImageJ software (version 1.8.0_112)

The procedure to determine the degree of orientation and fiber diameter as follow:

Degree of Orientation

a) SEM image was opened on the ImageJ software.
b) Angle tool was chosen on the tool bar as shown in Figure 3.8.

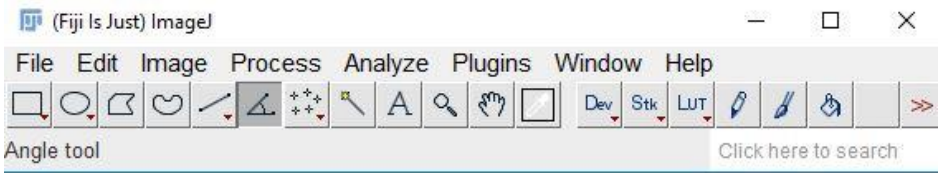


Figure 3.8: Angle Tool

c) Three point was picked on each fiber in the image as shown in Figure 3.9.

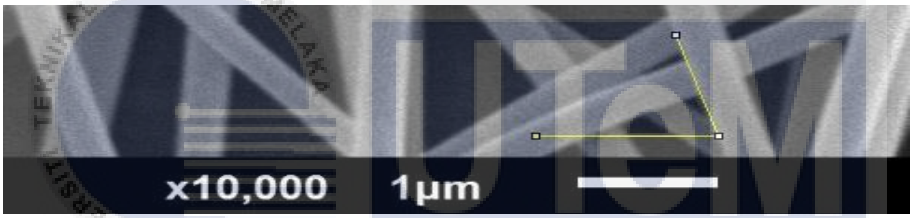


Figure 3.9: Picked three points

d) Pressed ‘M’ on the keyboard to show the result as shown in Figure 3.10

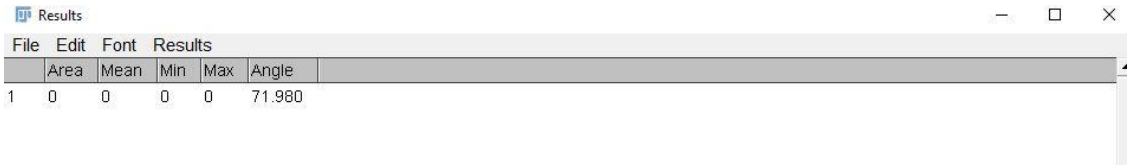


Figure 3.10: The result in ImageJ software

e) Repeat step c) and d) for 100 times at other fibers to get the average.

Diameter

a) SEM Image was opened on the ImageJ software
b) Choose straight line on the tool bar as shown in Figure 3.11

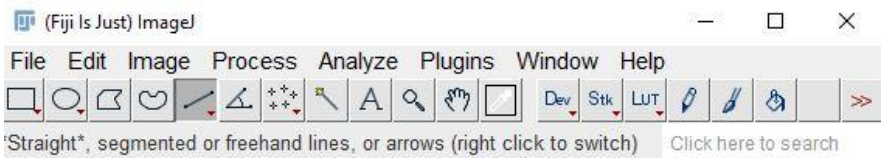


Figure 3.11: Straight line tool

c) Drew the straight line on the references line in the SEM image Figure 3.12

Figure 3.12: Straight line was drew at references line

d) Click the 'Analyzed' on the tool bar and choose 'Set Scale'. Changed the known distance to 1000 as 1micro meter equal to 1000 nano meter and unit length also changed to nm (nano meter). Then, press "OK" as shown in Figure 3.13

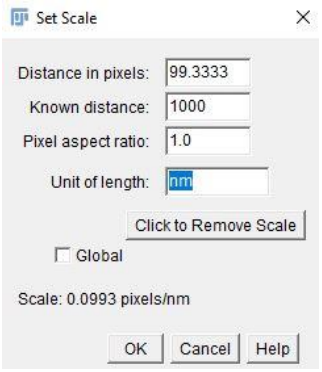


Figure 3.13: Set scale tool bar

e) Drew the line on each fiber to determine the diameter as shown in Figure 3.14.

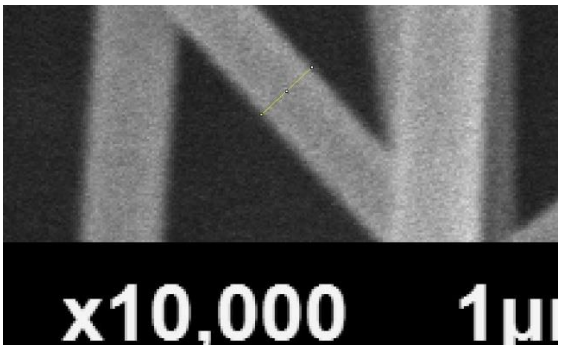


Figure 3.14: Drew straight line on each fiber

f) Press “M” on the keyboard to show the result as shown in Figure 3.15

Results

File Edit Font Results

	Label	Area	Mean	Min	Max	Angle	Length
1		3040.404	135.756	68.188	158.448	46.397	295.762
2		2939.057	134.302	81.688	167.026	43.531	282.967
3		3040.404	134.597	73.000	158.659	49.185	291.306
4		2939.057	146.001	129.205	178.335	45.000	283.012
5		3648.484	161.518	138.500	187.553	5.042	349.098
6		3952.525	165.604	117.062	196.651	3.013	383.377
7		3648.484	174.270	148.926	198.969	11.634	352.439
8		4256.565	157.995	123.250	193.494	0.000	407.749
9		3851.178	156.729	123.750	186.399	0.000	372.517
10		3749.831	156.811	120.188	175.676	0.000	365.011
11		3141.750	133.051	69.750	152.855	42.274	302.872
12		3040.404	141.639	87.000	163.761	38.047	289.430
13	Mean	3437.345	149.856	106.709	176.485	23.677	331.295
14	SD	462.330	14.079	28.845	16.179	21.678	44.972
15	Min	2939.057	133.051	68.188	152.855	0.000	282.967
16	Max	4256.565	174.270	148.926	198.969	49.185	407.749

Figure 3.16: The result of ImageJ software

g) Repeat step e) and f) for 100 times at other fibers to get the average.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results and Discussions

The process of electrospinning with rotating collector as shown in Figure 4.1 on side view of schematic setup. The electrospun nanofiber were collected for 7 minutes at speed 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600 RPM with 15 kV of power supply and the distance between needle tip to collector was 10 cm. The feed rate was applied at 0.5 ml/h. The rotating collector was wrap with aluminium foil to ease in transporting the electrospun nanofiber into SEM analysis and the aluminium foil was grounded in this process.

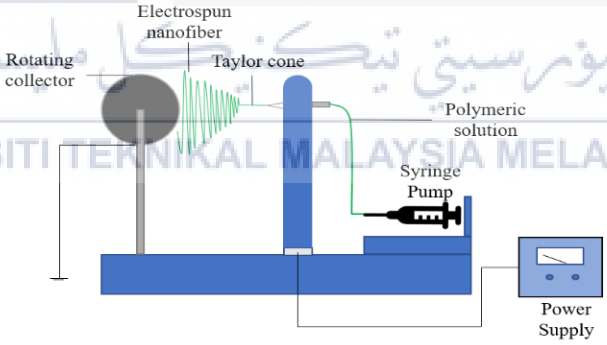


Figure 4.1: Schematic setup of electrospinning process

Once the polymeric solution was induced with high voltage power supply, whipping instability occur. Whipping instability occur in looping and continuously until reach collector. The use of rotating collector was to get aligned electrospun nanofiber as in whipping instability segment was stretch out once its reach the rotating collector. While for flat plate collector, it is static collector and random electrospun nanofiber are collected as the whipping

instability segment overlap each other. The rotary collector and flat plate collector are shown in Figure 4.2 (a) and 4.2 (b)

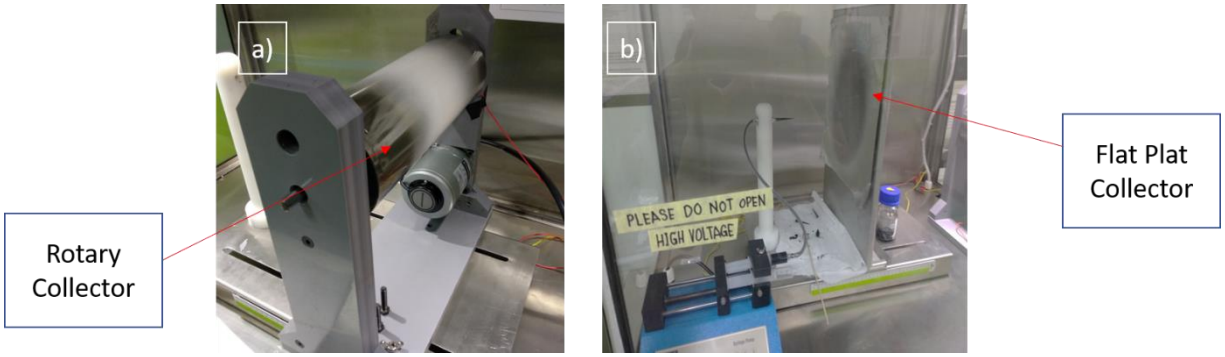


Figure 4.2: a) Rotary Collector b) Flat Plat Collector

4.2 Visual Observation

Other than that, the distance of between needle tip and rotating collector are important parameter in electrospinning process. Figure 4.3 and Figure 4.4 shown that the deposition of nanofiber with distance between needle tip to rotating collector, 15 cm and 10 cm respectively. At distance 15 cm distance show the attached of electrospun nanofiber on aluminum foil was wide. At distance 10 cm show the attached electrospun nanofiber in the aluminum foil much more concentrated at one straight path. The fabrication of electrospun nanofibers with distance at 15 cm were fabricated on preliminary testing. Hence, 10 cm distance between rotating collector and needle tip showed the most eligible in the study.

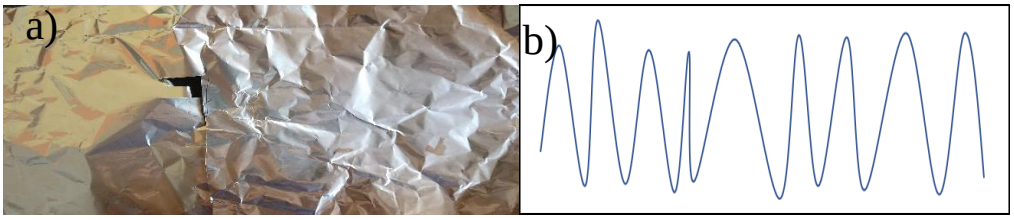


Figure 4.3: Deposition of electrospun nanofiber on distance 15 cm (a) on aluminum foil (b) Schematic drawing on aluminum foil

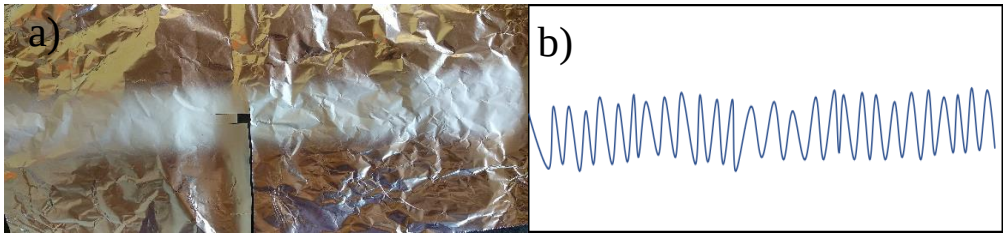


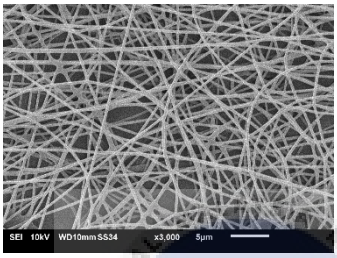
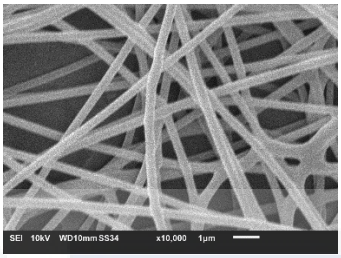
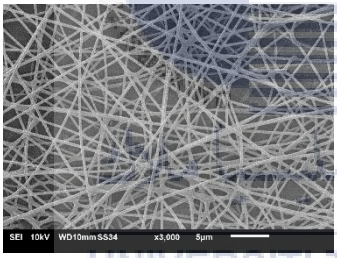
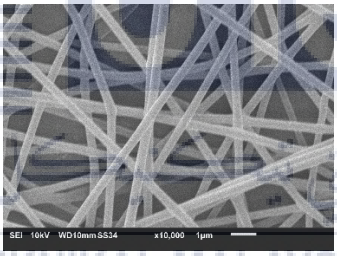
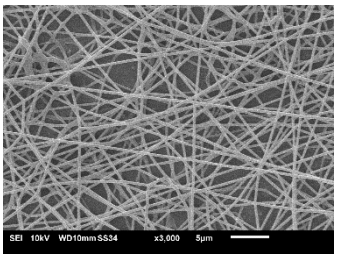
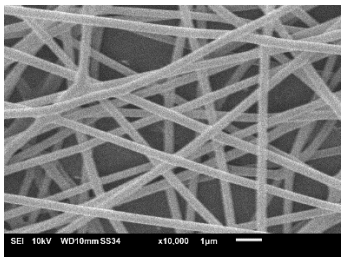
Figure 4.4: Deposition of electrospun nanofiber on distance 10 cm (a) On aluminum foil (b) Schematic drawing on aluminum foil

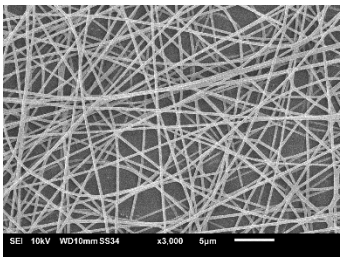
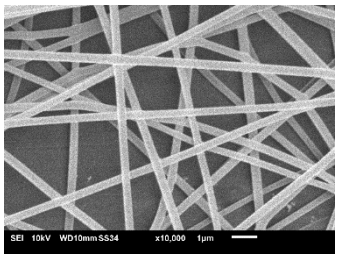
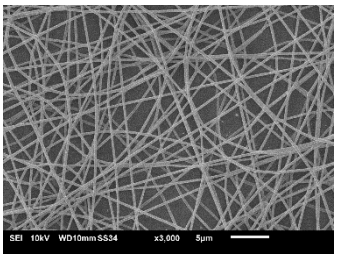
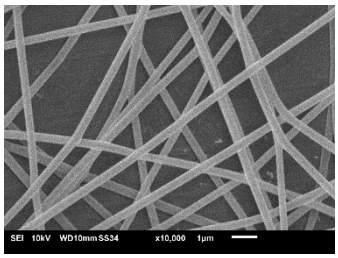
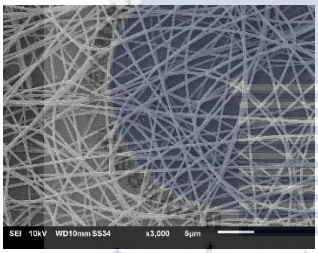
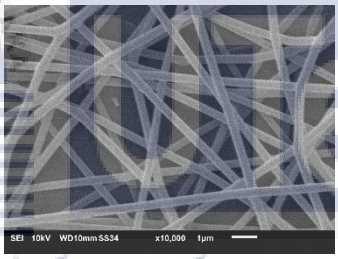
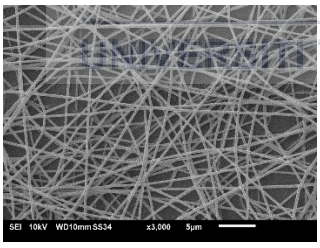
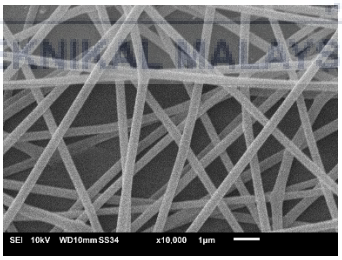
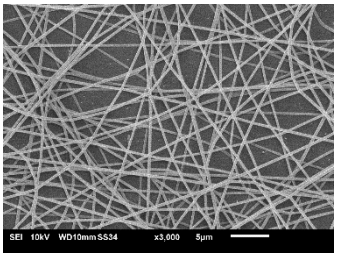
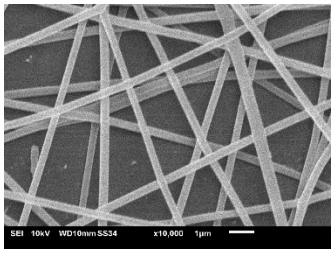
The deposition of nanofiber was affected by the distance between needle tips to rotating collector. The further the distance the less deposition of nanofiber were obtained. The Figure 4.3 shows that wide range of deposition of nanofiber because there was resistance of air on whipping instability and electrospun nanofiber itself also light in weight. As the whipping instability went through air resistance, the range of looping whipping instability keeps on increase as the distance increase.

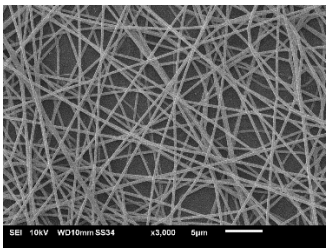
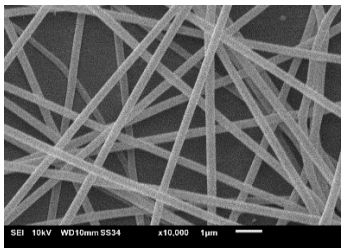
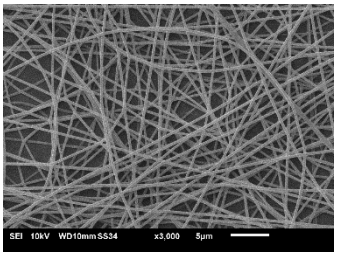
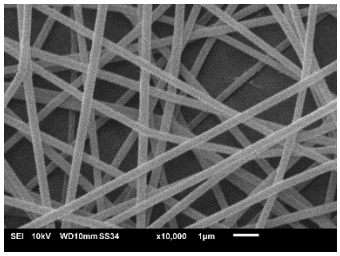
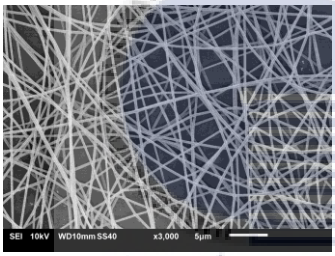
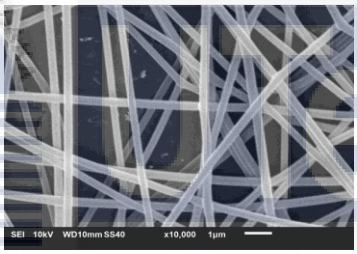
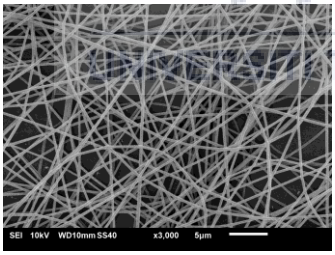
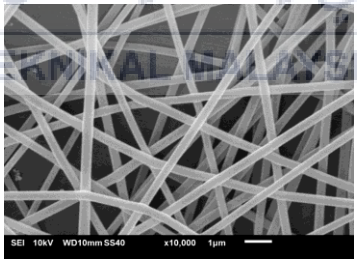
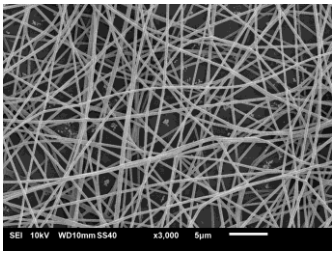
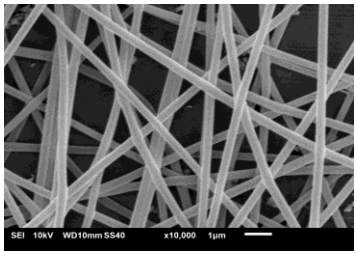
4.3 Diameter of Nanofiber

As the nanofiber had went through to the SEM image analysis, analysis on fiber diameter of the nanofiber had been identified by using ImageJ software and every single nanofiber have been measured on SEM micrograph (SEI 12 kV WD10mm SS49 ×10,000 1 µm). The fiber diameter and SEM micrograph was simplified in Table 4.1.

Table 4.1: Result of nanofiber

Speed of Collector (RPM)	**SEI 12 kV WD10mm SS49 ×3,000 5 µm**	**SEI 12 kV WD10mm SS49 ×10,000 1 µm**	**Fiber Diameter (nm)**
100			337 ± 34
200			339 ± 25
300			358 ± 27

400			335 ± 16
500			348 ± 13
600			375 ± 17
700			361 ± 22
800			378 ± 47

900			362 ± 15
1000			365 ± 22
1100			370 ± 19
1200			355 ± 25
1300			375 ± 21

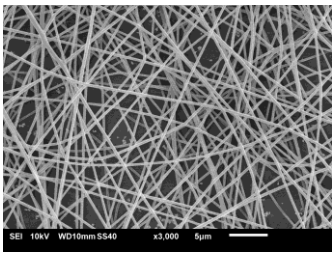
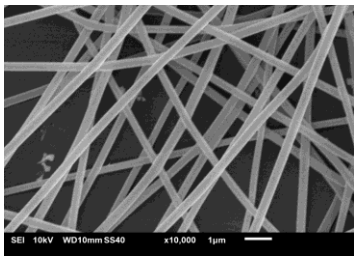
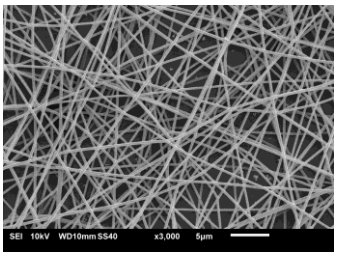
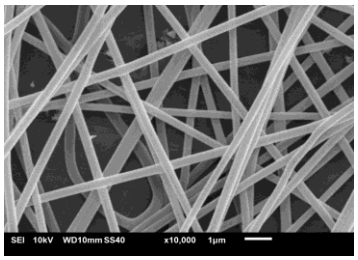
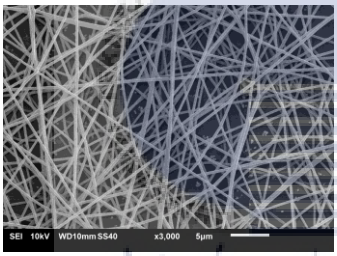
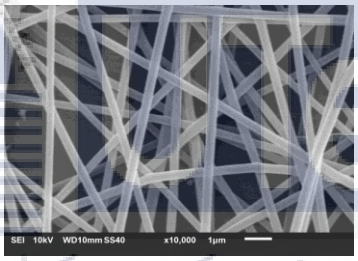
1400			370 ± 24
1500			350 ± 28
1600			359 ± 16

Figure 4.5 present graph of diameters of nanofiber against speed of collector. Based on the result, comparison between 100 RPM to 1600 RPM there was increase of fibers diameter from 337.10 nm to 359.97 nm. Furthermore, this process not taken in vacuum chamber.

The scatter plotted in Figure 4.5 clearly show there are positive correlation between diameter of electrospun nanofiber and speed of rotating collector. The value of correlation, R is 0.51 that obtain by using Microsoft Excel 2016 which near to zero. Hence, in this study there are no relationship obtain between diameter of PVA nanofiber and speed of collector.

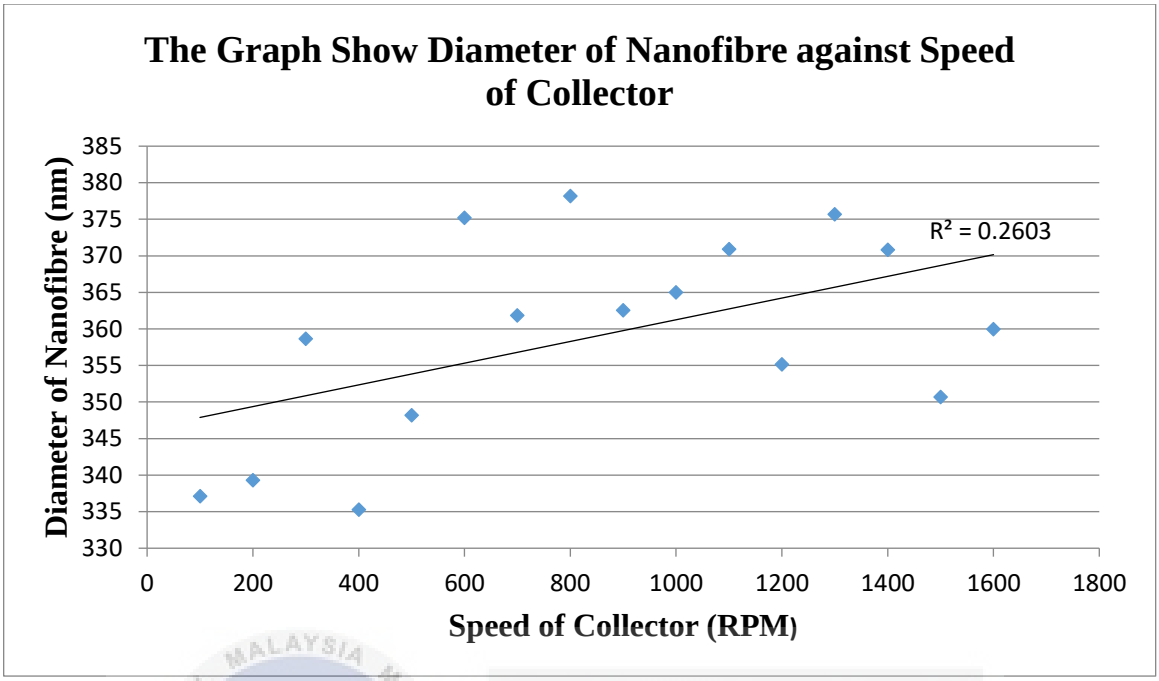
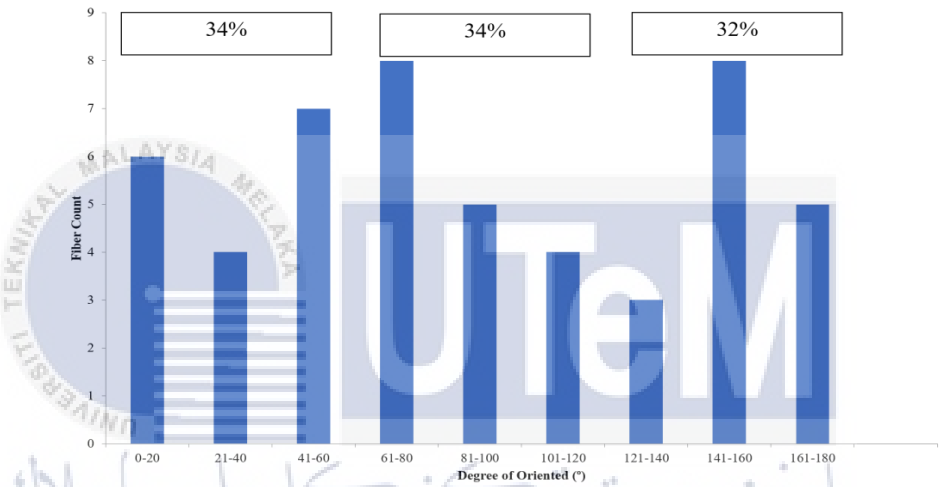
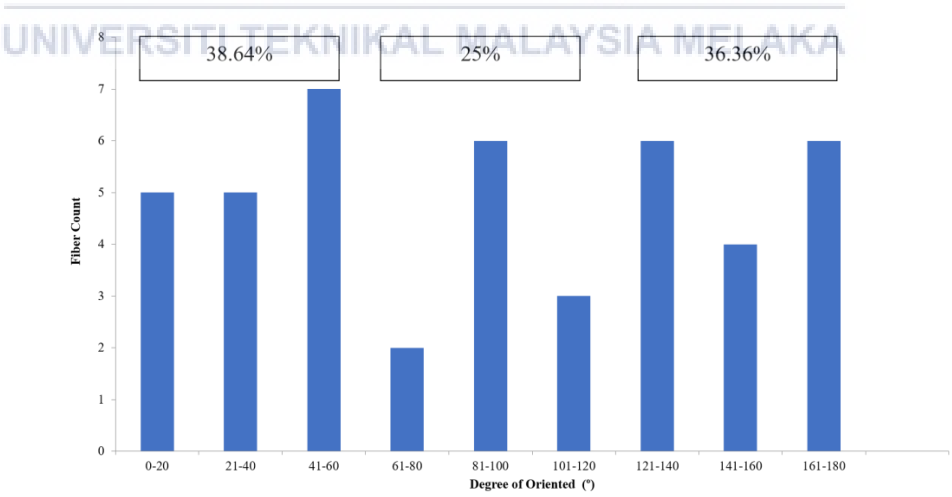


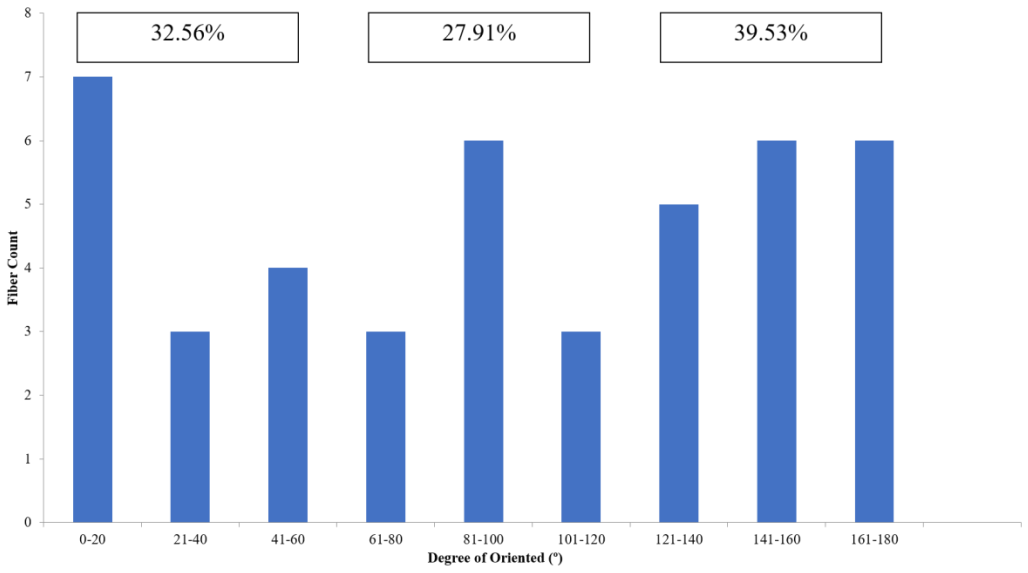
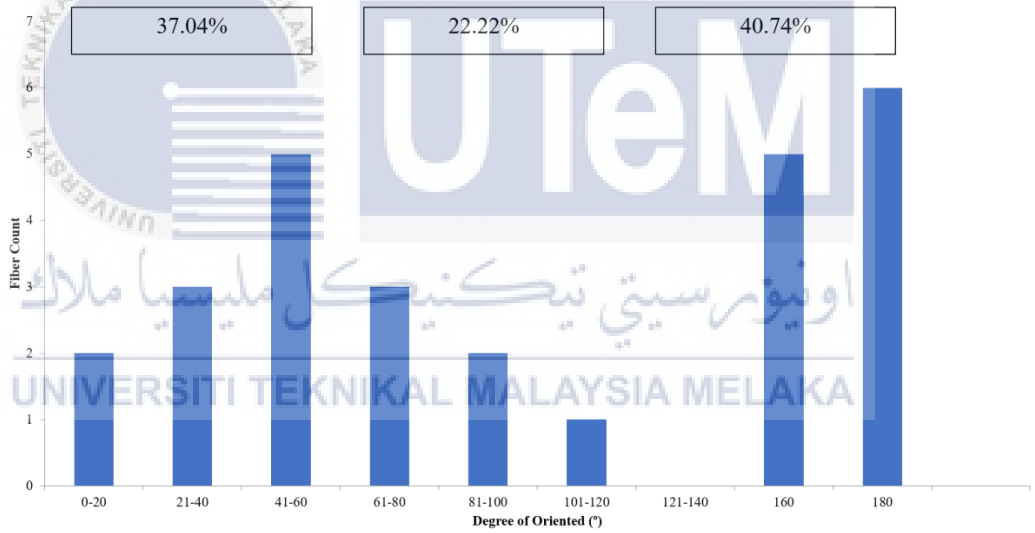
Figure 4.5: The graph shows diameter of nanofiber against speed of collector

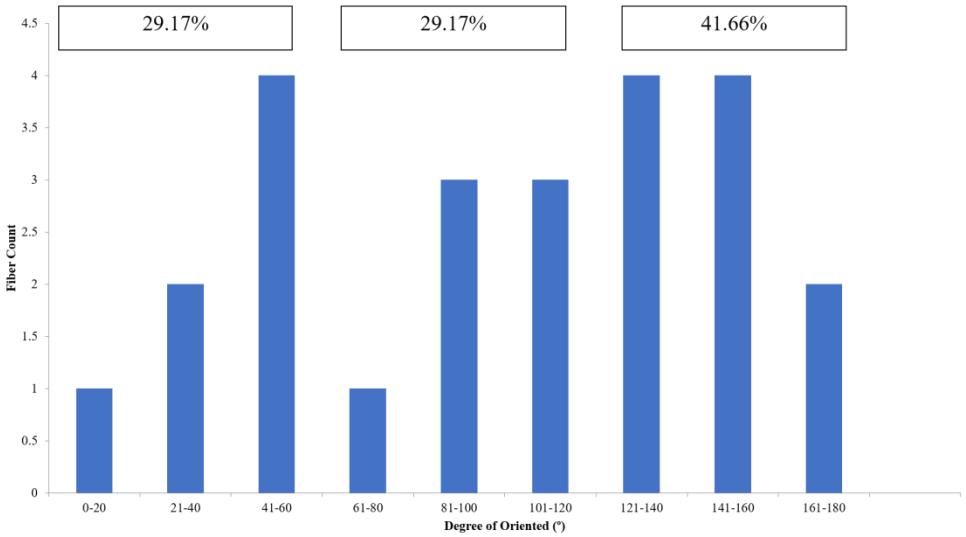
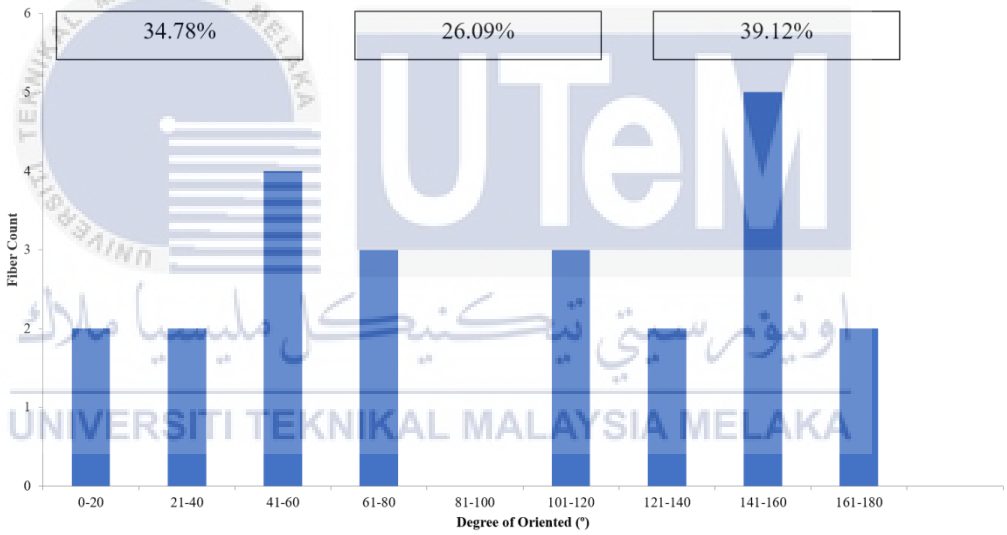
4.4 Alignment of Nanofiber

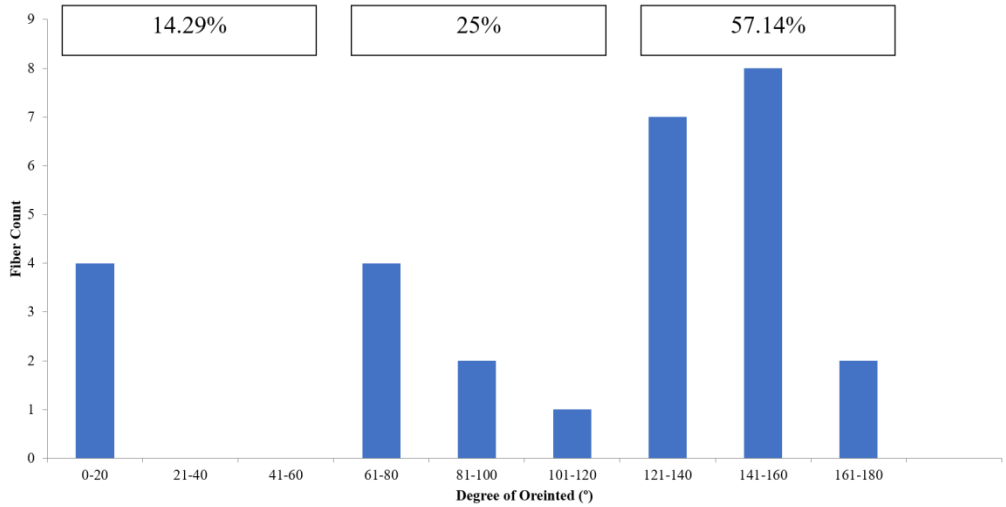
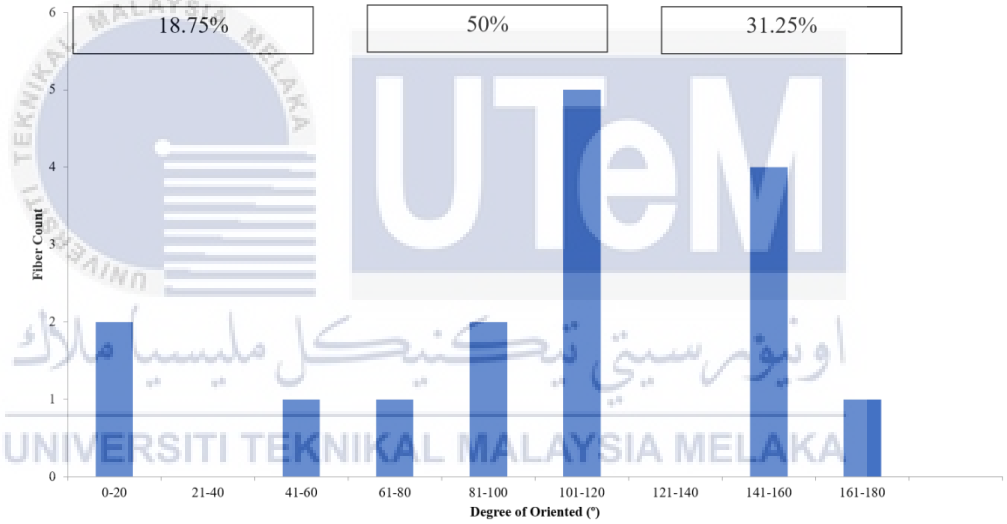
The results on degree of orientation of nanofiber for each speed have been list out in graph form by using ImageJ software as shown in Table 4.2. The graphs in Table 4.2 also indicates three segment percentage of fibers count; segment one (0º - 20º, 21º - 40º, 41º - 60º), segment three (61º - 80º, 81º - 100º, 101º - 120º) and segment three (121º - 140º, 141º - 160º, 161º - 180º). Assume that, at segment two was desirable to show aligned electrospun nanofiber. Based on the result, the most striking result to get aligned electrospun nanofiber at 1600 RPM which the maximum speed of the machine can achieved. There are nine of fibers were closest to 90º in 1600 RPM speed of rotating collector, which the highest fiber count among other speed. Based on Lee, Yoon and Kim (2009), the higher the speed of rotating collector the most aligned of nanofiber will deposited in the drum or rotating collector and obtained most aligned nanofiber at 1531 RPM compared to 640 RPM. What is interesting in this data is that at 1600 RPM also the highest percentage fiber count at segment two by 52.72% among other speed. These phenomena were discussed in next section.

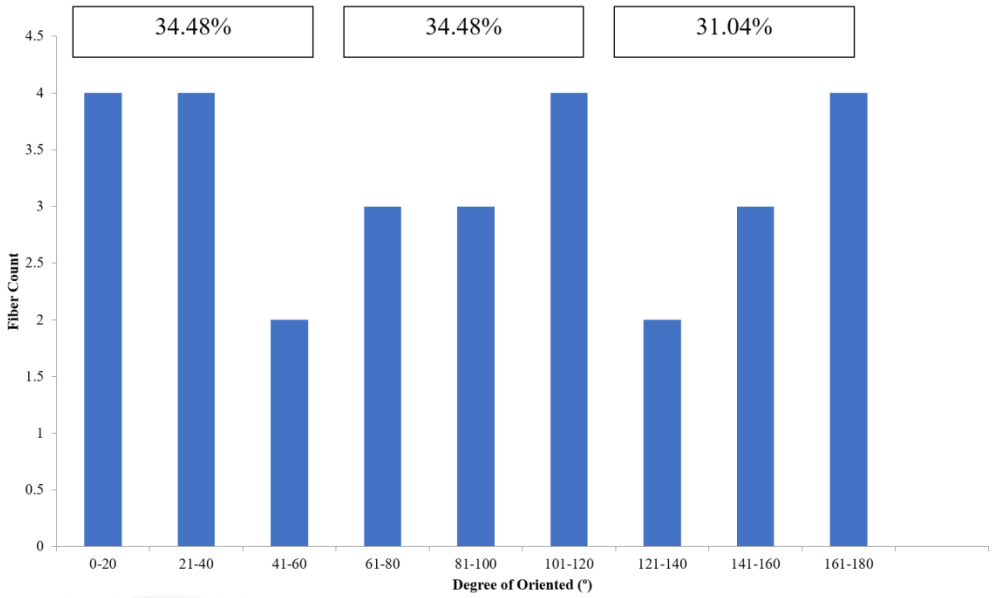
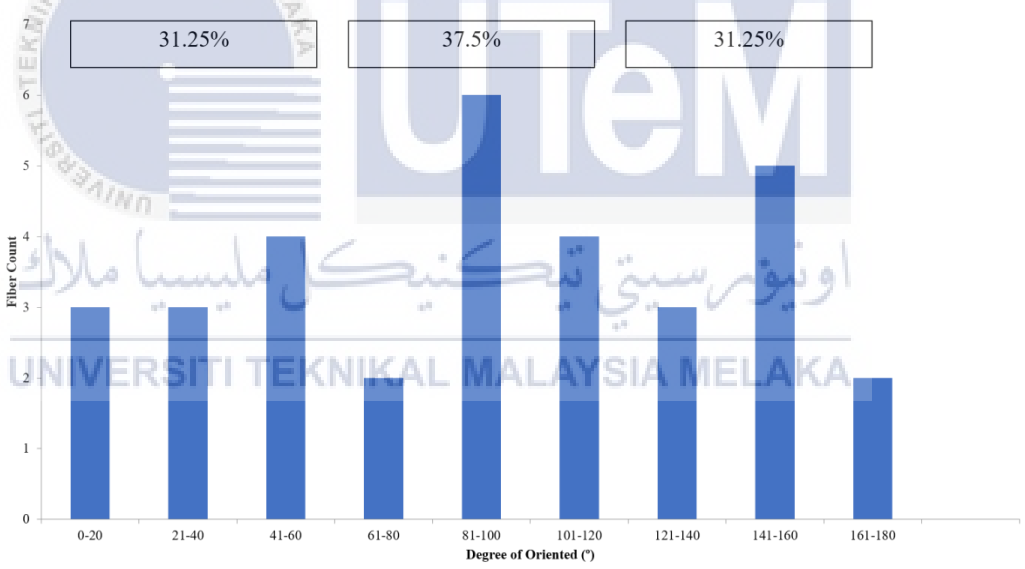
Table 4.2: Degree of Oriented

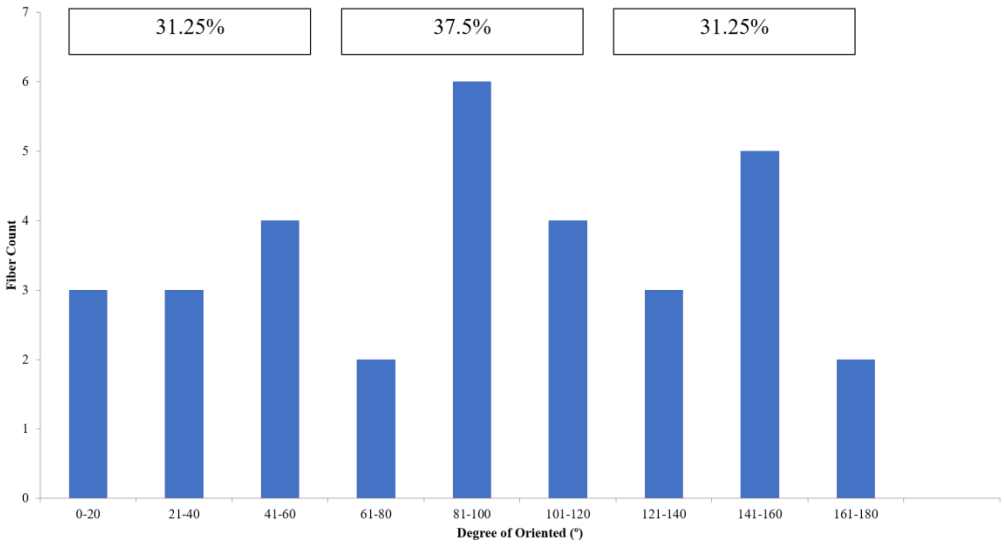
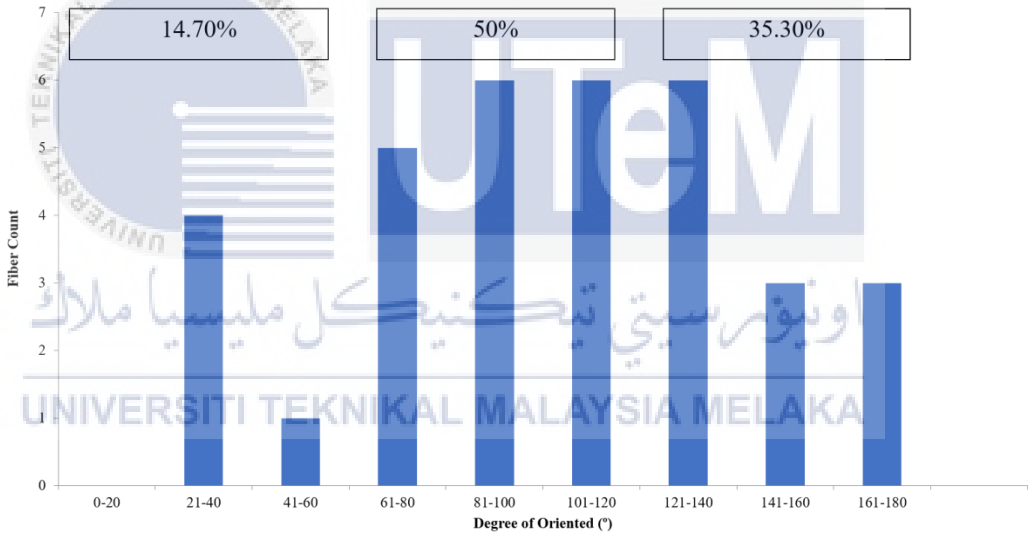
Speed of Rotating Collector (RPM)	**Graph between Number of Fibers Against Degree of Oriented (°)**
100	
200	

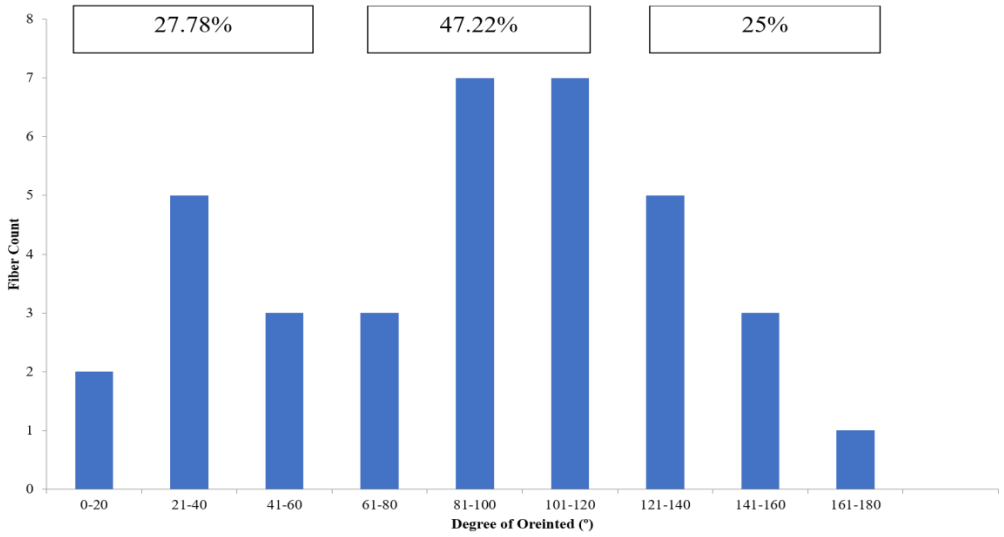
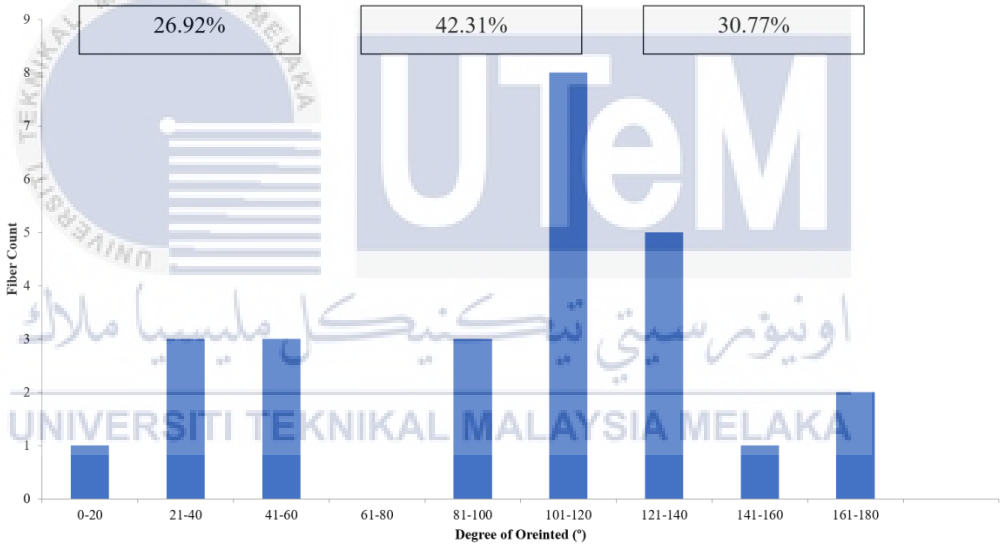
300	
400	

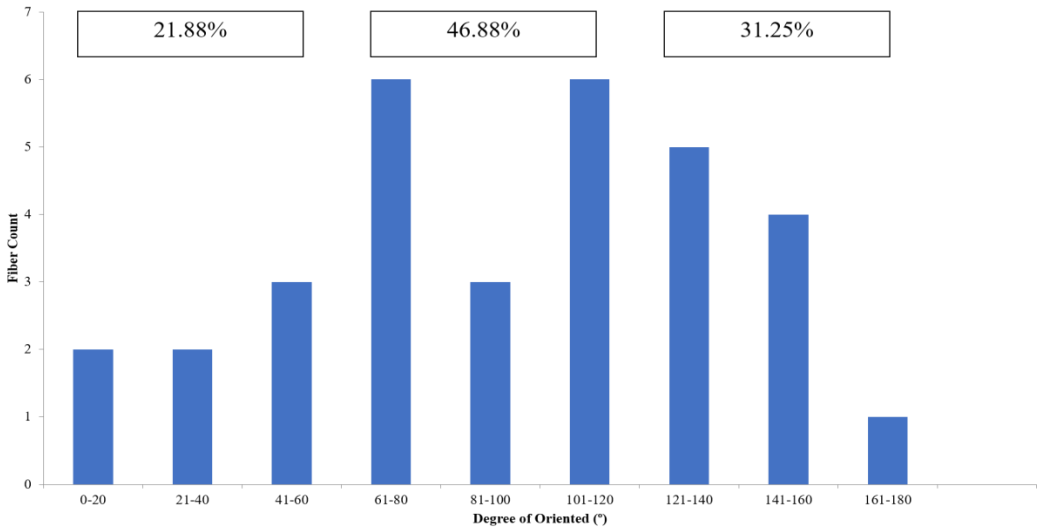
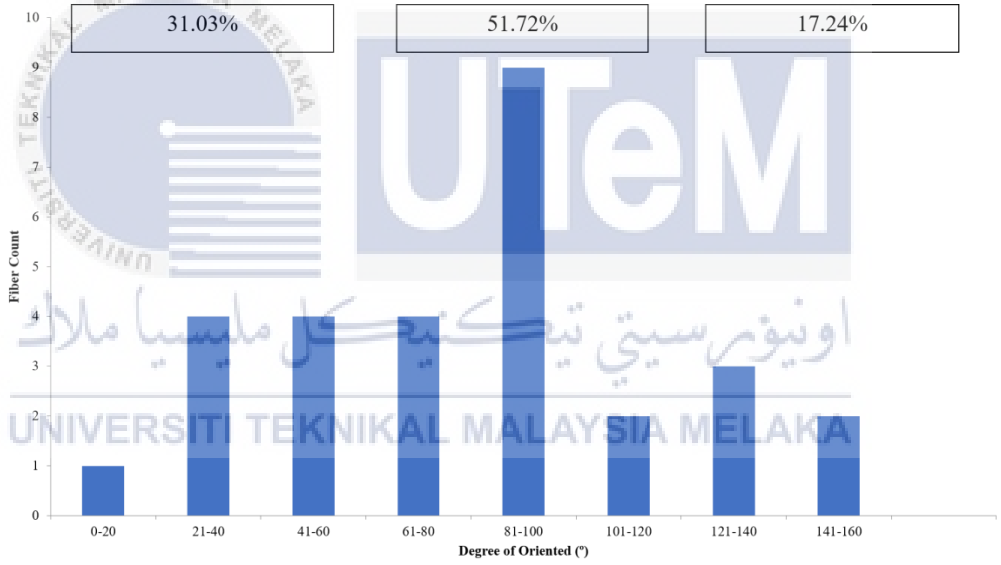
500	
600	

700	
800	

900	
1000	

1100	
1200	

1300	
1400	

1500	
1600	

I. Residual Charge

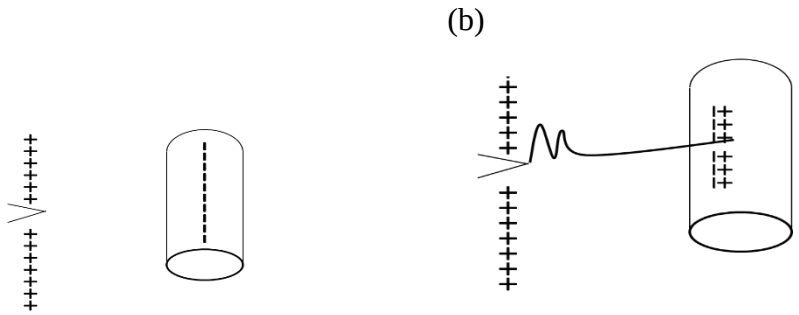


Figure 4.6: Schematic diagram of residual charge effect (a) before electrospinning process (b) during electrospinning process

The most common phenomena that occurs during electrospinning were residual charges as shown in Figure 4.6. It was happened once the electrospun nanofibers were deposited in the rotating collector. Residual charge was the charge remain on the rotating collector once electrospun nanofiber release at the needle tip due to induction of high voltage power supply at the polymeric solution. The finding is consistent with finding of past studies by Collins *et al.*, (2012), which measurable amount of residual charge accumulated on the electrospun nanofiber mat even after discharge of the electrospun fiber. Residual charges were enormously affect the degree of orientation of the nanofiber. These phenomena can explain some of the fiber not arrange at segment two. When the lower or background fiber first deposited with degree of oriented at segment two on the rotating collector, it contains residual charges that some positive charge were not discharge from the fiber as shown in Figure 4.7. The loop of whipping instability continues to overlap on background fiber but obtain different degree of orientation from the background fibers. This is because the remaining positive charge on the deposited fiber make the incoming fiber of electrospun nanofiber were repel each other because the incoming jet have some positive charge that still attached to the fibers.

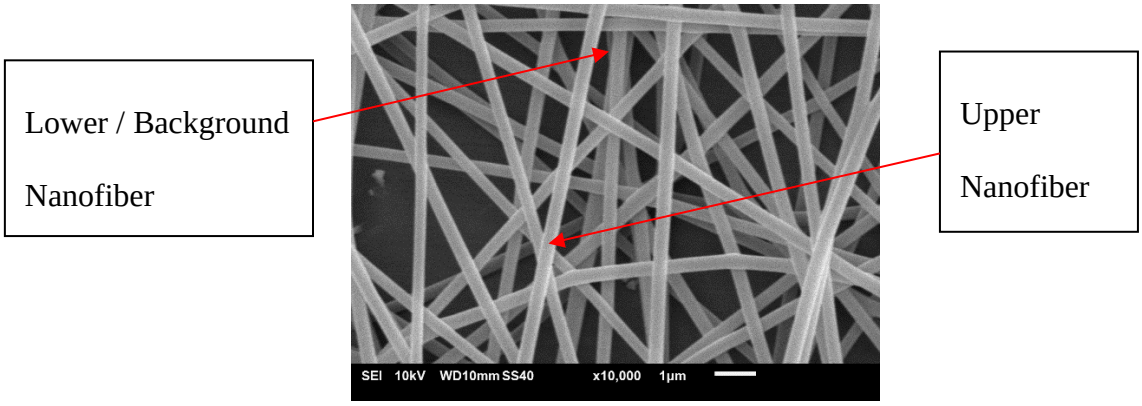


Figure 4.7: SEM micrograph on rotating collector at speed 1600 RPM

II. Speed of Jet and Speed of Rotating Collector

As theoretical, the electrospun nanofiber were light in weight. Thus, in this study there are several fibers in 1600 RPM were nearly achieved align nanofiber which 81º - 100º. Moreover, to relate the speed of jet with speed of rotating collector, the speed of rotating collector must be converted from RPM to m/s (meter per second). Hence, the equation of speed is stated below:

$$v = r\,w \qquad \text{[Equation 1]}$$

Where v = linear velocity (m/s), r = radius of rotating collector (m), w = angular velocity (rad/s) and the radius of rotating collector is 0.0505 m. The rotating collector are moving in circle and related to circumference which radius of rotating collector. Hence, RPM need to convert to rad/s before obtaining the speed of rotating collector in m/s. The relation equation between radius of rotating collector and speed are shown below:

$$rad/s = \frac{revolution}{minute} \times \frac{1minute}{60\ second} \times \frac{2\times\pi\times radian}{1revolution} \qquad \text{[Equation 2]}$$

Based on the Equation 1 and Equation 2, the speed of rotating collector in RPM were converted in unit m/s. After converted, the value of speed in m/s were obtained as shows in Table 4.3.

Table 4.3: Converted unit of speed of rotating collector

Speed of Rotating Collector (RPM)	Speed of Rotating Collector (m/s)
100	0.53
200	1.06
300	1.59
400	2.12
500	2.64
600	3.17
700	3.70
800	4.23
900	4.76
1000	5.29
1100	5.82
1200	6.35
1300	6.87
1400	7.40
1500	7.93
1600	8.46

Alignment of electrospun nanofiber were related by velocity of rotating collector and velocity of whipping instability. The velocity of both parameter must be the same to achieve alignment of electrospun nanofiber as shown in Figure 4.8. If the velocity of whipping instability higher than velocity of rotating collector, its might be accumulation of deposited electrospun nanofiber and random electrospun nanofiber were obtained. Hence, the velocity of rotating collector need to be same or higher to get alignment of nanofiber.

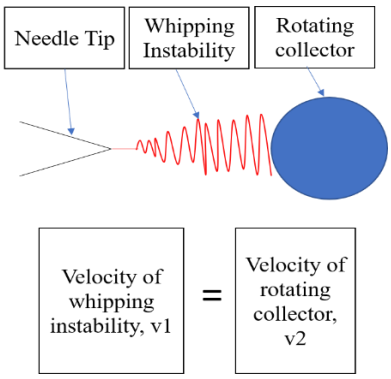


Figure 4.8: Schematic drawing of whipping instability during process electrospinning

The maximum speed of rotating collector is 1600 RPM which is 8.46 m/s. The speed of rotating collector cannot go beyond 8.46 m/s. Hence, at speed 8.46 m/s the percentage at segment two only 51.72% of fibers count. Assume that, the electrospun nanofiber must be 100% at segment two to obtain all electrospun nanofiber are align. Thus, the graph between percentage at segment two and velocity of rotating collector was plot as shown in Figure 4.9.

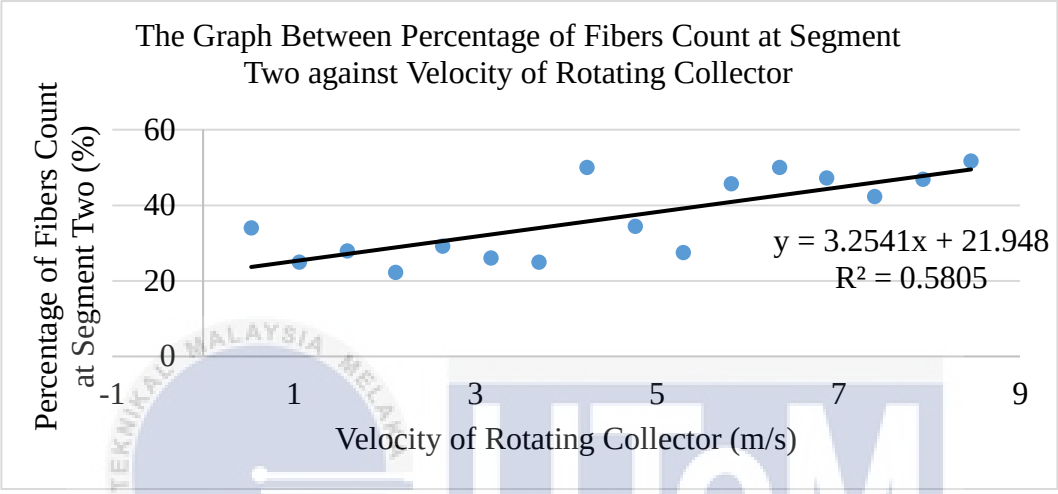


Figure 4.9: Graph show percentage of fibers count at segment two against velocity of rotating collector

Based on graph as shown in Figure 4.9, we can calculate the minimum velocity of rotating collector to obtained 100% fibers count at segment two via regression model that obtained from graph as shown in Figure 4.9. It also shown that the correlation, R is 0.762 which is near to 1. Hence, as the velocity of rotating collector increase, the percentage of fibers count at segment two increase. Based on Equation 3 that obtained in Figure 4.9, replace y with 100% of fiber count at segment two and obtained x which the velocity of rotating collector to get aligned electrospun nanofiber or 100% fibers count on segment two. Thus, the velocity obtained was 24 m/s that equal to 4538 RPM. This study was cover until 8.46 m/s of velocity of rotating collector due to limitation on the electrospinning machine. The random electrospun nanofiber can be eliminated if the speed of rotating collector reaches 5000 RPM.

$$y = 3.2541x + 21.948 \quad \text{[Equation 3]}$$

$$100\% = 3.2541x + 21.948$$

$$x = 24\, m/s$$

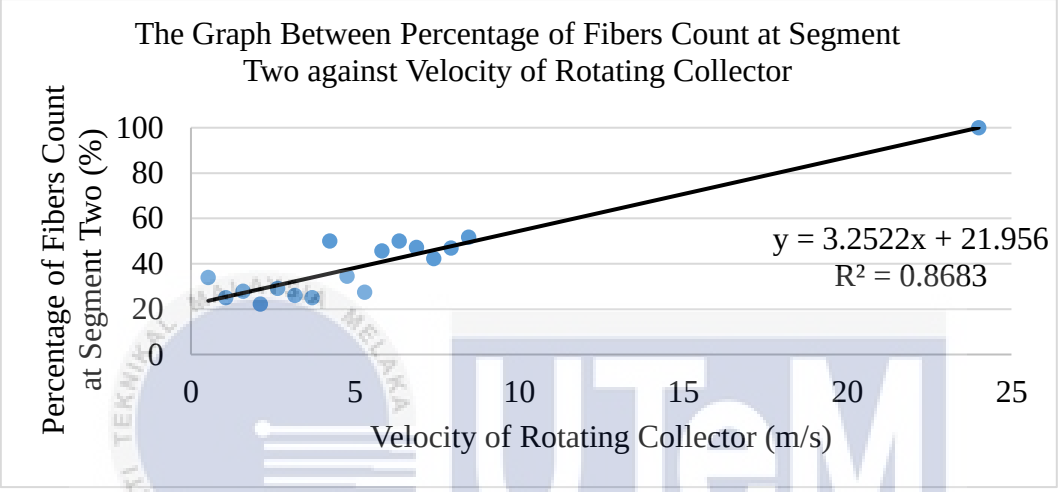


Figure 4.10: Graph show percentage of fibers count at segment two against velocity of rotating collector with exhibit new data

Based on calculation on Equation 3, we can obtain new graph with exhibit new data which 100% at segment two and the velocity of rotating collector need comply with 100% aligned electrospun nanofibers as shown in Figure 4.10.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study set out to conduct fabrication of uniaxially aligned electrospun nanofiber by using electrospinning process with rotating collector and to identify the suitable speed of rotating collector to get aligned nanofiber. PVA was used as polymeric solution in the electrospinning process with 8wt% dissolved in distilled water. The parameters used in this process were 15 kV of high voltage power supply, the distance between needle tip rotating collector was 15 cm and the feed rate used was 0.5 ml/h. The speeds of rotating collector were set up at 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600 RPM.

After the fabrication of electrospun nanofiber, all the samples went through SEM machine for further analysis on the morphology of the samples. The diameter of electrospun nanofiber had no relationship with increasing speed of rotating collector as the correlation is nearly to zero. The fabrication of uniaxially aligned electrospun nanofiber was achieved. This study has shown that the most desirable speed of rotating collector to get aligned electrospun nanofiber was 1600 RPM. However, there were also existence of random electrospun nanofibers due to the limitation speed of rotating collector used in the electrospinning machine. The second major finding was to determine the suitable speed of rotating collector to get aligned electrospun nanofiber. This study has found that the most suitable speed required for rotating collector get aligned electrospun nanofiber was approximately 24 m/s or 4538 RPM. Important conclusions drawn from this study were fabrication of aligned electrospun nanofiber has been achieved but there were still many random electrospun nanofiber were deposited and the speed of rotating collector need to be same or higher than 24 m/s to get aligned electrospun nanofibers.

5.2 Recommendation

The recommendation of future work to improve the results and analysis of this study is indeed. Foremost, a deeper understanding on the electrospinning behaviour and mechanism is important. A further reading on research and journal should be done to briefly understanding on how it will work include the procedure and process before testing, during testing and after testing. Knowledge on behaviour of speed of whipping instability and speed of rotating collector is needed. Next recommendation is the machine of electrospinning need to replace the motor that capable to rotate the rotating collector over 24 m/s. So, the aligned electrospun nanofiber can be obtained and analysis further.

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APPENDIX

- EVA emulsion
- EVA - VC/EVCL chlori
- VAE can disperse lat
- Water based vinyl ac
- Water-based acrylic
- Water-based silicone
- Water-based silicone
- Water-based polyuret
- Aqueous thickener
- Aqueous dispersants
- Water-based defoamin

名称：BP - 26 Taiwan changchun polyvinyl alcohol 价格：

Anticorrosive antise
Film-forming agent
PVA polyvinyl alcoho
Adhesive products
Covering power emuls
Curing agent
Environmental protec

Guangzhou R & D Chemical Ltd
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Town, Panyu, Guangzhou, China.

详细说明

General characteristics, PVA:

● appearance: white or light yellow powder or?

● proportion: true density 1.26~1.31, filling ratio of 0.5~0.7

● refraction?: 1.52-1.55 (absolute? State)

The specific heat of 1.65-1.67: J/g ℃

The thermal expansion coefficient?: 7-10 * 10-5/ ℃ (@ 0-45 ℃)

● glass transfer temperature: 58 ℃? (part of alkalized) ~ 85 ℃ (fully alkalized)

● point: 180 ℃ (partially alkalized) - 230 ℃ (fully alkalized)

● thermal stability: heating to above 100 ℃ began to gradually change color, heated to 150 ℃ color becomes deep, more than 200 ℃ or decomposition, to more than 300 DBG C is completely decomposed.

● chemical resistance, solvent resistance: resistance to acid, alkali, strong acid or alkali. But? Resistant to animal and plant oils, petroleum hydrocarbons, esters, ketones, alcohols and other high? Stability, is the best solvent resistant material? One.

● hygroscopicity: soluble polymer low moisture absorption, wet than other water? Little effect.

● permeability: PVA films with the exception of H2O, H2, N2, O2 and other gases are blocking.

● lightfastness: quality? By sunlight and affected.

● membrane: PVA membrane and its tensile strength, tear strength,???, wear-resistant properties, such as?? than other water-soluble resin.

● non-toxic: pure PVA is harmless to the human body.

The solubility of two:

● completely alkaline PVA (BP or AW) at room temperature in water absorption swelling and dissolution only?; under elevated temperature (80 ℃) quickly dissolved.

● part of alkaline type PVA (type BP) can be dissolved slowly at room temperature, normal use to shorten the dissolution time, still need to be heated and dissolved.

Polyvinyl alcohol (PVA)

Three application:

1, adhesive and adhesive: good adhesiveness and clay; and at the time of the initial adhesion increases, and the drying speed; good resistance to oil; film strength; quality will not change for a long tiue.

For office use paste, then wet paste, paper tube, paper bags, cartons, glued board, plywood, etc..

For building materials, ferrite, ceramics, pottery, phosphor (color TV picture tube), for blending in cement strengthened ink, pigment, paint, painting glue adhesive concrete. Slurry 2, fiber: film forming performance is good, soft and resilient tensile strength and elastic characteristics. Also rich in abrasion resistance, involvement, smoothness, feathers and a good effect. And compared with the starch slurry, without fear of spoilage, mold the situation is rare.

3, the paper industry: can be used for the surface coating and glazing, can significantly improve the resistance to ester,

solvent resistance and water resistance, and can produce more high fabric strength. Can also be used as adhesives in coating systems, used as a carrier for optical polishing agent.

4, polymerizing agent: as a dispersing agent or an effective stabilizer. They are mainly used as protective colloid, and could enhance the emulsification at very low concentration conditions.

5, polyvinyl alcohol can play a role in many other industrial applications, such as ceramics, temporary binder water-soluble film, a strippable coating and non fabric. These products can also be used for a variety of building materials, such as putty and plaster.

Taiwan Changchun (PVA):

Of the goods	viscosity(cps)	Alkalization degree(mole%)	Volatilization of (wt%以下)	ash(wt%以下)	Phvalue	The average degree of polymerization(DP)	The molecular weight(MW)
BP-26	50-58	86-89	5	0.5	5-7	2500-2650	124000-130000
BP-24	44-50	86-89	5	0.5	5-7	2400-2500	118000-124000
BP-17	21-26	86-89	5	0.5	5-7	1700-1800	84000-89000
BP-05	5-6	86-89	5	0.5	5-7	550-650	27000-32000

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TOP

Figure A: Properties of polyvinyl alcohol