Ministry of Higher Education and Scientific Research

University of Technology

Department of Materials Engineering

Recycling of PVC Pipe waste

A project

Submitted to the Materials Engineering Department/ University of Technology in Partial Fulfillment of Requirements for the Degree of B.Sc. in Materials Engineering

By:

Maryam Maher Jameel

4th Stage - Polymer and petrochemicals branch

Supervised by:

Lecturer Dr. Manar. Abdul- JabbarNajim

1442 A.H. **2020 A.D.**

وزارة التعليم العالي و البحث العلمي

الجامعة التكنولوجية

قسم هندسة المواد

إعادة تدوير نفايات أنابيب البولي فينيل كلورايد البلاستيكية

مشروع تخرج مقدم الى قسم هندسة المواد/ الجامعة التكنولوجية

كجزءمن متطلبات نيل شهادة البكالوريوس في هندسة المواد

من قبل:

مريم ماهر جميل

المرحلة الرابعة/ فرع البوليميرات والبتروكيمياويات

المشرف:

المدرس الدكتور منار عبد الجبار نجم

2020 1442

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ قَالَ الَّذِي عِندَهُ عِلْمٌ مِّنَ الْكِتَابِ أَنَا آتِيكَ بِهِ قَبْلَ أَن يَرْتَدَّ إِلَيْكَ طَرْفُكَ فَلَمَّا رَآهُ مُسْتَقِرًّا عِندَهُ قَالَ هَذَا مِن فَضْلِ رَبِّي لِيَبْلُوَنِي أَأَشْكُرُ أَمْ أَكْفُرُ وَمَن شَكَرَ فَإِنَّمَا يَشْكُرُ لِنَفْسِهِ وَمَن كَفَرَ فَإِنَّ رَبِّي غَنِيٌّ كَرِيمٌ ﴾ النمل: (40)

صدق الله العظيم

Dedication

I dedicate this project to my beloved family, especially my mother, whose continuous love and kindness had kept me going throughout the years, and without her, I wouldn`t be here. It`s also dedicated to my friends and the people who believed in me and supported me along the way.

Maryam Maher

2020

<u>Supervisor Certificate</u>

*I certify that the preparation of this project entitled **"Recycling of PVC Pipe waste"** was made under my supervision in the Materials Engineering Department in the University of Technology, as a partial fulfillment of the requirements of the B.Sc. Degree in Science of Materials Engineering.*

Signature:

Name: Dr. Manar Abdul- Jabbar Najim

Title: Lecturer

Date: 6 /9/2020

Acknowledgment

Firstly, I would like to thank God for guiding me during my life, and then I would like to thank my supervisor Dr. Manar A. Najim for her continuous support in preparing this research project and for being not only a supervisor, but a mother and friend to me as well.

Finally, I would like to give a special thanks to Dr. Ahmed Al Ghaban, his words of encouragement to us when we first joined here, they had their effect on me for four years and gave me faith in our department, I remember him saying: "One of the top universities in Cambridge have only two departments next to each other, college of dentistry and materials engineering".

I appreciate the help and support of Dr. Hussein Alaa our respected Dean and every single member working in the Department of Materials Engineering who made the project possible.

Maryam Maher

2020

Abstract

This project studied the preparation of a thin poly vinyl chloride PVC film, with a homogenous texture from PVC pipe waste using electrospinning technique and applying constant conditions. The solution of PVC polymer was prepared using a magnetic stirrer with the concentration of 10 w/v% PVC, and Dimethylformamide DMF as a solvent to dissolve the polymer. The solution was then successfully used to produce a thin PVC film from recycled PVC pipes. The effectiveness of recycled PVC film prepared by electrospinning in many applications was studied such as (labels, blood bags, I.V. bags and pallet wrap industrial and consumer goods, etc.). The importance of recycling was highlighted based on statistics and research as an effective method to reduce cost, protect the environment and save energy.

List of Contents

List of Abbreviations

Abbreviation	Meaning
PVC	Polyvinyl chloride
DMF	Dimethylformamide
SEM	Scanning Electron Microscope
THF	Tetrahydrofuran
PU	Polyurethane
PCL	Polycaprolactone
DMAc	Dimethylacetamide
Wt%	Weight percent
μm	Micrometer
PPFA	PVC Pipes and Fittings Association
PET	Polyethylene Terephthalate
CPP	Potentio-dynamic polarization
EIS	Electrochemical impedance spectroscopy
TGA	Thermal degradation analysis
PE	Polyethylene
PP	Polypropylene
W/V	Weight/volume

List of Figures

Chapter One

Introduction

Chapter One

1.1. <u>General Introduction: -</u>

PVC (polyvinyl chloride) is one of the most widely used polymers in the world. The polymer was one of the first modern plastic materials to be discovered. Although first synthesized in the laboratory in the 19th century, commercial development of the polymer commenced in the mid-1920s and saw a dramatic growth during the 1950s.Today, about 37 million tons of PVC is produced worldwide, of which around 5.5 million tones are made in Europe – making PVC Europe’s third most popular plastic. Due to its versatile nature, PVC has found applications across a broad range of industrial, technical and household uses.[1]

The ability to change PVC`s formulation parameters to improve the safety and eco-efficiency characteristics of the final product without compromising technical performance is useful in enabling the reuse and recycling of PVC into new products, without loss of performance. Re-use boosts the sustainability characteristics of PVC products – recycled PVC yields significant energy savings during production and reduces process emissions.[1]

Recycling is the reprocessing of used materials to a new form from its original state or sometimes destined for disposal of solid state. This is called post-consumer recycle and another type of recycling process which is created as normal part of the scarp from a manufacturing process is plant recycle.[2]

The PVC industry has a comprehensive understanding of its product's sustainability characteristics and is working systematically to ensure that the polymer will continue to play a useful role in enabling a more sustainable future for humanity and clearly demonstrating a circular economy.

Recycling PVC has the following benefits:

- PVC is well suited to recycling: it has the longest history of recycling of all plastics.
- PVC has advanced mechanical recycling systems.
- Large volumes of recyclable PVC waste are available.
- Using recycled PVC helps meet resource efficiency objectives and allows for the preservation of raw materials.
- Using recycled PVC reduces emission and landfill requirements. [1]

PVC can be recycled repeatedly (more than eight times in laboratory tests) depending on the application ,because the recycling process does not measurably decrease the chain length of PVC molecules. This has been proven by tests performed on

PVC pipes. Other significant contributions are made by pipes and fittings, cables, and flexible PVC applications, including roofing and waterproof membranes, flooring and coated fabric. Rigid PVC composite films from industrial waste also made a contribution of 5620 tons in 2012.Estimates for PVC waste availability in Europe in2020 show that considerable amounts of waste will be generated. 2.9 million tones are defined as available waste, with the total amount of available waste from building applications surpassing 1.1 million tones. [3], [1] Plastic disposal has many negative impacts on the nature. For that recovery and recycling is the best option to prevent that.[2] PVC has been a controversial material over many years due to concerns over the toxicity of additives such as plasticizers that give PVC its flexibility and the dioxins produced when PVC is burnt. The main risk of PVC being burnt is in uncontrolled landfill fires when PVC products reach the end of their life cycle. Avoidance of this risk is a driver for recycling and re-use of PVC products. [3]

With regard to the PVC waste types two major groups must be distinguished:

1) Pre-consumer wastes: are generated in the production of PVC final and intermediate products (production wastes) and installation wastes from the handling or installation of PVC products: The processing of PVC to final products takes one to more than three production steps, each of them may be carried out by a different company. [4]

2) Post-consumer waste: The recycling is generally more difficult to realize since they occur in form of products (end-of life products such as pipes, windows, packaging) and hence in more or less mixed waste fractions or as a part of composite materials. Depending on the specific products, PVC in wastes can occur as a more or less pure material fraction (in “mono fractions”) which can be extracted from the waste stream by sorting (e.g. bottles, pipes, some films, some profiles). [4]

PVC pipes and fittings can last more than 50 years, virtually semi-permanently, without significant deterioration when installed underground. By crushing them to flakes or powders, the wastes can become materials for new pipes and fittings if the quality of the collected products is high enough. The reborn products can be almost comparative to those made of virgin resins. [5]

1.2. Nanofibers by Electrospinning: -

Electrospinning is capable of fabricating fibers with nanometer range diameters, which yields very high specific surface areas, up to one to two orders of magnitude higher than current microfibers produced from conventional melting and dry/wet spinning methods. Therefore, electrospun nanofibers are very useful for developing a variety of products or structures whose functions are dependent on surface area [6]. When the diameters of polymer fiber materials are shrunk from micrometers to sub-microns or nanometers, there appear several amazing characteristics such as large surface area to volume ratio, flexibility in surface functionalities, and superior mechanical performance (e.g. stiffness and tensile strength) compared with any other known form of the material.[7] These outstanding properties make the extremely fine electrospun polymer nanofibers to be optimal candidates for many important advanced applications such as: •Filtrations, •Affinity membranes and recovery of metal ions, •Tissue engineering scaffolds, •Wound healing, •Release control, •Catalyst and enzyme carriers, •Sensors and •Energy storage. [8]

1.3 Aims of Study: -

This project aims to: -

1- Prepare a homogeneous solution by dissolving polyvinyl chloride (PVC) using a suitable solvent Dimethylformamide (DMF).

2- Transform the polymer solution into a thin PVC film using the electrospinning technique via a flat plate collector.

1.4 Literature Review: -

1- Zulfi, A. & Rezeki and other coworkers in (2018) [9] Synthesized fibers from the pipe waste of (PVC) successfully using electrospinning method. The PVC solutions were made with the solvents N, N dimethylformamide (DMF), tetrahydrofuran (THF) and dimethylacetamide (DMAc). The effects of PVC concentration on the morphology and the diameter of fibers were observed. The morphological change from particles to fibers took place along with the increasing concentration of PVC in DMF, DMAc, and THF. When DMF was used as the solvent, the average particle diameter was 2.91 μm for the concentration of 5 wt%. As the concentration was increased to 10 wt%, 15 wt%, and 20 wt%, fibers were obtained, and their mean diameters were 1.12, 1.47, and 1.63 μm, respectively. When DMAc was used, the average particle made of the precursor solutions of concentrations of 5 wt%, 10 wt%, and 15 wt% were 2.79 μm, 3.03 μm, and 3.31 μm, respectively. If the concentration was further increased to 20 wt%, then fibers were formed with the average diameter of 1.35 μm. Finally, with the use of THF solvent, the average particle diameters were 6.83 μm and 8.38 μm for the solution concentrations of 5 wt% and 10 wt%, respectively. When the concentrations were 15 wt% and 20 wt%, fibers were finally achieved with the average diameter of 1.38 μm and 2.83 μm, respectively. It was clearly found that there is a PVC critical concentration for a morphological transition from PVC particles to fibers.

2- Shigetaka Seki and Toshiaki Yoshioka (1998) [5] in Japan`s PVC Pipes and Fittings Association (PPFA) started a voluntary recycling system to promote recycling of waste PVC pipes and fittings and to produce pipes and fittings made of the recyclates. The system was successfully recognized by relevant laws as means to promote recycling. The voluntary action also contributed to improve the image of vinyl products. A key for success was to design a system which benefits both the PVC pipes and fitting industry and the existing companies engaged in waste treatment, processing, and recycling. To increase the amount of recycling, it was important to develop a system in a way that quality post-use products were stably collected and the manufacturers of products made with recyclates could find customers.

3- Prestes and co-workers in (2011) [10], examined the possibility of recycling of PVC pipes collected from construction and demolition waste in a sorting facility, PVC was found to represent one-third of the plastics separated by workers. Pipes were sorted carefully to preclude any possible contamination by (PET) found in the waste. The material was ground into two distinct particle sizes (final mesh of 12.7 and 8 mm), washed, dried and recycled. The average formulation of the pipes was determined based on ash content tests and used in the fabrication of a similar compound made mainly of virgin PVC. Samples of recycled pipes and of compound based on virgin material were subjected to tensile and impact tests and provided very similar results. These results are a good indication of the application potential of the recycled material and of the fact that longer grinding to obtain finer particles is not necessarily beneficial.

4- C. D. Papaspyrides and D. C. Diakoulaki (1986) [11] have performed solvent recycling of (PVC), on the basis of the cyclohexanone/n-hexane system. By also using water during the washing stage, hexane quantities employed and solvents separation costs involved are drastically reduced. The modification proposed does not result in any alteration of the main characteristics of the process which further can be extended to rigid PVC pipes. No degradation effects were detected while the polymer recycled exhibits mechanical properties comparable with those of the virgin grade PVC especially with waste material of low additives content. Nevertheless, even from pipes, the polymer recovered was in the form of small grains, with excellent molecular weight and mechanical properties retention hence, proved quite suitable for similar applications.

5- Essaheb Mahir and coworkers [7] developed nano-woven fibrous structures using electrospinning. The electrospun polymer nanofiber coating of PVC was successfully deposited on aluminum, steel and brass. The coated samples were then tested to assess the corrosion properties and the characteristics of the coated surfaces in 3.5 wt.% NaCl solutions using cyclic potentio-dynamic polarization (CPP) and electrochemical impedance spectroscopy (EIS). The morphologies and the microstructures of the nanofiber coatings are characterized and assessed using scanning electron microscopy (SEM) and thermal degradation analysis (TGA). The nanofiber coatings were of diameters from 80 to 100 nm and lengths from 3 to 5 μm and were compact and entangled with each other. This new coating is believed to have a big impact on corrosion and maintenance cost savings in the various industries.

Chapter Two

Theoretical Background

Chapter two

2.1. Introduction

The use of recyclable materials has been continuously increasing worldwide due to economic, environmental, and technological developments. Not re-using recyclable materials means that they will be degraded or corroded, and then completely destroyed by nature, thus representing a waste of resources and much environmental damage. Recycling is a series of activities consisting of collecting any kind of recyclable materials and devices that would otherwise be considered waste, and sorting and processing them into raw materials. Examples of recyclable materials include ferrous and nonferrous metals and alloys, plastic, glass, ceramics, composites, wood, concrete, asphalt, chemicals, and paper [12],[13],[14]. More than 5,000 recyclable materials are available worldwide, and this number continuously increases based on economic, social, and technological developments [12]. Most parts of recyclable devices, such as televisions, cellular phones, computers, laptops, and music players, currently end up in landfills. In addition to valuable metals, such as aluminum, copper, gold, silver, platinum, and stainless steel, these devices often contain hazardous toxic materials (e.g., mercury, lead, cadmium, arsenic, etc.), which can contaminate air, soil, and water, even in small quantities, and can cause severe environmental and health problems. Peoples usually put plastics in landfills or burn it, but both these practices cause very serious threats to the environment as well as human and animal health. Burning of plastics usually produces some noxious gases like furans and dioxins, which are some dangerous greenhouse gases and play an important role in ozone layer depletion. In fact, dioxins cause serious problems in the human endocrine hormone activity and thus are a major concern for the human health. Dioxins also cause serious soil pollution, which is a great concern for the scientific community worldwide. For workers in the plastics industry, the major route of exposure to toxic substances is by inhalation and absorption through the lungs, which causes serious health hazards. [15]

By reducing waste through recycling, waste material is collected, separated, treated, and reused in the same or other processes, thus promoting sustainable and long-term use of limited natural resources with lesser environmental concerns. [12]

The first benefit of recycling is found in saving energy and oil resources. For example, we can save vast amounts of energy required from create raw materials. These materials need big quantities of oil to be processed and refined. Another benefit of recycling is saving landfill space. A large space of landfills is taken for storing waste materials such as plastic bottles, papers, cans, etc. One of the main reasons for recycling is to reduce the amount of garbage sent to landfills. The space of landfills can be minimized to create a better environment. Furthermore, recycling is useful for mitigating global warming and pollution which have significant economic consequences. Recycling does not require much processing as virgin materials do which reduces the amount of pollution. [16]

2.2 PVC polymer and recycling:

Poly Vinyl Chloride (PVC) belongs to the thermoplastic group. Rigid plasticized PVC possesses physical and chemical advantages as well as anti-degradable properties and low production costs. Therefore, it is one of the most commonly used thermo plastic materials and is the second most produced thermoplastic after polyethylene. It is commonly used in pipes, packaging materials, bottles, window framing, floor coverings, roofing sheets, cables and even medical device, hospitals throughout the world use PVC blood pouches, transfusion and stomach piping, surgical gloves, oxygen tents and many other vital devices [17]. Thereby, it is discarded at a high rate. The flexibility of the PVC application then causes an accumulation of waste due to the growth of the plastic industry. Adopting an appropriate recycling pathway is of both an economic value and an environmental benefit [18],[9].

Up to now, several scientists and industrialists suggested that PVC can be successfully recycled into a variety of products such as bottles, various pipes, pipe fittings and other profiles with good appearance and properties [19], [20], [21], [22]. They also claimed that the profiles properties were unaffected when virgin PVC was replaced by PVC recyclates[19].

PVC is now one of the largest recycled polymers by volume in developed countries (as shown in Figure 2.1), because it is suitable for practically all recycling methods. [22], [19]

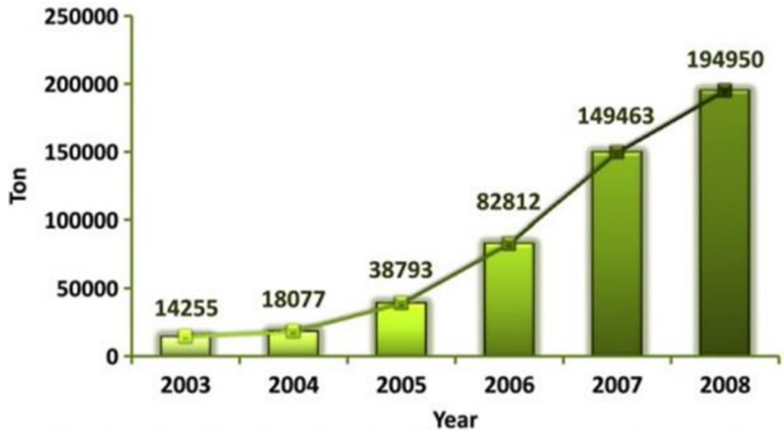

Figure (2.1): The tonnage of recycled PVC in Europe from 2003 till 2008. [19]

2.3 *PVC waste recycling methods:*

1-Energy-recovery techniques: An approach which can be used to dispose the PVC wastes, particularly when they contain a large amount of impurities and/or combustible solids is called energy-recycling technique which consists of the energy recovery from the wastes by incineration. Incineration aiming at the recovery of energy is currently the most effective way to reduce the volume of organic materials. Although polymers are actually high-yielding energy sources, this method has been widely accused as ecologically unacceptable owing to the health risk from air born toxic substances due to the problem of the formation of toxic compounds e.g. dioxins (in the case of chlorine containing polymers) and pollutants in both air emissions and solid waste residues. [23], [19]

2-Mechanical recycling: The collection of the recyclable pipes is organized by the producers. The pipes are delivered in bulk to the recycling plant. It is a mixture of PVC and PE-pipes, with variable contamination by rubber, metals, sand, glass, stones, etc. The sequence of the purification operations is as follows: •manual pre-sorting of PVC and PE • the pipes are then crushed and guillotined in a powerful press. In this operation the dimensions of the material are reduced to 30 cm to obtain better handling characteristic. PVC pipes are broken whereas the more ductile PE (if any remains) does not break, and can be easily identified and sorted out in the following operations • the material is sieved in order to remove the sand • an operator sorts manually rubber and other non-PVC material from the main PVC flow conveyed on a belt• the material is ground, to reduce the particles size, and also to liberate the admixtures which can be entangled; the material is sieved for the second time to eliminate sand and other fine particles • the material is purified from ferrous metals in a magnetic separator operating with an over-band • the material is then sieved in a classifier which accepts PVC powder between 1.5 mm and 15 mm • after the last purification to remove very small particles of impurities by shaking, the PVC powder is ground again until a particle size of less than 8 mm is reached, and finally micronized to 800 microns[20].

The pipes produced with a foamed layer made of recycled PVC satisfy the requirements of Properties of the pipes produced (using co-extrusion) with recycled PVC are at least as good as those achieved when foamed layer consists of virgin PVC. The pipes with recycled PVC meet the technical standards for building discharge pipes and sewage pipes, including stiffness and impact resistance requirements [24], [20].

2.4 ***PVC pipes***

The major applications of PVC pipe for buildings are municipal water supply pipe line, sewerage line and air duct. PVC pipe has an excellent durability, and can be used for more than 50 years as underground sewerage. However, the PVC pipe for buildings often ends up its service life much earlier than its natural life as the result of building modification or demolishing. PVC pipe has the majority of share, i.e. more than 80%, in the total sewerage pipe applications such as the drain pipe and the sewage pipe, due to its excellent features including superior strength, durability, corrosion resistance, low price and workability [24].

Manufacturers of PVC have been taking left-over from building sites and used material from conversion and renovation work for many years. The term ‘used material’ designates piping that has been in use for 10,20 or 40 years but which is far from having reached the end of its expected life, which can extend to 100 years or more. Large-scale quantities of used PVC are not expected to become available until the year 2010 at the earliest. The amounts available today are thus small, making it impossible for individual pipe manufacturers to set up an economic collection system. The Association of Plastics Pipe System Manufacturers in the Netherlands has already been tackling this problem by collecting material from building sites by a container collection system and sent to a compounding plant. The first stage involves manual sorting of the PVC, PE and PP piping, coarse grinding and the elimination of coarse impurities. In the second stage, the used material is finely ground to approximately 0.5 mm. With added blowing agent, this recyclate is then used for the foamed inner layer of a three-layer sewer pipe [17].

2.5 *Electrospinning*:

Electrospinning is currently the most promising technique to produce continuous nanofibers on a large scale and the fiber diameter can be adjusted from nanometers to microns. Also, electrospinning is a relatively easy and fast process to produce nanofibers. Polymeric nanofiber films produced by electrospinning have extremely high surface-to-mass (or volume) ratio and a porous structure with excellent pore-interconnectivity. These outstanding properties make them to be optimal candidates for many important applications [8].

In electrospinning, a polymer solution of synthetic or natural polymer with its solvent is pumped at a specific flow rate through a syringe and a small diameter metallic needle which is connected to a high voltage source (5- 30) KV and this will be the first electrode of the high intensity electric field that results when the voltage source is turned on, while the second electrode is the grounded metallic collector [25]. When the electric field is generated, it will produce an electrostatic force overcomes the solution surface tension and deforms the shape of the droplet formed at the tip of the needle from a spherical shape to a conical shape known as Taylor cone as the applied voltage increases, as shown in Figure (2.2). The Taylor cone becomes instable with time and as this instability increases, the solvent will evaporate and this cone will be divided into fiber jets collected onto the grounded metallic collector [26].

Fig. (2.2): Taylor cone formation, A. spherical droplet, B. the spherical droplet starts to change shape with increasing applied voltage, C. Taylor cone forms when the equilibrium between surface tension and the electrostatic force is achieved [26].

The electrospinning technique can be used for making scaffolds with aligned and non- aligned fibrous structure according to the type of collector used, for example the highly aligned fibrous structure can be achieved using sharp- edge disk collector, while the non- aligned fibrous structure can be achieved using a plate collector, as shown in Figure (2.3). [27]

The electrospinning apparatus is available in two different set up, vertical set up and horizontal set up, as shown in Figure (2.4).

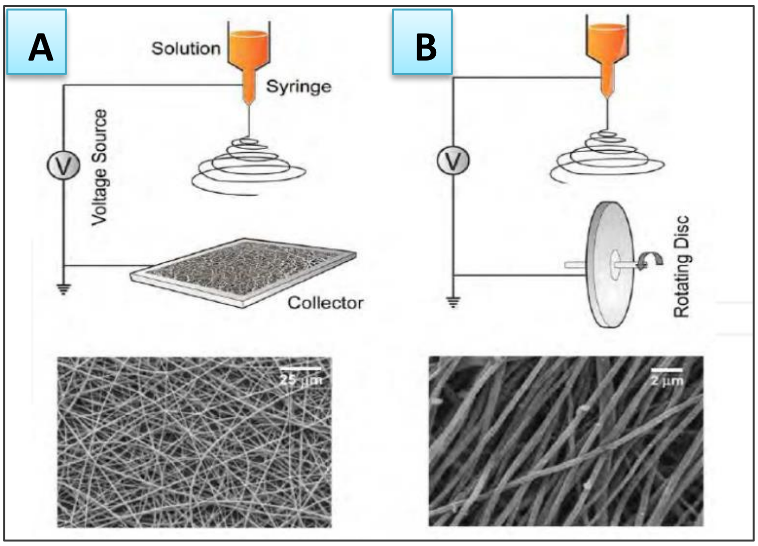

Fig. (2.3): Formation of different fiber alignment using different collectors, **A.** plate collector gives non- aligned fibrous structure, **B.** sharp- edge disk collector gives aligned fibrous structure [27].

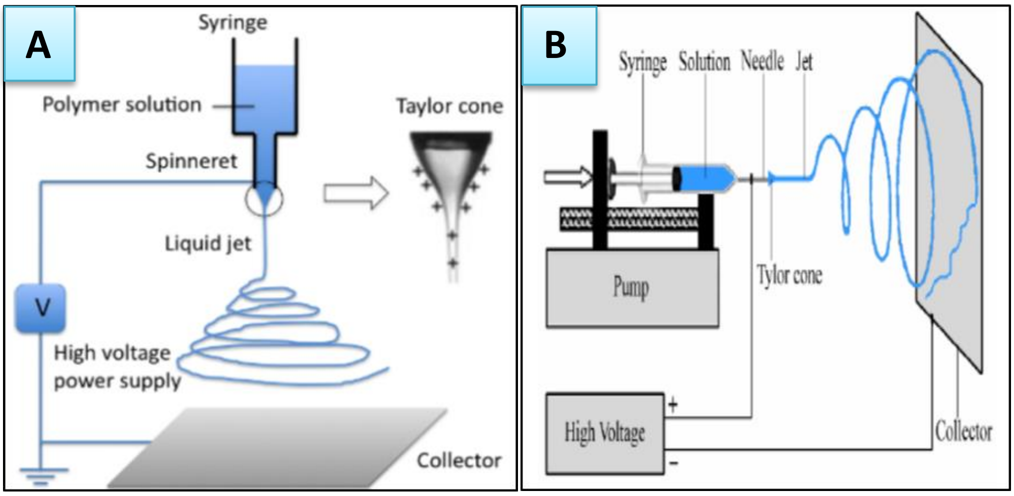

Fig. (2.4): Electrospinning set up [28], **A.** Vertical set up, and **B.** Horizontal set up [29].

2.6 ***Factors affecting electrospinning:***

There are several parameters affecting electrospinning technique, these parameters can be classified as solution parameters, process parameters and environmental parameters [29].

2.6.1 Solution parameters: -

-Polymer concentration, molecular weight and viscosity.

-Surface tension.

-Solution conductivity.

-Dielectric effect of the solvent.

2.6.2 Process parameters: -

-Applied voltage.

- Feed rate.

- Needle- collector distance.

2.6.3 Environmental parameters: -

-Temperature.

- Humidity.

- Air velocity in the spinning chamber.

2.7 *Applied Voltage: -*

The applied voltage is considered as the critical parameter in electrospinning because it provides the surface charges on the polymer jet and affects the fiber diameter. Generally, increasing the applied voltage will increase the electrostatic repulsive forces on the fluid jet and lead to a decrease in fiber diameter. The applied voltage should be suitable for the formation of a stable Taylor cone, as shown in Figure (2.5).

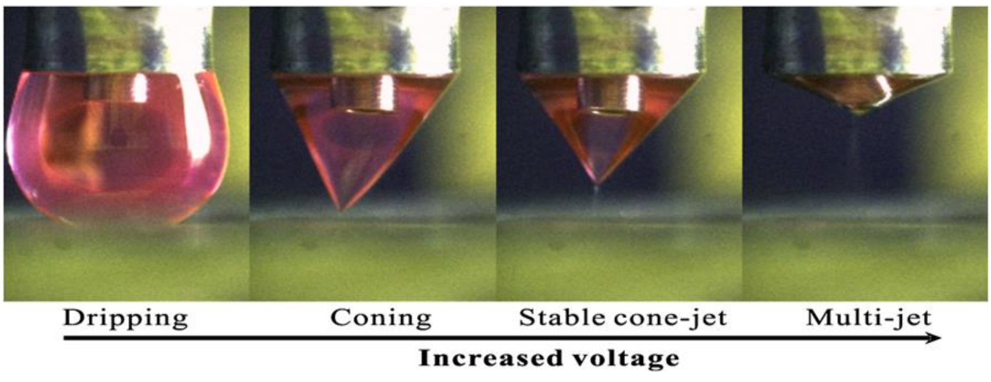

Fig. (2.5): The variation in Taylor cone shape with increasing the applied voltage [30].

Further increase in the applied voltage results in greater amounts of charges and more volume of the solution will be drawn from the tip of the needle which makes the Taylor cone smaller and less stable. When the applied voltage increased to a limit makes the polymer solution drawing faster than the supply from the syringe pump, and then the Taylor cone may recede inside the needle. Besides reducing the fiber diameter, increasing the applied voltage will result in faster solvent evaporation to get drier fibers, and also increasing the applied voltage will increase the crystallinity of the polymer fibers because the electrostatic field will encourage the polymer molecules to be more ordered which results in high crystallinity in the fibers [30].

Chapter Three

Experimental Part

And Conclusions

Chapter three

3.1. Introduction

This chapter is focusing on displaying the properties of the used material and the methodology of the experimental part, including preparing the solutions for electrospinning to prepare Polyvinylchloride PVC electrospun samples with the description of the electrospinning parameters, used apparatus, materials and devices. As well as a description of the specimen.

3.2 Polyvinylchloride

Polyvinylchloride (PVC) (Fig 3.1) is a commercially sold thermoplastic material. It can be used for a variety of applications such as water and sewage pipes.

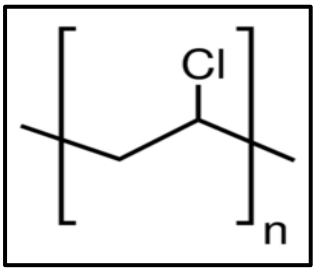

Fig (3.1): The structure of PVC

3.3 Solution Preparation

Polyvinylchloride solution of concentration 10% w/v was prepared. The solution of Polyvinylchloride was prepared by using Dimethyl formamide (DMF) as a solvent and mixed by using magnetic stirrer (shown in Figure 3.2) for 2-3 hours at room temperature until getting a homogenous solution suitable for electrospinning (shown in Figure 3.3).

Figure (3.2): Magnetic Stirrer Device used in preparation of the polymer solution.

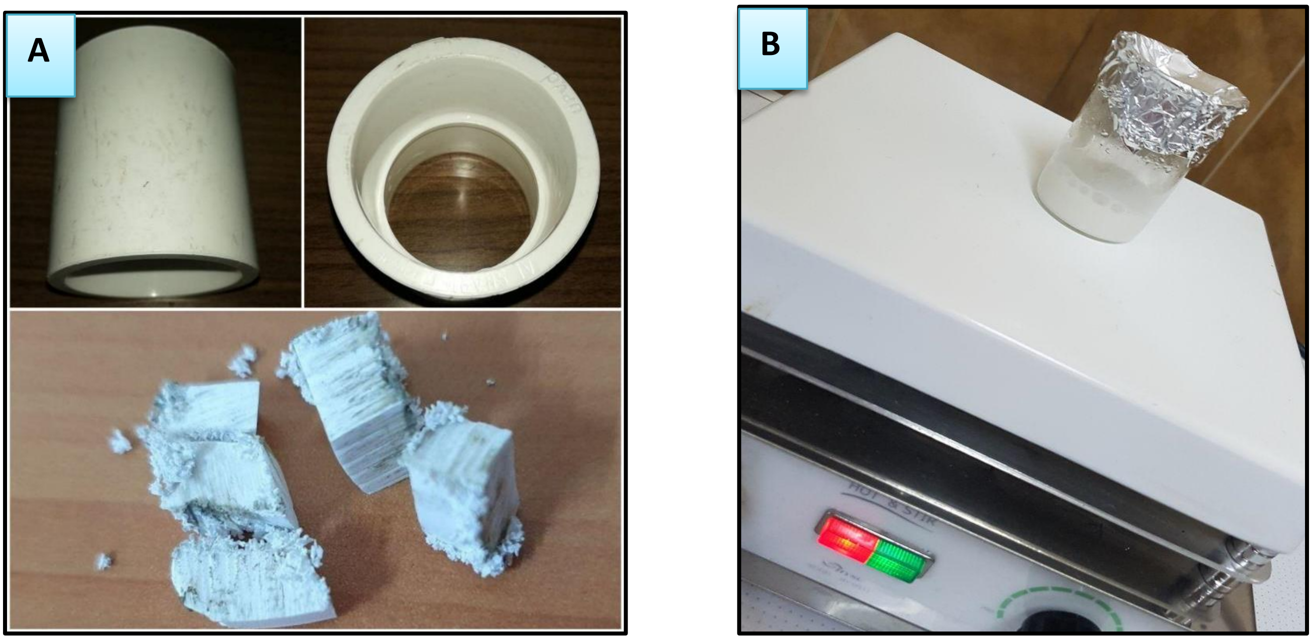

Fig. (3.3): **A.** The PVC pipe is cut and used for the sample. **B.** The polymer solution consisting of PVC polymer and DMF solvent, with a concentration of 10 w/v%.

3.4 Electrospinning:

The electrospinning process was carried out by an electrospinning/ Electrospray system ESB-200, provided by Nano NC, South Korea, as shown in Figure (3.4). The spinning parameters depended for shaping the specimens are explained in table (3.1).

Table (3.1): Electrospinning parameters used in shaping study specimens.

Electrospinning parameters	Specification
Concentration w/v%	10% PVC
High voltage applied	20 KV
Capillary- collector distance	15 cm
Orifice size	22G = 0.7 mm
Collector type	Flat plate,20*20 cm
Flow rate	1 ml/hr

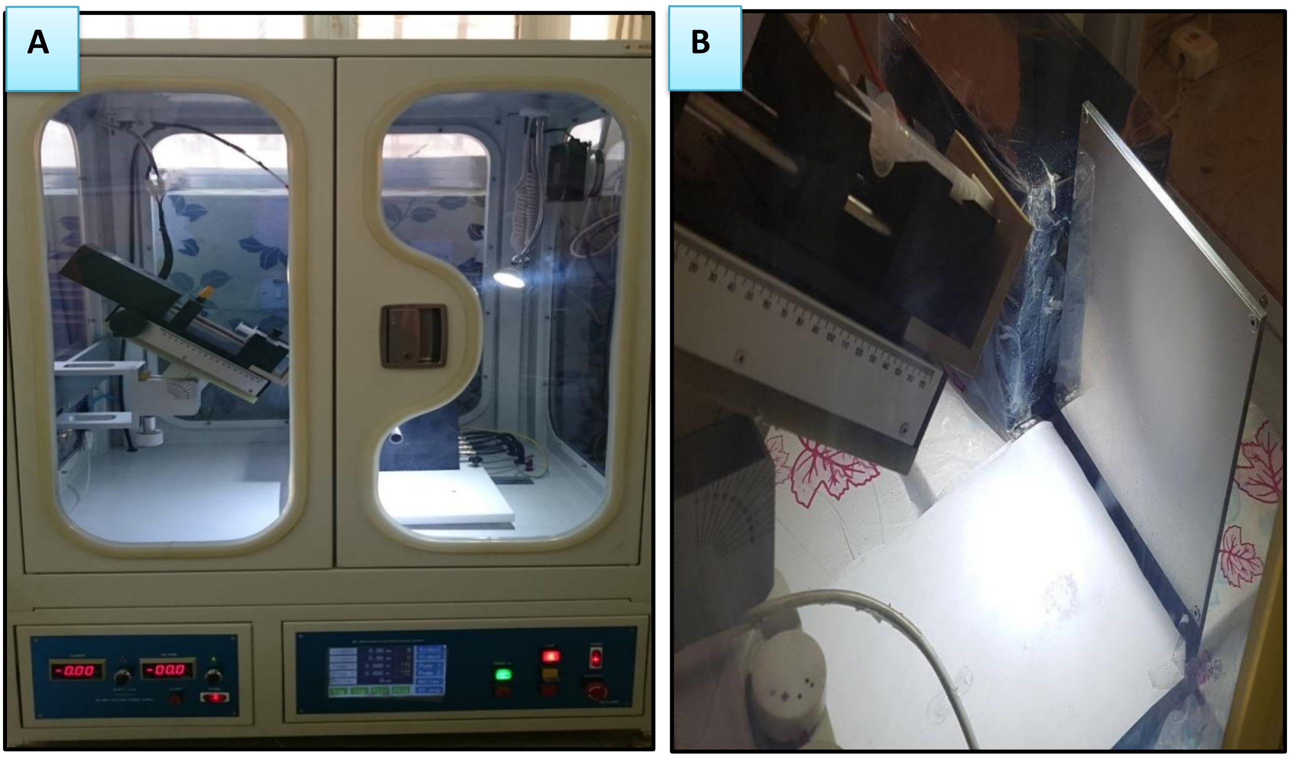

Fig. (3.4): A. Electrospinning/ Electrospray system, **B.** The collector used for film shaping, Flat plate (20*20cm).

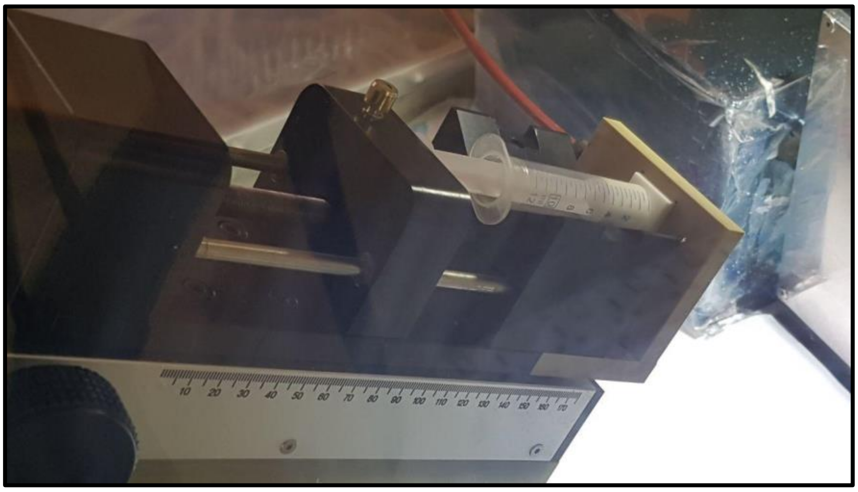

Fig. (3.5): Illustrating the syringe pump used in electrospinning device.

The used collector (Flat plate, 20*20cm) resulted in preparing a thin sheet of PVC polymer could be used in drug delivery medium, sensors, catalysts, filters, protective clothing, protective sheets in hospitals, etc. as shown in Figure (3.6).

Fig. (3.6): Illustrating the thin sheet of PVC polymer formed by electrospinning technique at a flowrate of 1 ml/hr.

3.5 Conclusions:

The following conclusions can be summarized from the data above and from the research done on PVC films:

1- At a concentration of 10 w/v% of Polyvinylchloride (PVC) using DMF solvent, a homogeneous solution was obtained.

2- A thin morphologically homogenous PVC film was obtained using an electrospinning device by applying a high voltage (20 KV), a flat plate collector (20*20 cm) was used, the distance between the capillary and the collector was 15 cm, and the flow rate at which the polymer solution was flowing from the capillary was 1 ml/hr.

3- The recycling of PVC pipe waste and transforming it into a thin PVC film was done successfully. It has been found by several researches and experiments that films from recycled PVC pipe waste are almost identical to films made from virgin PVC properties-wise, thus, they can be used in several applications, reinforce existing pipes, provide economic benefits and save the environment by reducing carbon emissions from disposing of PVC in landfills.

*3.6 **Recommendations:***

It is recommended to accomplish the following:

1- Scanning Electron Microscope Test (SEM) of electrospun PVC sample to measure the fiber diameter.

2- Tensile testing to measure the tensile properties of the PVC specimen.

3- A surface wettability test based on the measurement of the material surface contact angle is preferred to determine the effectiveness of the PVC film in a specific application. In waterproof applications it is important that the polymer is hydrophobic enough.

4- Blending PVC with other polymers such as Polyurethane (PU) and Polycaprolactone (PCL) is recommended to enhance the elasticity, ductility and increase the biocompatibility of the PVC film among other properties that are required in certain applications, for example surgical protective sheets in hospitals that are in direct contact with the patient`s body.

References: -

[1] Vinylplus; the European Council of Vinyl Manufacturers (ECVM) (2017). “PVC Recycling Technologies” [Brochure]. Brussels, Belgium: Author. 2-142.

[2] Shimo, Hyat Ullah. “Plastic Recycling in Bangladesh, What needs to be done?” (2015).

[3] Heathcote, M. (2011). “The Plastic Industry Pipe Association (PIPA) recycling PVC pipes into new product.” National Waste Policy, 1-2.

[4] European Commission, Plastic Consult (Italy), & COWI (Denmark). (2000, January). “Mechanical Recycling of PVC Pipe Wastes.” Eckhard Plinke, Niklaus Wenk, Gunther Wolff.

[5] Seki, Shigetaka & Yoshioka, Toshiaki. (2015). “Recycling of PVC pipes and fittings in Japan: proactive approach of industry to and its impacts on legal/technical frameworks.” Journal of Material Cycles and Waste Management. 19. 10.

[6] Liu, H., Ding, X., Zhou, G., Li, P., Wei, X., & Fan, Y. (2013). “Electrospinning of Nanofibers for Tissue Engineering Applications.” Journal of Nanomaterials, 2013, 1–11.

[7] Essaheb, Mahir & Elzatahry, Ahmed & Sherif, El-Sayed & Alkaraki, Ahmad. (2012). “A Novel Electrospinning Application for Polyvinyl Chloride Nanofiber Coating Deposition as a Corrosion Inhibitor for Aluminum, Steel, and Brass in Chloride Solutions”. International journal of electrochemical science, no. (7). 5962-5976.

[8] Fang, J., Niu, H., Lin, T., & Wang, X. (2008). “Applications of Electrospun Nanofibers.” Science Bulletin, 53(15), 2265–2286.

[9] Zulfi, A. & Rezeki, Yulianto & Edikresnha, Dhewa & Munir, Muhammad Miftahul & Khairurrijal, Khairurrijal. (2018). “Synthesis of Fibers and Particles from Polyvinyl Chloride (PVC) Waste Using Electrospinning.” IOP Conference Series: Materials Science and Engineering. 367.

[10] Prestes, Sabrina & Mancini, Sandro & Rodolfo Jr, Antonio & Keiroglo, Raquel. (2011). “Construction and demolition waste as a source of PVC for recycling.” Waste Management & Research. 30. 115-121.

[11] Papaspyrides, C. D., & Diakoulaki, D. C. (1986). “Recovery of reusable Poly(vinyl chloride) from plastics waste”. Journal of Vinyl and Additive Technology, 8(2), 83–85.

[12] Asmatulu, R., & Asmatulu, E. (2011). “Importance of recycling education: a curriculum development at WSU.” Journal of Material Cycles and Waste Management, 13(2), 131–138.

[13] Rao, SR. (2006). “Resource recovery and recycling from metallurgical wastes.” Elsevier, Amsterdam.

[14] Lund, HF. (2000). “Recycling handbook.”, 2nd ed. McGraw-Hill, New York.

[15] Tripathi, Smriti & Yadav, Ashutosh & Trapathi, Devendra. (2016). “Plastic Waste: Environmental Pollution, Health Hazards and Biodegradation Strategies.”

[16] Al-Shuaibi, Abdulghani. (2014). “The Benefits of Recycling.” Citizen Journalist Forum Science and Technology.

[17] Menges, G. (1996). “PVC Recycling Management.” Pure and Applied Chemistry, 68(9), 1809–1822.

[18] Janajreh, Isam & Alshrah, Mohammed & Zamzam, Samih. (2015). “Mechanical Recycling of PVC Plastic Waste Streams from Cable Industry: A Case Study”. Sustainable Cities and Society, 18, 13-20.

[19] Sadat-Shojai, M., & Bakhshandeh, G.-R. (2011). “Recycling of PVC wastes.” Polymer Degradation and Stability, 96(4), 404–415.

[20] La Mantia FP. “Recycling of PVC and mixed plastic waste.” Toronto: ChemTec Publishing; 1996.

[21] Sombatsompop N, Thongsang S. “Rheology, morphology, and mechanical and thermal properties of recycled PVC pipes.” Journal of Applied Polymer Science, 2001;82:2478-86.

[22] Hegberg B.A., Hallenbeck W.H., Brenniman G.R. (1993). “Plastics recycling rates.” Resources, Conservation and Recycling, 9(1-2), 89–107.

[23] Achilias, Dimitris & Andriotis, Lefteris & Koutsidis, Ioannis & Louka, Dimitra & Nianias, Nikos & Siafaka, Panoraia & Tsagkalias, I.s & Tsintzou, Georgia. (2012). “Recent Advances in the Chemical Recycling of Polymers (PP, PS, LDPE, HDPE, PVC, PC, Nylon, PMMA).” 10.5772/33457.

[24] Matsuzawa, T., & Iseki, I. (2005). “PVC Pipe Recycling and Recycled Pipe in Japan.” (World Sustainable Building Conference, pp. 1-8). Tokyo, Japan: Japan PVC pipe and Fittings Association.

[25] Zhu, Ning, and Xiongbiao Chen. "Biofabrication of tissue scaffolds." In Advances in biomaterials science and biomedical applications. IntechOpen, 2013.

[26] AK S, Sanpui P., and K. Chatterjee. "Fabrication of poly (caprolactone) nanofibers by electrospinning." J Polym Biopolym Phys Chem 2, no. 4 (2014): 62-66.

[27] Ziabari, M., V. Mottaghitalab, and A. K. Haghi. "Application of direct tracking method for measuring electrospun nanofiber diameter." Brazilian Journal of Chemical Engineering 26, no. 1 (2009): 53-62.

[28] Li, Zhenyu, and Ce Wang. "One-dimensional nanostructures: electrospinning technique and unique nanofibers." Heidelberg/New York/Dordrecht/London: Springer, 2013.

[29] Li, Zhenyu, and Ce Wang. "Effects of working parameters on electrospinning." In One-dimensional nanostructures, pp. 15-28. Springer, Berlin, Heidelberg, 2013.

[30] Huang, Mei-Na, Yuan-Liang Wang, and Yan-Feng Luo. "Biodegradable and bioactive porous polyurethanes scaffolds for bone tissue engineering." Journal of Biomedical Science and Engineering 2, no. 01 (2009): 36.