COATING OF TITANIUM DIOXIDE/SILICON DIOXIDE NANOPARTICLES ONTO ALUMINUM FINS FOR HYDROPHILIC AND HYDROPHOBIC SURFACE

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A project report submitted in partial fulfilment of the requirements for the awardof the degree of Bachelor of Engineering (Hons.) Environmental Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"COATING OF TITANIUM DIOXIDE/SILICON DIOXIDE NANOPARTICLES ONTO ALUMINUM FINS FOR HYDROPHILIC AND HYDROPHOBIC SURFACE"** was prepared by **LIM SOON YOUNG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Environmental Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________

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Date : 21/4/2022

Specially dedicated to

My beloved family members.

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ABSTRACT

Indoor pollution is getting worst and worst year by year due to the air pollution and this causes a lot of adverse health impacts are appeared. Air conditioner industry has become the main key cope with this situation due to air condition is almost at every indoor facility. Therefore, the installment of air conditioner which contain aluminum fins which coated with coating which has superhydrophobic properties to give self-cleaning effect is very important. It can be used to reduce the indoor air pollution. The purpose of this research is to synthesis TiO_2/SiO_2 nano powder using sol-gel method and then coat it on aluminum fins by using the method which is simple and practical. After that, the coating will be studied in terms of the hydrophobic effect. In this research, there are 3 different number of layers of coating were prepared, which are 5 layers, 10 layers and 12 layers. Moreover, 2 different materials of coating are used which are TiO_2 and TiO_2/SiO_2. The performances of the coating were determined in terms of wettability, FESEM and XRD analysis. The XRD analysis has proven that the TiO_2 and TiO_2/SiO_2 powder that have been synthesis in this experiment was correct. Besides that, the wettability of the coating is tested based on the contact water angle. The contact water angle of the TiO_2/SiO_2 coating showed the best result among the others that is 129.30º, which is classified as hydrophobic. Then based of the image captured by FESEM, the coating of TiO_2/SiO_2 on the aluminum is homogenous and rough. Therefore, it can provide the hydrophobic effect. In conclusion, the coating of TiO_2/SiO_2 with 5 layers provide the best result in terms of hydrophobicity compare with others layers and the coating of TiO_2.

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LIST OF SYMBOLS/ABBREVIATIONS

Na_2SiO_3	Sodium Metasilicate
SiO_2	Silicon Dioxide
$FeTiO_3$	Ilmenite
TiO_2/SiO_2	Titanium Dioxide/Silicon Dioxide
TiO_2	Titanium Dioxide
$(NaPO_3)_6$	Sodium Hexametaphosphate
WHO	World Health Organization
VOCs	Volatile Organic Compounds
FESEM	Field emission scanning electron microscopy
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-ray powder diffraction
°C	Degree Celsius
UV	Ultraviolet
H_2O	Water
OH-	Hydroxyl Group
H+	Hydrogen Ion
CO_2	Carbon Dioxide
CVD	Chemical Vapour Deposition
nm	Nanometre
AFM	Atomic force microscope
$C_4H_{10}OTi$	Tetrabutyl Titanate
CH_3COOH	Acetic Acid
Na_2SiO_3	Sodium Metasilicate

CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1 Introduction

The usage of self-cleaning properties based on semiconducting materials have gotten a lot of attention in the last decade. The self-cleaning capability has long been thought to be a result of photocatalysis and hydrophilicity working together (Euvananont. C., 2008). Self-cleaning coating can provide significant effects for various applications especially on protecting the uncoated material. Catalyst such as TiO_2 is the best material for such approach. This is due to the titanium dioxide is a strong photocatalyst, stable chemical and it has good chemical properties. Due to its photocatalytic and wettability properties, it can be a degrading organic compound when it is contacted with UV light. Therefore, TiO_2 is can be used as the self-cleaning material (Jiang.Y. et al., 2019).

The self-cleaning coating, titanium dioxide is separated into two kinds of surfaces, which are superhydrophilic and superhydrophobic surfaces. These two surfaces can be affected by changing the chemical composition or its surface structure (Ren.Y. et al., 2020). On hydrophobic surface, the water will form spherical shape. Then, it will carry the pollutant on the surface with them while in contact with water. Moreover, if the dirty water falls on the hydrophobic surface, it will be removed instantaneously before it evaporates. The rolling motion of water droplets is a key process for the self-cleaning effect. This effect is called as the Lotus-Effect (Parkin.I.P. et al., 2005). The hydrophobic surface can greatly reduce the maintenance cost, increase durability and provide protection against pollution (Sushanta Kumar Sethi & Gaurav Manik, 2018).

For a hydrophilic surface, it does not only rely on the flow of the water to clean the surface, it also need to rely on the light to break down the dirt by photocatalysis

(Parkin.I.P. et al., 2005). However, this method is mostly works on inorganic substrates. This is because the catalytic effect will degrade the organic substrate. Therefore, an organic or inorganic layer is needed to prevent the catalysis and this will make it cost more (Rios. P. F. et al., 2009). Furthermore, hydrophilic self-cleaning is not suitable for those applications that are large scaled due to its complex procedure and high cost (Appasamy et al., 2020).

There are several techniques for producing titanium dioxide have been published in the literature, including electron beam evaporation, DC magnetron sputtering, chemical vapour deposition and the sol–gel process. These approaches produce non-stoichiometric and non-homogenous films, as well as require expensive equipment. On the contrary, sol-gel process is more reliable for coating on large area substrates as it has advantages in terms of speed and efficiency. This process only requires a very low energy consumption and it also consume very less materials. Moreover, it is very easy and fast in deposition (Shadravan. A. et al., 2015).

There various types of coating methods that have been used by the researches. Those methods include thermal spraying, electrochemical and sputtering. Even so, all these methods have their own shortcomings. These methods require a lot of technical skills and uneconomical. For example, thermal spraying needs to control the temperature of the coating so that it will not affect the micro structure of the titanium dioxide (Leong. K. H. et al., 2019). Moreover, the electrochemical method may defect the coating surfaces during the electrochemical processes and lead to ununiformed coating (Asri et al., 2015). On the other hand, the dipping method is currently a cost-effective process that may be used on a variety of substrates (Dinh.N.N., 2003). Furthermore, due to the use of extremely basic equipment, the dip coating process has numerous advantages over other deposition procedures. Additionally, the final film's stoichiometry and homogeneity can be controlled. The substrate has to be dipped in a liquid and subsequently withdrawn at a controlled speed under controlled temperature and ambient conditions in this procedure (Jahromi.H.S., 2009).

1.2 Problem Statement

A study was recently undertaken in the United States that looked into the costs of corrosion in several sectors of daily life. This study revealed that corrosion can cause substantial problems and expenses in practically all sectors where metallic elements are used. Many citizens may be unaware that corrosion concerns can damage the entire public infrastructure, including all kinds of transportation (Fürbeth. W. & Schütze, M., 2009).

In our daily lives and operations, metal corrosion causes significant economic loss and societal hardship. Corrosion failures have gotten costlier as products and manufacturing processes have become more complicated, and higher awareness has been produced (Fayomi.O.S.I., 2019). According to statistics, nearly 1/3 of the world's yearly metal scrap production is due to corrosion of metal materials and equipment. The direct economic losses are estimated to be between 2% and 4% of each country's gross domestic product. This loss is six times the amount lost caused by natural disasters (Huo. X. et al., 2018). According to Bardal. E, the cost of corrosion in developed countries is around 3-4 percent of GDP. Deductively, third-world countries spend ten times more to control rust than the current estimate (Fayomi.O.S.I., 2019).

Besides that, when it comes to our daily lives, corrosion has both direct and indirect consequences, shortening the useful service life of our assets. Companies that manufacture things and provide services bear the costs of corrosion, which they pass on to consumers. Body panels on automobiles, charcoal grills, outdoor furniture, and metal tools in the home are all susceptible to corrosion. Corrosion has a substantially greater influence on our lives when we are travelling from our homes to our places of employment or education. Additionally, corrosion of steel reinforcing bars in concrete can occur behind the scenes, resulting in the collapse of a section of roadway, the collapse of electrical towers, and damage to buildings, parking structures, and bridges, all of which result in high repair costs and the public safety at risk. Rust can form in large industrial facilities, such as electrical power plants or chemical processing plants, as well as smaller facilities. Perhaps the most detrimental of all is the current scenario. Corrosion can and frequently does cause plant shutdowns and equipment failure. (Davis. J.R.ed., 2000).

Moreover, material-environment interaction is critical to the engineering material's optimal design and performance. This is because the utility and retention of certain properties are intimately connected to the surrounding environment. Therefore, any fundamental approach to the corrosion phenomenon must be taken into consideration for the engineering materials' structural features, the nature of the environment and the material's reactivity to the environment (Fayomi.O.S.I., 2019).

Furthermore, because all surroundings are corrosive in some way, corrosion must be explained in terms of the environment. The environment that caused corrosion can be mainly split into two, which are the aqueous environment and the atmospheric environment. However, there are lot of factors that are common for both of these environments. For example, temperature, pressure, fluid (acids, salts, water, steam, alkalis and gases) flow velocities, air and humidity. The major factors that cause the corrosion of metals is due to the concentration of reactive species (Fayomi.O.S.I., 2019). Therefore, coating the corrosive material with photocatalyst could address the issue of severe corrosion to happen on most of our daily appliances.

1.3 Objectives

The aim of the research is to investigate the feasibility of using TiO_2 and TiO_2/SiO_2 as the coating of the aluminium fins. The aim of the research was accomplished through the following objectives which expressed as below:

- To synthesis TiO_2/SiO_2 nano powder using sol-gel method.
- To coat the TiO_2 and TiO_2/SiO_2 nanoparticles on aluminum fins using a simple and practical method.
- To study the hydrophobic effects of TiO_2 and TiO_2/SiO_2 coating on aluminum fins.

1.4 Scopes of Study

In this research study, TiO_2 and TiO_2/SiO_2 was utilized as a material for the aluminum fins coating. This was to help the aluminum fins to achieve self-cleaning. Sol-gel synthesis technique will be used to obtain the TiO_2 and TiO_2/SiO_2. For coating method, dipping method will be used as a way to coat the TiO_2 and TiO_2/SiO_2 onto the aluminum fins. The characterization of TiO2 and TiO_2/SiO_2 will be examined through Field emission scanning electron microscopy (FESEM), water angle analysis and X-ray powder diffraction (XRD).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Self-cleaning

Self-cleaning coatings technology has advanced significantly in recent years. Their commercial potential is enormous and their market is genuinely worldwide. Due to the wide range of potential uses, including window glass, cement, and textiles, self-cleaning coatings may become a significant labor-saving device (Parkin.I.P. et al., 2005). This technology also has a number of advantages, including lower maintenance costs, the removal of tiresome human workers and a reduction in cleaning time.

Many natural surfaces have self-cleaning capabilities. There are a few of examples like butterfly wings, the leaves of plants like cabbage and lotus (Ganesh, V. A. et al., 2005). For more than 2,000 years in Asia, the sacred lotus (Nelumbo nucifera) has been a symbol of purity. It is the beginning of the storey of natural self-cleaning surfaces. Over the last few decades, many alternative synthesis procedures have been created to design and construct self-cleaning surfaces. Today, a wide range of self-cleaning surfaces are available for purchase (Liu, K., and Jiang, L., 2012).

2.2 Titanium Dioxide

Titanium dioxide is a chemically inert, semiconducting substance which having photocatalytic activity when exposed to light with an energy equal to or greater than its band-gap energy. These traits can be used in a variety of ways. Because of these factors, as well as the comparatively inexpensive cost of the raw material and its processing, it has attracted a lot of attention in recent decades (Skocaj, M. et al., 2011).

Titanium dioxide has been classed as biologically inert in human and animals. It is often regarded as a "natural" material, which adds to its relatively favorable public perception. In fact, for nearly a century, most titanium dioxide has been produced from the mineral ilmenite, $FeTiO_3$, using the "sulphate" or "chloride" process. The yearly global production of titanium dioxide powder was predicted to reach over 5 million tons in 2005, raising concerns about its environmental abundance. The proportion of nano-sized titanium dioxide was predicted to be around 2.5% in 2009, rising to 10% by 2015, showing an exponential increase over the previous decade (Skocaj, M. et al., 2011).

Figure 2.1: Titanium Dioxide Powder (Patra, D., 2018).

2.2.1 Structure and Properties of Titanium Dioxide

Anatase, rutile, and brookite are the three forms of polymorphs of titanium dioxide. The main source of titanium dioxide is rutile, which is the most stable form. All these three polymorphs can be easily synthesised in the lab and when the titanium dioxide is calcined at temperatures above 600°C, the metastable anatase and brookite will convert into the thermodynamically stable rutile. Titanium atoms are linked to six oxygen atoms in all three forms, which forms TiO_6 octahedra. Anatase is a tetragonal structure made up of corner sharing octahedra that form planes. The octahedra in rutile share edges at planes to form a tetragonal structure, whereas the octahedra in brookite share both edges and corners to form an orthorhombic structure (Pelaez, M. et al., 2012).

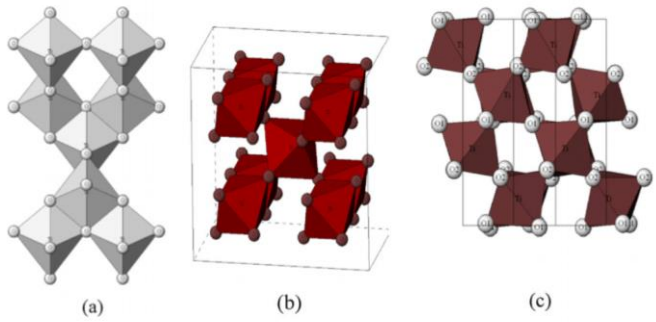


Figure 2.2: Crystalline structures of titanium dioxide (a) anatase, (b) rutile, (c) brookite (Pelaez, M. et al., 2012).

Titanium dioxide's photocatalytic activity is typically influenced by its phase structure, size of the crystal, specific surface area and structure of pore. Despite the fact that anatase has a lower solar light absorption than rutile due to its greater band gap (3.2 eV) than rutile's (3.0 eV), anatase's photocatalytic activity is higher compare to rutile's. Anatase has a larger hydroxyl group surface adsorption capacity and a lower charge carrier recombination rate than rutile. Rutile has a decreased photocatalytic activity due to its bigger particle size, smaller specific surface areas and poorer surface adsorption capacity (Zhang, J. et al, 2014).

In addition, anatase has a far longer lifespan than rutile when comparing the lifetime of photogenerated electrons and holes. As a result, the probability of photoexcited electrons and holes in anatase engaging in surface chemical processes is greatly increased as a result of the photoexcitation. Apart from that, the electronic structures of photocatalysts as well as the effective mass of photogenerated charge carriers have an impact on the transfer of electron and hole pairs, their separation, and their mobility. As a result, the study of anatase, rutile and brookite titanium dioxide and the photocatalyst electronic structures and effective masses is critical for understanding the differences in photocatalytic performance between them (Zhang, J. et al, 2014).

2.3 Application of Titanium Dioxide

Titanium dioxide is the semiconductor catalyst that is used the most. This is because it is chemical and biologically inert, safe for people and the environment, stable and doesn't have a lot of side effects. Furthermore, titanium dioxide can act as a self-cleaning surface when used as a photocatalyst. The use of titanium dioxide–carbon nanotube nano-composites for environmental cleaning, such as organic compound decomposition in contaminated air and waste waters, has expanded in recent years. Due to carbon nanotubes have a large specific surface area, they absorb organic and inorganic contaminants onto the surface of the titanium dioxide-carbon nanotube composite, which can be regarded a significant photocatalytic process. (Shadravan, A. et al., 2015).

Titanium dioxide can also be used as a coating layer to protect metallic substrates from corrosion has also been researched. According to the manufacturer, titanium dioxide, a chemically stable molecule with excellent heat resistance, is supposed to improve the corrosion resistance of metallic substrates in two ways: first, by increasing the surface area of the metal. It has the potential to function as a protective ceramic barrier on a surface. Besides that, photo-generated current under UV irradiation can make it as a cathodic protection (Din, R.U. et al., 2016). In addition, titanium dioxide is thought to work as a photoanode, providing generated conduction band electrons to the metallic electrode then promoting cathodic protection. Aluminium has great corrosion resistance due to the formation of a passive aluminium oxide layer on its surface. (Shadravan, A. et al., 2015).

Table 2.1: Summary of Related Literature Reviews that Use of Titanium Dioxide as Coating Material.

Application	**Material**	**Performances**	**Reference**
Improve the water resistance and dimensional stability of wood	Wood	After extensive washing of the specimens, no substantial loss of titanium was discovered, indicating a strong adhesion of the titanium dioxide coating to the wood surface.For water immersion test, the wood only increased 20.5% of weight after 90 days.	Sun. Q. et al, 2010
Provide self-cleaning of dirt particles and remove organic solvent	Glass	On the titanium dioxide nanowire coated surface, water droplets have a spherical form, with contact angle of approximately 158±2º. The contaminating particles were quickly adsorbed on the water droplet's surface when they came into contact with it. The pollutants were entirely absorbed by the water drop after numerous sliding processes. A drop of organic solvent rapidly wetted the coated surface with the contact angle of around 0º. The organic layer evaporated completely after about 50 seconds and the surface returned to its superhydrophobic state.	Zhang. X. et al, 2013

To test the wettability of the surface and to observe the hydrophobicity surface	AISI 316L stainless steel	Micro-sized coral-shaped nanoparticles were deposited close to each other and met the critical requirement for hydrophobicity. The water contact test showed that the coating has the contact angle of 150°, it indicates that the coating is superhydrophobic.	Emarati. S. M., & Mozammel. M., 2018
Fabrication and characterization of superhydrophobic high opacity paper	High opacity paper	For a 5 µL droplet, the water contact angle ranges from 126.5º to 154.2º. As the result, the samples are entirely water repellent. For this same sample, 153.5±0.8º and 157.7±1.3º was resulted for advancing and receding contact angle. This showed that the surface of the coating is highly water repellent.	Huang. L. et al, 2010
Self-Clean Coating for Lightweight Composite	Lightweight Concrete	Solidified equatorial sunlight-induced surface characteristics such as sunburn, fracture, filth, greasy deposition and roughness were preserved for a longer amount of time by concrete coated with 2.5 percent titanium dioxide (TiO_2). Able to synthesis potent agents which capable of oxidizing and decomposing a wide	Rus. A. Z. M. et al, 2013

		range of bacteria as well as organic and inorganic materials	

2.4 Titanium Dioxide Photocatalyst

Since around 1971, photocatalysis has become a focus of intense research, with a similar activity in photoelectro chemistry. Other photocatalytic compounds, such as zinc oxide and cadmium sulphide, have been used, but titanium dioxide remains the most popular in photocatalyst (Bickley, R. I. et al., 1991).

Despite the fact that titanium dioxide is one of the most efficient photocatalysts available, efficient photoexcitation of titanium dioxide semiconductor particles requires the use of light with a higher energy than the band gap energy of the titanium dioxide semiconductor particles (Ebg). Because Ebg(anatase)= 3.2 eV and Ebg(rutile)= 3.02 eV for anatase and rutile, respectively, and Ebg(rutile)= 3.02 eV for rutile. So the absorption thresholds for titanium are 380 and 410 nanometers, respectively, for the two titanium forms. (Dvoranová, D. et al., 2002).

2.4.1 Mechanism of Titanium Dioxide as Photocatalyst

Catalysis and photochemistry are combined in the process of photocatalysis. A chemical reaction can only be initiated or precipitated if both light and a catalyst are present. The photocatalytic process is initiated by the absorption of electromagnetic light, which excites one electron from the valence band to the conduction band and subsequently leaves a hole in the valence band once it has completed its cycle. The UV light irradiation is used by the photon energy which is greater than or equal to the titanium dioxide band gap energy ($hv \geq 3.20$ eV at $\lambda \leq 380$ nm). Therefore, electron-holes pairs are generated during this process. As the negatively charged electron transitions from the valance band to the conduction band, the positively charged hole is left behind. Then the electron and hole participate in reduction oxidation processes involving species adsorbed on the surface of titanium dioxide, such as water, hydroxide ions, organic compounds and oxygen. Although both the hole and the electron are oxidising in the valence band, the electron in the conduction band is highly reducing. A highly potent and non-selective oxidant, the hydroxyl radical is formed when H_2O, or the OH- ion, is oxidised by the charge carrier H+ to form H_2O

radical. It quickly degrades contaminants adsorbed on titanium dioxide's surface or in aqueous solution, converting them to H_2O and CO_2. The electron decreases adsorbed oxygen species to superoxide on the conduction band, then conducts a series of reactions to produce the hydroxyl radical. When these radicals come into contact with organic matter, pollutants in the environment or harmful microbes, it decomposes them (Haider, A. J. et al., 2019).

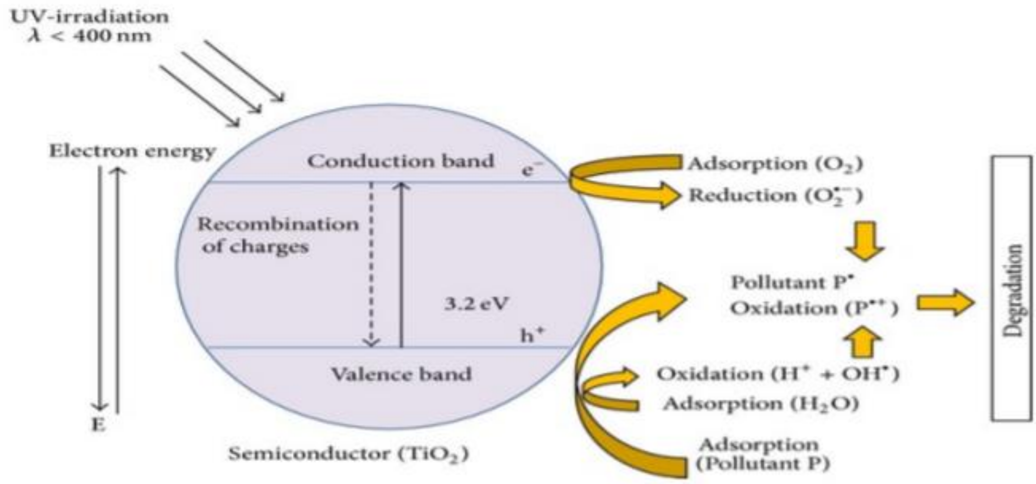


Figure 2.3: Principal photocatalytic process in the titanium dioxide particles (Haider, A. J. et al., 2019).

2.4.2 Recombination

Recombination of the charge carriers occurs when the processes mentioned above do not occur and energy is released in the form of heat. As the result, the efficiency of titanium dioxide photocatalysis is greatly reduced. Electron-hole recombination is reaction competing with hole-donor and electron-acceptor electron-transfer reactions. Recombination can happen in the semiconductor bulk or at the surface, causing release of heat or light. It is unfavourable to photocatalytic activity because the semiconductor's redox characteristics are quenched (Haider, A. J. et al., 2019).

There are several factors that can influence the photocatalysis performance, including mass/concentration, light intensity, wavelength, pH, and temperature, as well as the nature of the photocatalyst, particle size, surface area, adsorption type and substrate concentration. Air purification, water purification, decontamination, antimicrobial, tooth paste, UV protection, photocatalysis, sensing, and paint application are just a few of the many applications for TiO2 nanoparticles (Haider, A. J. et al., 2019).

2.5 Titanium Dioxide as Self-cleaning Coating

In these recent year, there is a lot of attention given to titanium dioxide as self-cleaning coating. Since, automobile windshields, window glasses, roof tiles, car mirrors, and solar cell panel covers, as well as fabrics, furnishing materials, screens of numerous electronic gadgets and optical instruments, have all benefited from self-cleaning coatings. Hydrophobic surfaces and hydrophilic surfaces are the two types of self-cleaning surfaces. Both of these two surface effects, superhydrophobic or superhydrophilic can be achieved by modifying the surface structure or chemical composition (Ren.Y. et al., 2020).

Thomas Young modelled the static contact angle of a droplet on a flat surface in the nineteenth century. He claimed that the water contact angle was governed by the interaction of the surface free energy of the solid–liquid, solid–gas, and liquid–gas boundaries. He stated that, the static contact angle will be smaller than 90 degrees if the wetted surface is more energetically favourable than the dry surface, and the surface will be described as hydrophilic. If the dry surface is preferable, the surface is hydrophobic, with a static contact angle greater than 90 degrees (Parkin.I.P. et al., 2005). Similarly, a surface with a water contact angle that approaching to zero is considered as superhydrophilic, whereas a surface with a contact angle greater than 150 degrees is considered as superhydrophobic. With the use of both superhydrophilic or superhydrophobic surfaces self-cleaning effect can be achieved (Rios. P. F. et al., 2009).

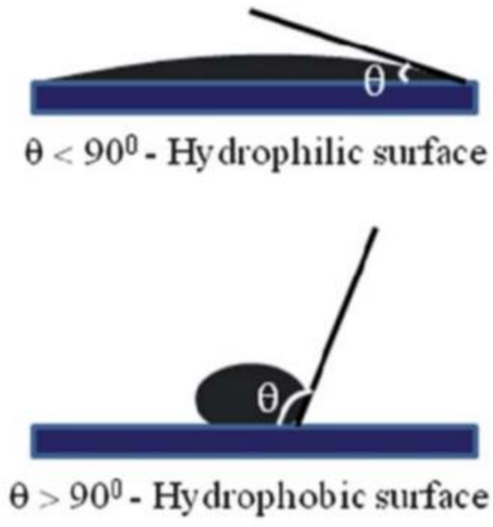


Figure 2.4: Schematic Diagram of hydrophilic and hydrophobic surface (Ganesh, V. A. et al., 2011).

On hydrophobic surface, due to the water repellent and low adhesive capabilities of hydrophobic surfaces, water droplets can roll down off the surface quickly to eliminate impurities. On the other side, for hydrophilic surfaces, contaminants on the surface can be washed away during the spreading process if water droplets can spread fast across the entire surface and form a water film (Ren.Y. et al., 2020).

(a) Superhydrophilic Surface *(b) Superhydrophobic Surface*

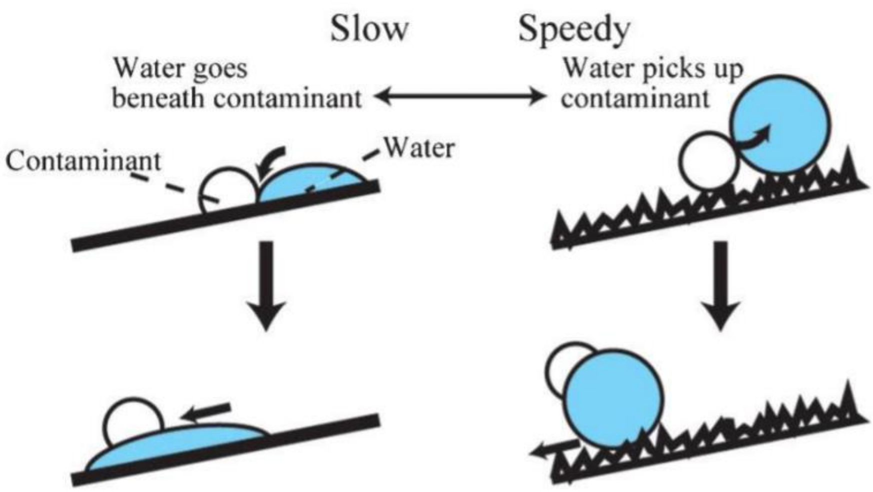


Figure 2.5: Schematic diagram of self-cleaning processes on (a) asuperhydrophilic and (b) a superhydrophobic surface (Banerjee, S. et al., 2015).

2.5.1 Superhydrophilic Coating

Since the discovery of titanium dioxide film's superhydrophilicity, numerous investigations on its superhydrophilic mechanism have been conducted and it has been discovered that the superhydrophilic properties of titanium dioxide surface and the photocatalytic features appear to be closely linked. Different crystal forms of titanium dioxide demonstrated different consistency in their superhydrophilic and photocatalytic properties. The surface of anatase type titanium dioxide had greater superhydrophilicity than rutile type titanium dioxide and the surface porosity was advantageous to both photocatalytic and superhydrophilicity of titanium dioxide (Guo, K. et al., 2021).

When exposed to UV light, all nonpolar liquids will spread across the surface with contact angles of (0±1) º. Independent of their photocatalytic activity, both anatase and rutile titanium dioxide surfaces will show the same wettability change. The titanium dioxide surface's strong amphiphilicity was maintained even after a few days of storage in the dark. With a prolonged storage period, the water contact angle will be gradually increased, demonstrating the surface wettability tendency toward hydrophobicity. This unique behaviour is thought to be explained by the formation of a microstructure composite between hydrophilic and oleophilic phases as a result of photogenerated Ti^{3+} defects at specific sites. As a result, water spreads quickly on a UV-illuminated titanium dioxide surface, giving it superhydrophilic characteristics. The number of accessible oxygen vacancies on a surface increases as the concentration of nano-titanium dioxide on the surface increases, improving the capacity for water absorption. The hydrophilicity process for a titanium dioxide coated surface is represented in Figure 2.5.1 (Olveira, S. et al., 2015).

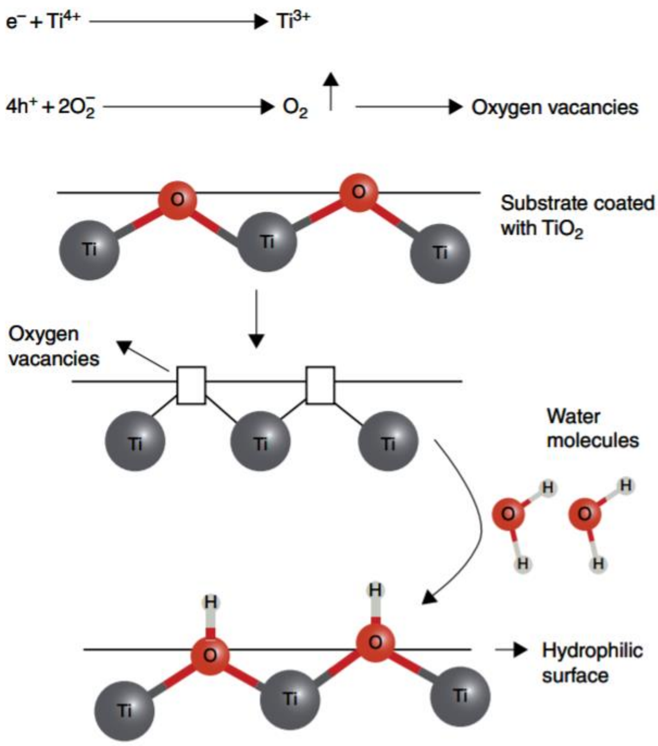


Figure 2.6: Mechanism of hydrophilicity on surfaces coated by titanium dioxide (Olveira, S. et al., 2015).

2.5.1.1 Drawback of Superhydrophilic Coating

Since this superhydrophilic self-cleaning requires UV illumination, therefore it is only suitable when there is sunny day or outside environment. Furthermore, because the same catalytic effect that dissolves surface contaminants, it may also degrade organic based substrates like plastics. Therefore, it is best suited for inorganic substrates like glass. In this scenario, an intermediate layer with a organic or inorganic graded structure would be required, complicating and increasing the expense of the technique (Rios. P. F. et al., 2009).

2.6 Superhydrophobic Coating

In nature, surfaces that are superhydrophobic and self-cleaning can be found all around the places (Rios. P. F. et al, 2009). There are numerous examples of superhydrophobic surfaces that occur naturally. These include the surfaces of both plants and insects. The lotus leaf has the most noticeable natural superhydrophobic surface (Simpson. J. T. et al, 2015). In Asian religions, the lotus blossom is regarded as a sign of purity (Ganesh. V. A. et al, 2011). Its leaves remain pure and free of dirt and contamination even after rising from murky waters. The ‘lotus effect,' a word given to botanist Wilhelm Barthlott which describes this self-cleaning property (Rios. P. F. et al, 2009).

Hydrophobic coatings' self-cleaning ability is due to their high water contact angles. Water on this hydrophobic surface forms into nearly spherical droplets that easily roll away, bringing dust and grime with them. Water which full of dust and grime that falls over the hydrophobic coating is removed before it has a chance to evaporate. The rolling motion of droplets is an important self-cleaning mechanism as well as a complicated physical phenomenon (Parkin I. P. & Palgrave, R. G., 2005).

2.6.1 Lotus Effect

Superhydrophobic surfaces are the self-cleaning coatings of choice for the natural world. There are more than 200 types of plant, probably most famously the Lotus plant native to Southeast Asia, are known to use rolling droplets of water to keep clean. Efforts to duplicate this biological cleansing mechanism resulted in the ‘Lotus-Effect,' which was described in a 1998 patent granted to biologists Neinhaus and Barthlott (Parkin I. P. & Palgrave, R. G., 2005).

The lotus flower's self-cleaning effect occurs because its hydrophobicity repels water and creates a high contact angle which is more than 150 degrees and minimizing the area of contact between the water drop and the leaf surface. On the other hand, the roughness helps to limit the adhesion of water drops to the surface. The water droplets easily detach and rolls across the leaf surface while gathering and transporting dirt particles during the process. (Rios. P. F. et al., 2009).

Lotus effect was discovered that micrometer-scale papillae and epicuticular wax play a crucial part in the lotus leaf's superhydrophobicity. It features a high water contact angle of roughly 160 degrees and a low sliding angle of about 2 degrees. In 2002, there was a report showed the nano-structures on every papilla has nanostructures with a diameter of around 120nm which looks like fine branches. These nanostructures can considerably improve the roughness of the lotus surface and effectively resist water droplet adhesion. Therefore, contaminating particles will be connected to droplets that roll on the tops of epicuticular wax crystals on the top of papillose epidermal cells and taken away (Yu. C. et al, 2020).

The micro or nano hierarchical structures and low surface-tension energy has caused the water droplets will have a very small contact area with superhydrophobic surfaces, ranging from 2% to 3%, Consequently, due to mud and dirt are often larger than the micro or nano structures of the Lotus leaf, which are endowed with minimal adhesive force to a solid surface, the contact area of mud or dirt on a Lotus leaf is similarly relatively small. Nevertheless, the adhesive forces between mud or dirt particles and water droplets are rather high due to their quick wetting nature. Therefore, water droplets will easily wash away mud or dirt particles on a superhydrophobic surface. On the other hand, due to the contact area of mud or dirt particles on solid smooth surfaces is significant, it can cause a large adhesive force. As a result, the particles cannot be removed due to the adhesive force created by water wetting is insufficient, but it will simply regulate their positions (Yu. C. et al, 2020).

2.7 Coating Methods

Electrochemical deposition, phase separation, emulsion, plasma method, template method, electrospinning, dipping, chemical vapour deposition, wet chemical reaction, crystallization control, sol-gel processing, lithography, and other methods for synthesis of superhydrophobic surfaces have all been reported in the literature. Some of the methods are easy and affordable. On the other hands, some others need multistep methods, extreme conditions or specific reagents and equipment, all of which increase the cost of coating (Kumar. A., & Nanda. D., 2019).

2.7.1 Sol-gel Method

The sol–gel process is commonly used to create porous network structures. It's a low-temperature method that's easy to use, inexpensive and controllable. The morphologies and chemical components at the surface of the produced films can be varied by altering the composition of the precursor solution by the hydrolysis and polycondensation processes (Olveira. S. et al, 2015).

The sol–gel process is an industrially promising technique for the preparation of thin films on large area substrates because it has advantages such as low energy consumption, low material consumption rate, easiness and quick deposition on various area of substrates with good homogeneity and most important, it does not require expensive equipment (Shadravan. A. et al, 2015).

Table 2.2: Summary of Related Literature Reviews that Use Sol-gel Coating Method.

Material	Performances	Reference
Glass	Due to the numerous coating processes, a high porosity is achieved across the layer, resulting in a somewhat more compact material near the substrate, and hence a pore distribution gradient. Furthermore, the sol-gel layers have bigger particles with a diameter of 100 nm, with a few reaching 200 nm.	Li. Y. et al, 1999
Windshield	There are only a few flaws on the surface, which is exceedingly smooth. Nano-scale spherical particles were produced with a mean particle size of less than 50 nm.	Alzamani. M. et al, 2013
Quartz and silicon wafers	There were a few of reasonably large particles, 80-100 nm in size, with defined boundaries before the concentration phase. In the backdrop, there were also a few smaller particles, about 10-20 nm in size. The maximum particle size after the concentration step was only 30-50 nm. There was also no cracks on the surface of the coating.	Nagpal. V. J. et al, 1995
316L stainless steel	The coating was dense and uniform. Titanium dioxide particle diameters and pores sizes are around 40 and 58% nm, respectively. Coating adhesion and defection are influenced by the stress created in the film thickness as a result of successive sol applications.	Shen. G. X. et al, 2005

2.7.2 Electrochemical Method

Electrochemical deposition, anodization, galvanic cell reactions, and electrochemical polymerization are examples of electrochemical methods. Regardless of the size or shape of the substrate, these are simple methods for creating rough surfaces (Olveira. S. et al, 2015).

Although the electrochemical method is effective, quick, simple, and inexpensive, however it is not eco-friendly (Kumar. A., & Nanda. D., 2019). Besides that, they also require an externally imposed polarization. Therefore, it causes changes in system-specific properties. For example, formation of surface layers, surface structure and roughness, inhibitor sorption processes, hydrogen adsorption and absorption, superimposed redox reactions and so on (Lorenz. W. J. & Mansfeld. F., 1981).

Table 2.3: Summary of Related Literature Reviews that Use Electrochemical Coating Method.

Material	**Performances**	**Reference**
Titanium wire	After anodization, the as-fabricated fiber has a rough microscopic surface and displays the randomly arranged nanosheets coating at higher magnification. Due to the effect of anodic duration on TiO2-nanosheet coatings, in situ growth of TiO2-nanosheets was enhanced in the longitudinal direction from and their width and thickness were approximately constant.	Li. Y. et al, 2014
AISI 316L stainless steel	The substrate was coated uniformly in all directions. This was due to the consistent dispersion of the coating's basic elements. The uniform buildup of titanium dioxide nanoparticles has resulted in a significant amount of roughness. In fact, under the applied electrical field, uniform deposition of nanoparticles resulted in a rough and uniform coating.	Emarati. S. M., & Mozammel. M., 2018

2.7.3 Dip Coating Method

Dip coating is a popular and easy process for making thin films. Flat or cylindrical substrates can be coated with uniform films. Spin coating is a comparable technology that is frequently utilized in industrial applications. Furthermore, dip coating can also be used to create surfaces with variable wettability for guiding water droplets. To achieve a superhydrophobic condition, silicon nanowires can be dip coated in dodecyltrichlorosilane, and subsequently the wettability can be changed to hydrophilic using UV-enhanced photodecomposition (Olveira. S. et al, 2015).

However, the most significant disadvantage of the traditional dip coating process is that when covering a large substrate, it necessitates a huge volume of solution. As a result, there could be a lot of solution waste, which isn't good for large-scale industrial applications. Particularly if the solution is costly or combustible (Mousavi. S. H. et al, 2017).

Table 2.4: Summary of Related Literature Reviews that Use Dip Coating Method.

Material	**Performances**	**Reference**
Soda lime glass slide	The titanium dioxide from the produced precursor was dipped and it creates a denser film. The thickness and roughness of the titanium dioxide film produced by increasing the dip coating duration from one to three times the prepared precursor resulted in thicker and less rough films.	Euvananont. C. et al, 2008
Glass	Nanowires have a diameter of around 20–40 nm and a length ranging from 5 to more than 10 m. They are solid and it is not hollow. Since nanowires tend to form bundles, they appear bulky. TiO2 nanowires clump together to form dendritic formations, which are more complex and can provide increased surface roughness.	Zhang. X. et al, 2013
Titanium substrate	The particle size, measured in terms of hydrodynamic diameter, does not vary significantly over time. Only the particle size distribution shows changes in particle size and morphology. The particles in titanium dioxide became noticeable a few hours after the dip coating. Because of its relatively larger particle size and broader particle size dispersion, titanium dioxide is expected to contain more aggregated particles.	Jokinen. M. et al, 1998

2.7.4 Chemical Vapour Deposition (CVD) Method

In an activated environment like heat, light or plasma environment, chemical vapour deposition involves the dissociation and/or chemical reactions of gaseous reactants. Besides that, it also creates stable solid product. The deposition involves Homogeneous gas phase reactions in the gas phase, as well as heterogeneous chemical reactions on/near a heated surface were also involved in the deposition. Therefore, it will form powders or films respectively as the final product (Choy. K., 2003).

There are also some drawbacks of chemical vapour deposition, which include the chemical and safety hazard of carry out the CVD. These risk is mainly caused by the usage of toxic, corrosive, flammable and/or explosive precursor gases. However, this disadvantages can be mitigated by utilizing more environmentally friendly precursors in CVD versions such as Electrostatic Spray Assisted Vapour Deposition and Combustion Chemical Vapour Deposition. Moreover, CVD variants such as low pressure or ultrahigh vacuum CVD, plasma assisted CVD and photo-assisted CVD require more sophisticated reactors and/or vacuum systems, which tends to raise manufacturing costs (Choy. K., 2003).

Table 2.5: Summary of Related Literature Reviews that Use Chemical Vapour Deposition Coating Method.

Material	Performances	Reference
Glass	The films were all clear with thicknesses ranging from 40 to 130 nanometers. Variations in diffracted intensity will be related to either crystallinity or film thickness changes. For the most part, there was only a minor difference in intensity. It was verified that all of the samples contained anatase, with no signs of rutile or other elements.	Yates. H. M. et al, 2006
Glass	The transmission curves of the resulting titanium oxide layers were created in the wavelength range of 200 to 900 nm. The titanium dioxide films do not appear to be smooth, but rather appear to be made up of small grains that form larger aggregates. The surface of the morphology matches that of broccoli.	Sobczyk-Guzenda. A. et al, 2009
Silicon Wafer	The film thickness varies between opposite faces of the same pyramid, thus the $TiO2$ film has two distinct layers. The inner layer is amorphous, while the outer layer has tiny crystals throughout its thickness.	Vallejo. B. et al, 2005
Tin oxide coated glass	Crystallite was formed with the size of 10±2 nanometer. The coating is homogenous in appearance, albeit there is some overgrowth on the surface. Titanium dioxide is polycrystalline, with an anatase phase with a tetragonal crystal structure. The films are 975 nm thick, transparent and have a transmittance of more than 80%. Images taken with an atomic force microscope (AFM) demonstrate a nanocrystalline morphology with a grain size of 200 nanometers.	Shinde. P. S., & Bhosale. C. H., 2008

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The materials used to produce titanium dioxide/silicon oxide, TiO_2 and TiO_2/SiO_2 are mentioned in this chapter, and several laboratory tests including Field emission scanning electron microscopy (FESEM), water contact angle analysis and X-ray powder diffraction (XRD) tests which were conducted to test the characteristics of titanium dioxide/silicon dioxide on the aluminum film. The whole process of this research is summarized in Figure 3.1.

Materials Preparation

Preparation of Aluminum Fin

1. The aluminum fin is cut into pieces.
2. The fin is sand with No.80 sandpaper.
3. The fin is rinsed with distilled water and acetone.
4. The fin is dried by using oven.

Preparation of TiO_2 and TiO_2/SiO_2 Solution

1. 15 g/L of TiO_2 and TiO_2/SiO_2 solution is prepared.
2. The solution is put on hot plate to boil it.

Process of Coating

1. The fin is put into boiling coating solution for 5 minutes.
2. The fin is taken out and put in 85ºc oven for 30 minutes.
3. Step 1 & 2 is repeated until it is coated with the number of layers that you have planned.
4. The fin is put into the 200ºc oven for 6 hours.

Characterization

Field emission scanning electron microscopy (FESEM)
Water contact angle analysis
X-ray powder diffraction (XRD)

Data Analysis

Report Writing

Figure 3.1: Flowchart Related the Summary of Whole Process of This Research.

3.2 Chemicals

3.2.1 Titanium Dioxide

The most important crystalline forms of titanium dioxide are rutile and anatase, It is a white and natural source of mineral (Patra, Debasmita, 2018). It has been found to be inactive in both humans and animals. Photocatalysis can be occur when it is under the presence of light with an energy equivalent to or greater than its band-gap energy (Skocaj, Matej et al, 2011).

Figure 3.2: Image of TiO_2 powder (Cameron Mitchell, 2016).

3.2.2 Sodium Hexametaphosphate

The chemical formula of sodium hexametaphsphate is $(NaPO_3)_6$. It is a water-soluble polyphosphate. It composed of chains of six repeating phosphate units. $(NaPO_3)_6$ is a mixture of polymeric metaphosphates, of which the hexamer is one. It is used in the production of a variety of chemicals. The more accurate name for this compound is sodium polymetaphosphate (James Han, 2020).

3.2.3 Sodium Metasilicate

The chemical formula of sodium hexametaphosphate is Na_2SiO_3. It is the primary constituent of most sodium silicate solutions. This ionic combination of this is Na_2SiO_3 is made up of polymeric metasilicate which is the anion and sodium cations. This chemical is colourless, crystallised, deliquescent and hygroscopic (ChemicalBook).

3.2.4 Titanium Dioxide/Silicon Dioxide

TiO_2/SiO_2 can be prepared by following a standard procedure in preparing sample. First, 75 ml solution containing 0.05 g of $(NaPO_3)_6$ and 5 g of TiO_2 nanopowders was used in a typical sample preparation method. The pH of the solution was adjusted to 9–10 by heating it to 80 °C in a water bath with glacial acetic acid. Then, the solution is slowly pour in the Na_2SiO_3 solution while stirring rapidly. After that, a slurry material is obtained and then it is aged for 10 hours at room temperature. Lastly, it is washed with centrifuge, dried and crushed and finally the TiO_2/SiO_2 powder is obtained (Pengqi Chen et al, 2019),

3.3 Sol-gel Dipping

The surface that is going to coat on in this study is aluminium film. The aluminium films are going to be separate into 5 pieces, which 3 of it is for the TiO_2 coating and another 2 is for TiO_2/SiO_2 coating. Each aluminium film has to remove its oxide layer by using sand paper before the coating. Then, each aluminium film has its own numbers of layers of coating.

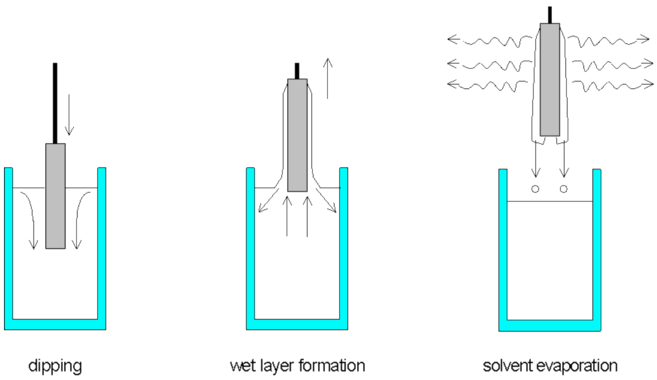


Figure 3.3: Sol-gel dipping process (H. Schmidt, M. Mennig, 2000).

3.4 Characterization Chemicals

3.4.1 Field emission scanning electron microscopy (FESEM)

The field emission scanning electron microscope (FESEM) can see features on the surface of a material which is small until 1 nanometre. The observation magnification can be modified and taken into account depending on the requirements. It can be used to examine the morphology and geometry of electrospun nanofibers. The FESEM is a microscope that uses electrons with a negative charge instead of light to perform its operation. A field emission source liberates these electrons. The object is scanned in a zig-zag pattern using electrons (Semnani, D., 2017).

Figure 3.4: Field emission scanning electron microscopy (UKM)

3.4.2 Water Contact Angle Analysis

Water contact angle analysis is a most common used method to determine the characteristics of the surface whether it is hydrophobic or hydrophilic (Farris, Stefano et al, 2011). The intersection between the solid and the liquid will create a water angle. This geometric measurement of the angle created provide the basis for this theory. This method is mostly employed in the evaluation of the wettability of a surface (Thiago Matheus Guimarães Selva et al, 2021).

Figure 3.5: Contact Angle Measurement Equipment (nanoScience)

3.4.3 X-ray powder diffraction (XRD)

The most basic characteristics of sediments are their size and composition. Optical microscopy can easily identify sand and coarse silt-sized crystalline material. However, the most popular technique that usually used to study the crystalline structure's characteristics is the X-ray powder diffraction. This XRD method is very famous because of its speed and convenience of use, as well as the fact that it requires little material, is non-destructive, and may be used to do semi-quantitative examinations of poly-mineralic mixtures (Poppe. L. J. et al, 2001).

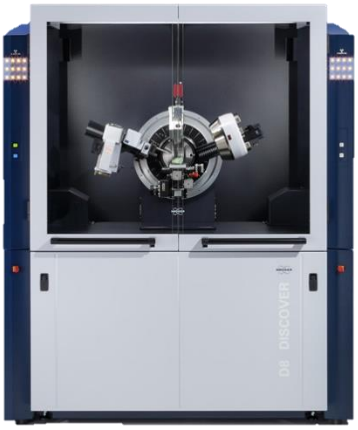


Figure 3.6: X-Ray Diffractometer (Bruker)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

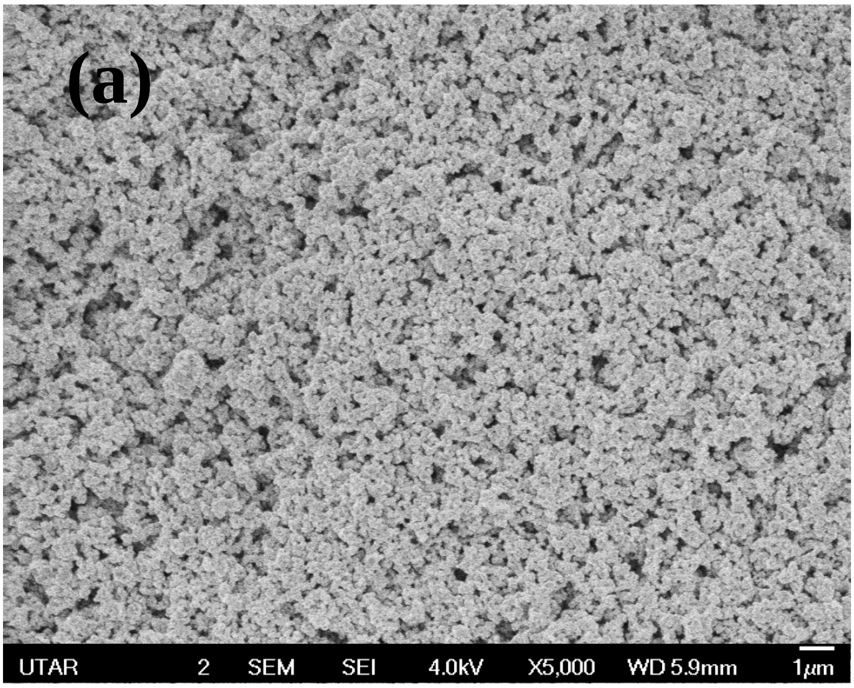
The results of wettability which is tested by the waster angle analysis, morphology properties by Field Emission Scanning Electron Microscope (FESEM) and structure of titanium dioxide particles by X-Ray Diffraction (XRD) were discussed in this chapter. These 3 analysis are used to determine the hydrophobic characteristic of the coating to achieve the self-cleaning effect.

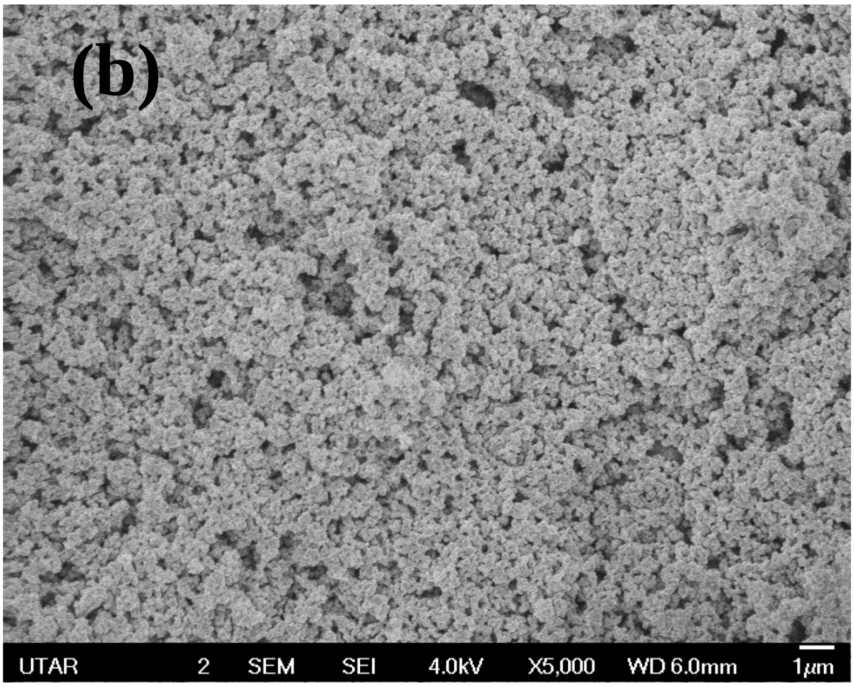
4.2 Morphology Properties

4.2.1 Morphology Properties of TiO_2 Coating

The micro-nanostructure of the titanium dioxide coating was analysed by conducting the Field Emission Scanning Electron Microscope (FESEM) analysis. The coating's superhydrophobic wetting capabilities are mostly determined by the micro-nanostructure of the coating that was used in its preparation. Surface microstructures with a rough hierarchical structure were discovered for the superhydrophobic coatings that were produced (Wang, Yan Fen et al, 2014).

Figure 4.1 shows the FESEM images that were prepared in different numbers of layers of titanium dioxide coating, which are 5 layers (a), 10 layers (b) and 12 layers (c). The coating of titanium dioxide is coated on the aluminium by undergoing several heat reactions especially the calcination. As we can see in figure 4.1 which is under magnification of ×5,000, the surface morphology was rough, and the aluminium fins are coated homogeneously. Similar morphologies were also obtained from previous researchers where titanium dioxide is used as the coating materials. Their surface of coating is also indicating a rough and homogenous (Wang, Yanfen et al, 2014; Takashi Kamegawa et al, 2012). This prove the successful synthesis and coating of TiO_2 onto the aluminium fins by a facile method as reported in Chapter 3.





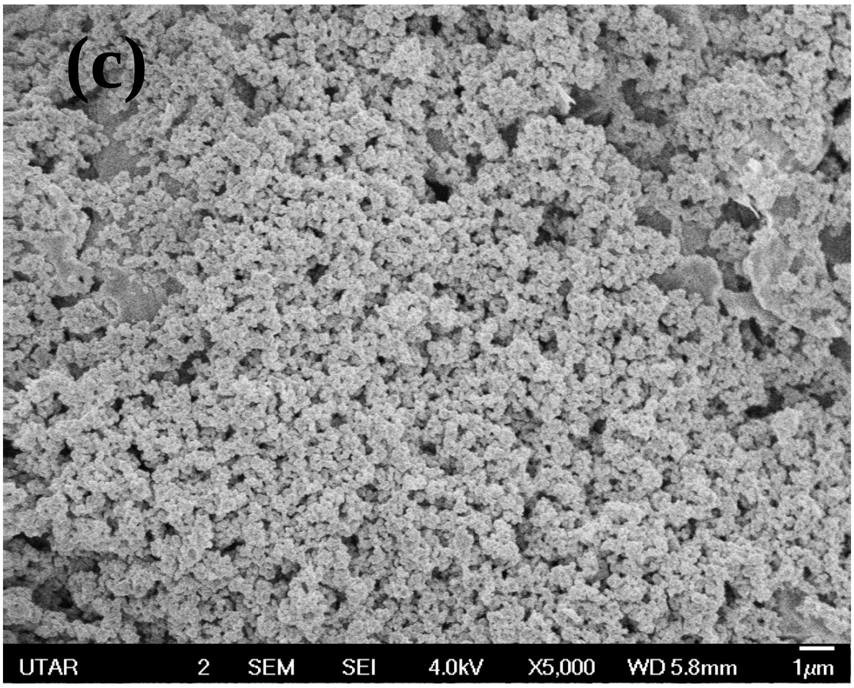
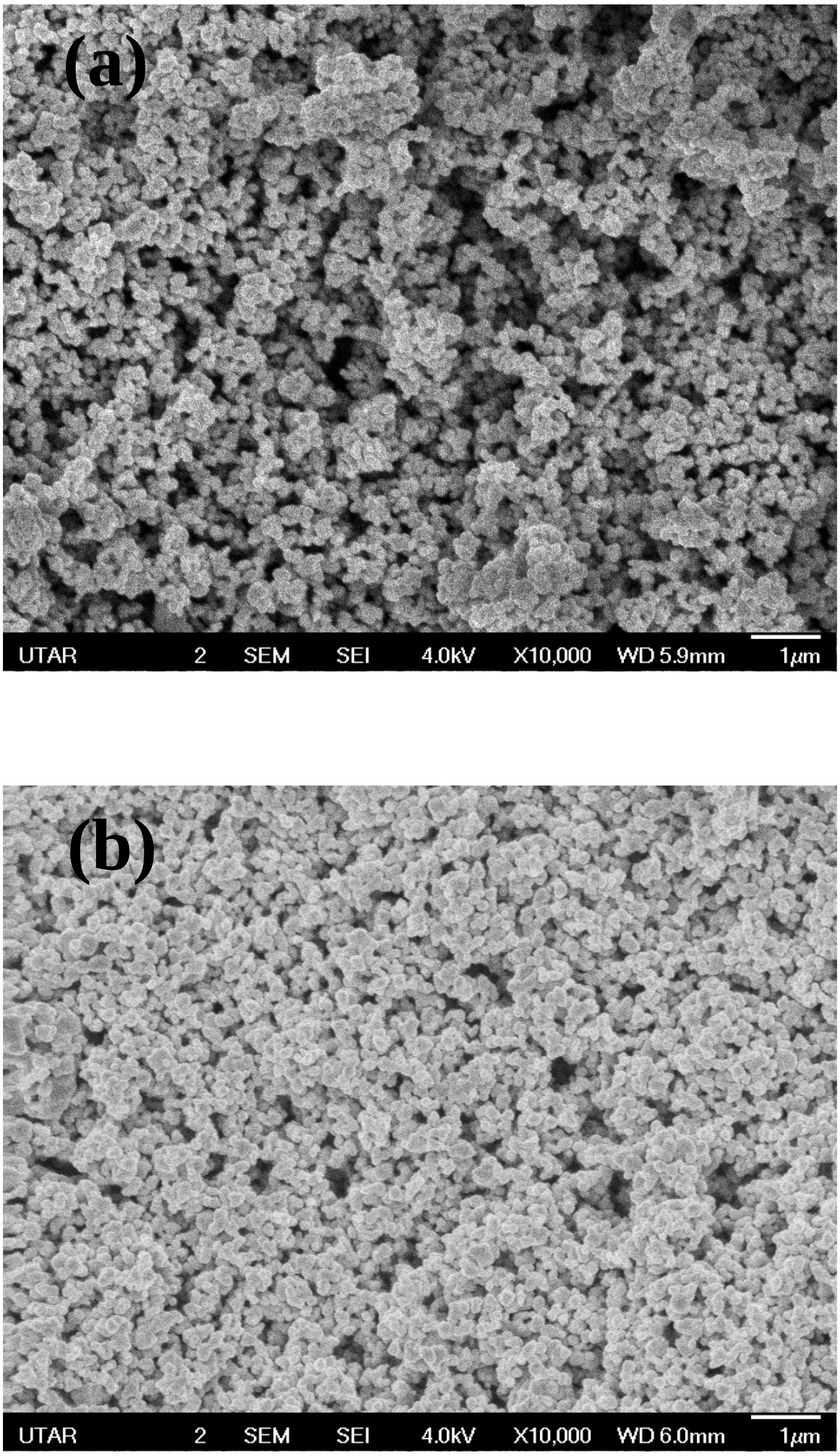


Figure 4.1: FESEM image of TiO_2 coating with x5,000 magnifications, (a) 5 layers, (b) 10 layers, (c) 12 layers.

Figure 4.2 shows the magnification ×10,000 FESEM image of the TiO_2 coating. The nature shape of the TiO_2 can be clearly seen from Figure 4.2 (a-c). The nanoparticles are all spherical in shape. Higher magnification photographs clearly show the surface morphology of calcined titanium dioxide as well as the crystalline form of the material. Due to the obvious aggregation of the nanoparticles, the FESEM revealed a larger particle size (Kah Hon Leong et al, 2014).


(a)
UTAR 2 SEM SEI 4.0kV X10,000 WD 5.9mm 1μm
(b)
UTAR 2 SEM SEI 4.0kV X10,000 WD 6.0mm 1μm

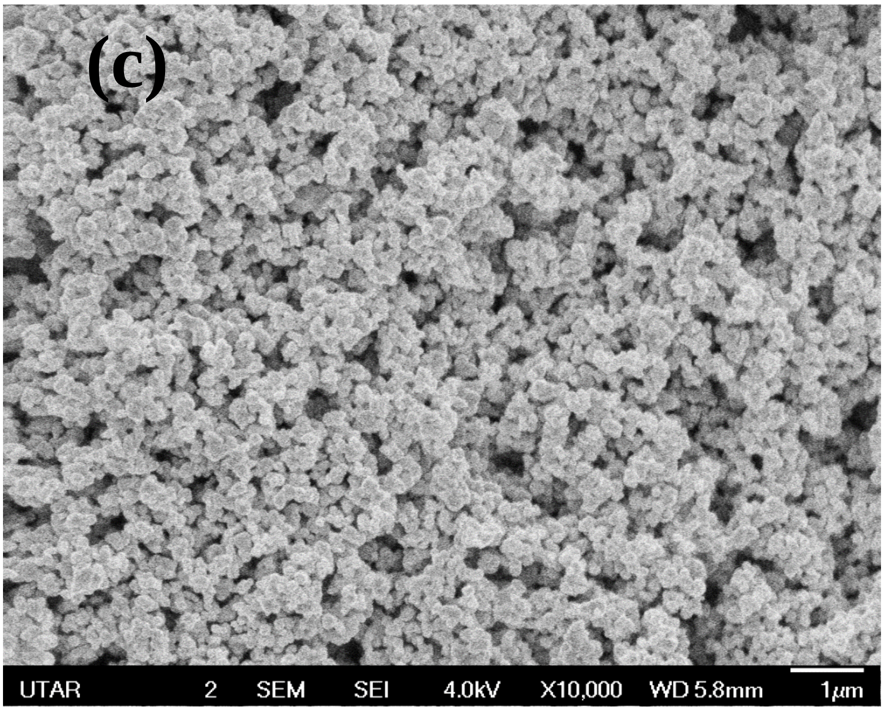


Figure 4.2: FESEM image of TiO_2 coating with ×10,000 magnifications, (a) 5 layers, (b) 10 layers, (c) 12 layers.

4.2.2 Morphology Properties of TiO_2/SiO_2 Coating

Figure 4.3 shows the FESEM image of the TiO_2/SiO_2 coating with the magnification of x5000. Figure 4.3 (a) and (b) shows the number of coating layer of 5 layers and 10 layers respectively. Both of the coating undergoes the same degree Celsius of calcination with the TiO_2 coating, which is 200ºC. From the figure 4.3, it clearly shows that both of the coating are homogenous and rough. However, figure 4.3 (a) have the best homogeneity compare to figure 4.3 (b) and figure 4.1 (a-c) which is the TiO_2 coating. Besides that, the overall homogeneity of the coating of TiO_2/SiO_2 is better than the TiO_2 coating. This is mainly due to presence of silicon substrate that improved the homogeneity during the surface coating process (Holtzinger, C. et al, 2013).

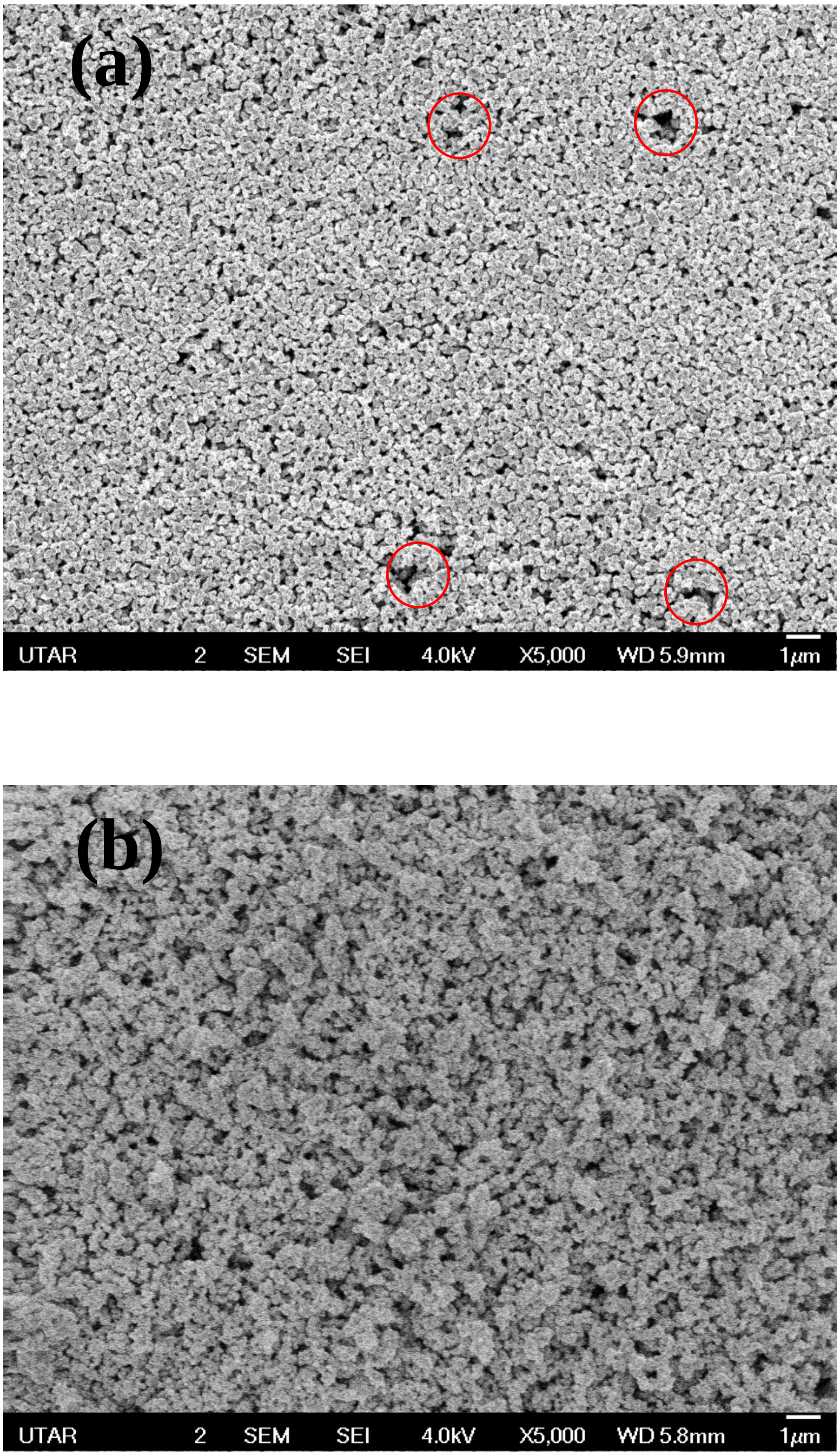


Figure 4.3: FESEM image of TiO_2/SiO_2 coating with x5,000 magnifications, (a) 5 layers, (b) 10 layers.

Figure 4.4 (a-b) is the FESEM image of TiO_2/SiO_2 coating with a magnification of ×10,000. In figure 4.4, the shape of TiO_2/SiO_2 nanoparticles is also spherical in shape which is same with the TiO_2 nanoparticles. Moreover, in figure 4.3 and figure 4.4, there are some air pockets have been circled in red colour. The air pockets which are on the surface make the surface rougher and enhance the hydrophobicity of the coating. There are two kinds of air pockets, the air pockets which are sealed inside the nano-structures and another type is open air pockets are continuous with the atmosphere (Qing, Yongquan et al, 2015).

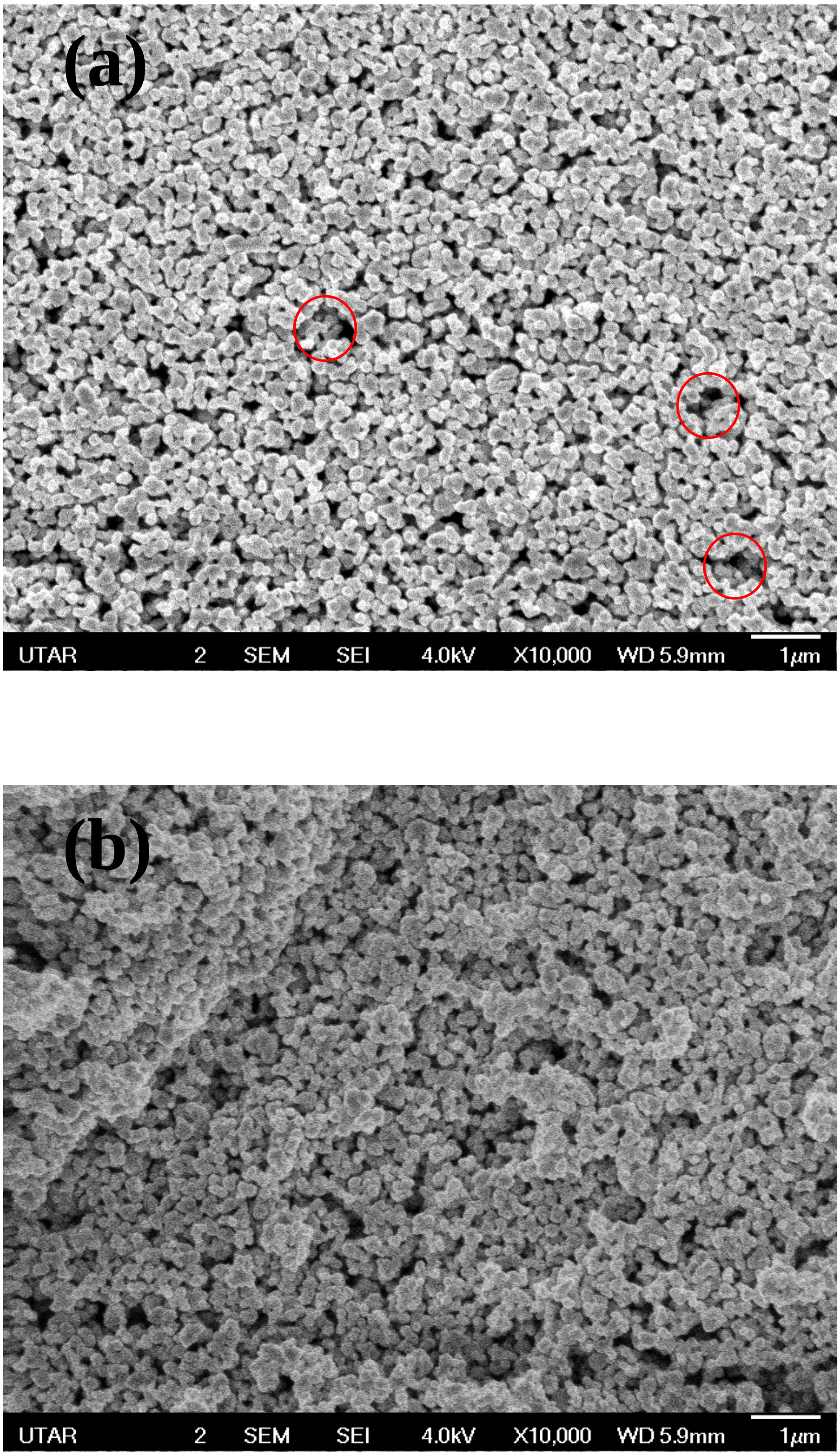


Figure 4.4: FESEM image of TiO_2/SiO_2 coating with ×10,000 magnifications, (a) 5 layers, (b) 10 layers.

4.3 Structure of Particles

4.3.1 Structure of TiO_2 Particles

The X-ray diffraction diagram of TiO_2 after calcination at 200 ºc is shown in Figure 4.5. By referring to the JCPDS Card No.: 21-1272, the diffraction peaks of the XRD graph can be matched perfectly. The XRD pattern of TiO_2 of each number of layers of coating shows the diffraction peaks at almost the same degree. For the anatase phase based on the lattice plane, the diffraction peaks that we get are 2Ө = 25.52º (101), 38.00º (004), 48.32º (200), 54.16º (105), 65.26º (215). Then for the rutile and brookite phase, both peaks at 2Ө = 27.5º (110) and 30.8º (121) are missing respectively. Therefore, it can conclude that the synthesized TiO_2 is a pure anatase phase without a rutile and brookite phase and also crystalline structure of TiO_2 can be formed by undergoing 200ºC of calcination (Kah Hon Leong et al, 2014). The presence of all the major peaks indicate the successful synthesis and TiO_2 coating onto the aluminium fins without destroying the TIO_2 structure.

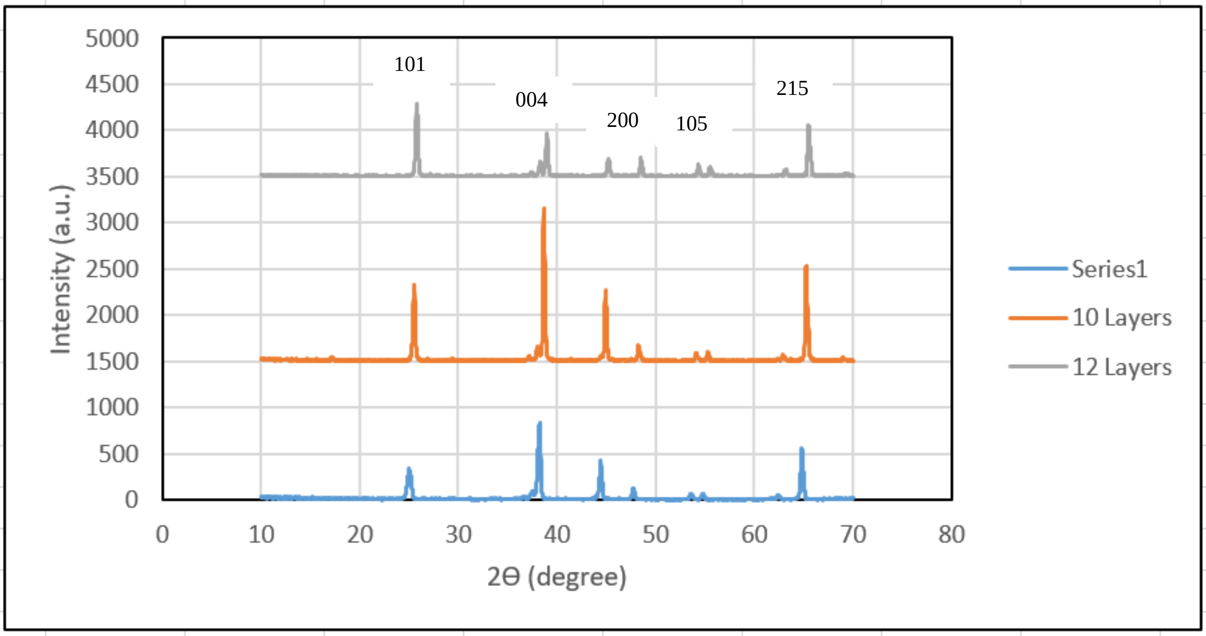


Figure 4.5: XRD pattern of TiO_2.

4.3.2 Structure of TiO_2/SiO_2 Particles

Figure 4.6 shows the X-ray diffraction diagram of TiO_2/SiO_2 after calcination at 200 ºc. For TiO_2/SiO_2, both 5 and 10 layers of coating have the almost same degree which shows the diffraction peak. The diffraction peaks that we get for anatase phase of TiO_2 are 2Θ = 25.38º (101), 37.84º (004), 48.1º (200), 53.92º (105), 65.14º (215) by referring to JCPDS Card No.: 21-1272. For rutile and brookite phase, both also missing same with the TiO_2 coating. Then, by referring ICSD 98-015-5245, the diffraction peak of SiO_2 can be seen at 29.52º. However, the coating with 10 layers has the higher peak than the coating which is 5 layers. Therefore, we can conclude that 200ºc of calcination also is enough for TiO_2/SiO_2 to form crystalline structure and it consists SiO_2 as well as pure anatase phase of TiO_2. This finding proves the successful synthesis of TiO_2/SiO_2 together with its coating using the simple coating route. In addition, the presence of all the main peaks clearly indicates the stability of the TiO_2/SiO_2 even after coating it onto the aluminium fins.

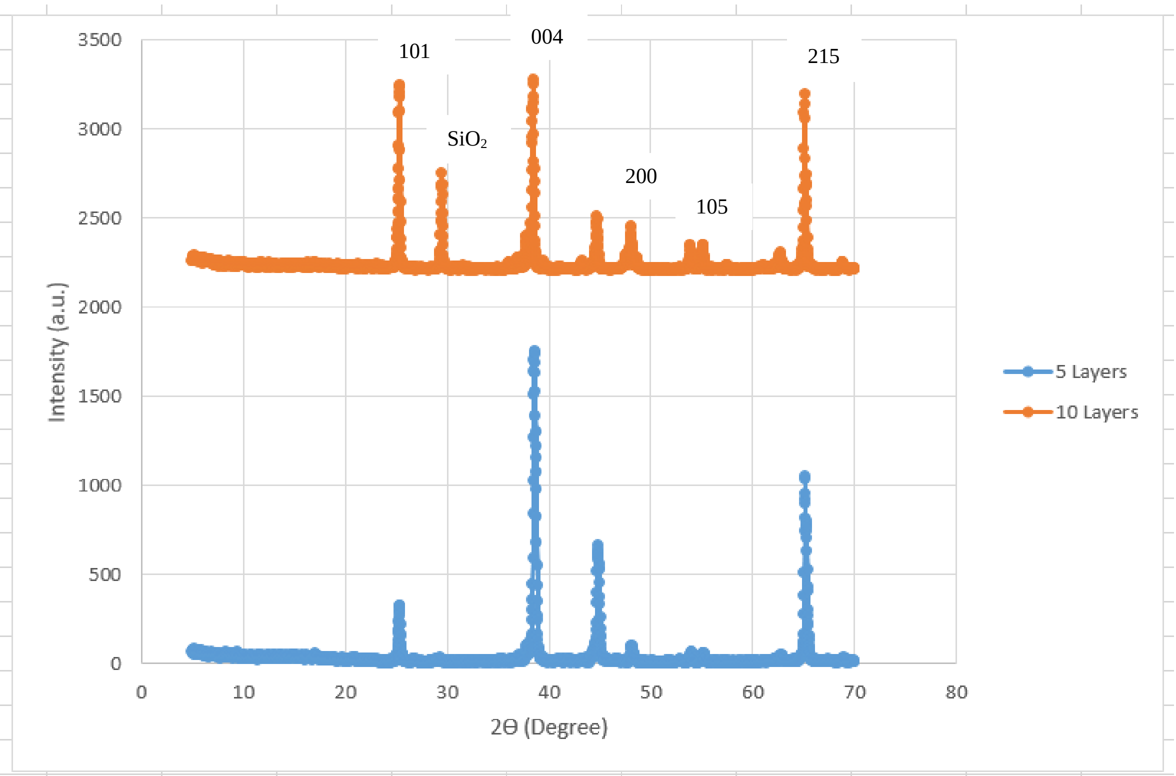


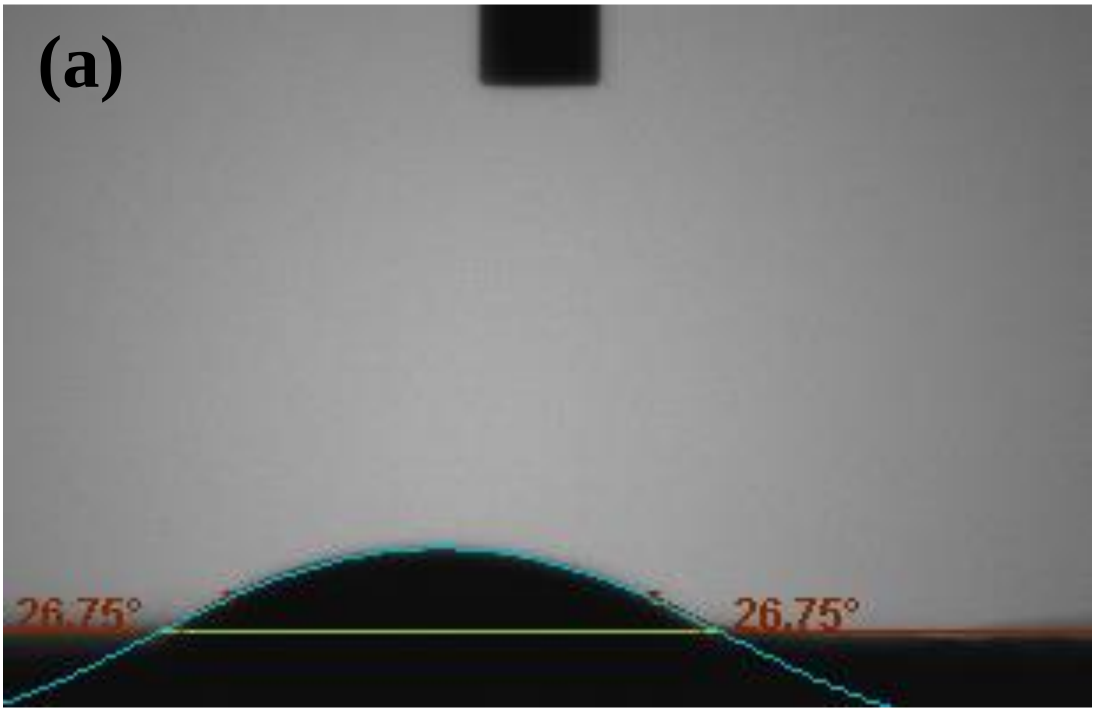
Figure 4.6: XRD pattern of TiO_2/SiO_2.

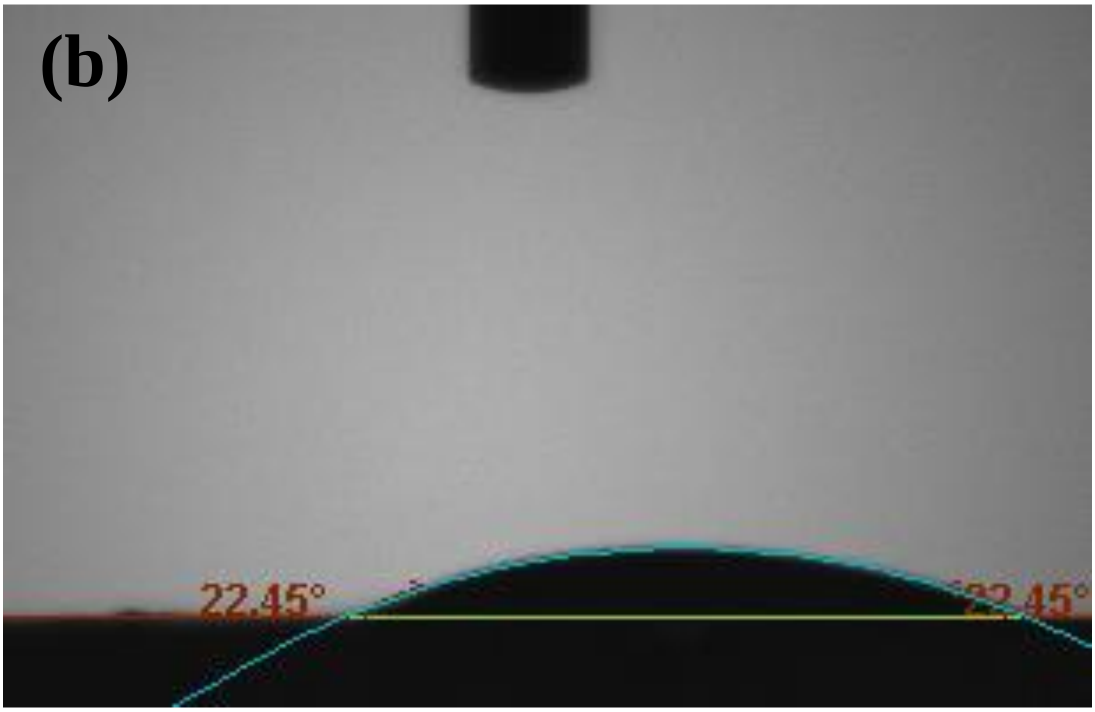
4.4 Wettability

The wettability of the surface coating can be examined by water angle analysis. The surface of coating whether it is hydrophobic or hydrophilic can be judged by the water contact angle. If the water contact angle is larger than 90º, then it is hydrophobic. On the other hand, if the water contact angle is smaller than 90º, then it is hydrophilic (Mozammel, Mahdi et al, 2018).

4.4.1 Wettability of TiO_2 Coating

Figure 4.7 shows the image of water angle analysis of TiO_2 coating. Figure 4.7 (a), (b) and (c) are referred as 5 layers, 10 layers and 12 layers of coating respectively. As observed, 5 layers of coating has the water angle of 26.75º, then 10 layers and 12 layers have the water angle of 22.45º and 8.31º respectively. As it can conclude, all of these aluminium with the coating of TiO_2 does not achieve the hydrophobic but just remain as hydrophilic. From Figure 4.2 (TiO_2 coating) and Figure 4.4 (TiO_2/SiO_2 coating) which both is the FESEM image under the magnification of x10,000. The size of the particles can be clearly seen that the particles of TiO_2/SiO_2 are bigger than the TiO_2. Based on Cho, Kwun Lun et al, the roughness of the coating surface can be affected by the size of the particles. Due to the size of particles of TiO_2 are smaller than then particles of TiO_2/SiO_2, the roughness of the TiO_2/SiO_2 coating is greater than the TiO_2 coating (Cho, Kwun Lun et al, 2010). Besides that, enhancement of the surface roughness can improve the hydrophobicity of the surface. Therefore, the aluminium fin with 5 layers of TiO_2/SiO_2 coating can achieved hydrophobic but TiO_2 coating could not (Ahmad, N.A et al, 2013).


(a)
26.75°
26.75°


(b)
22.45°

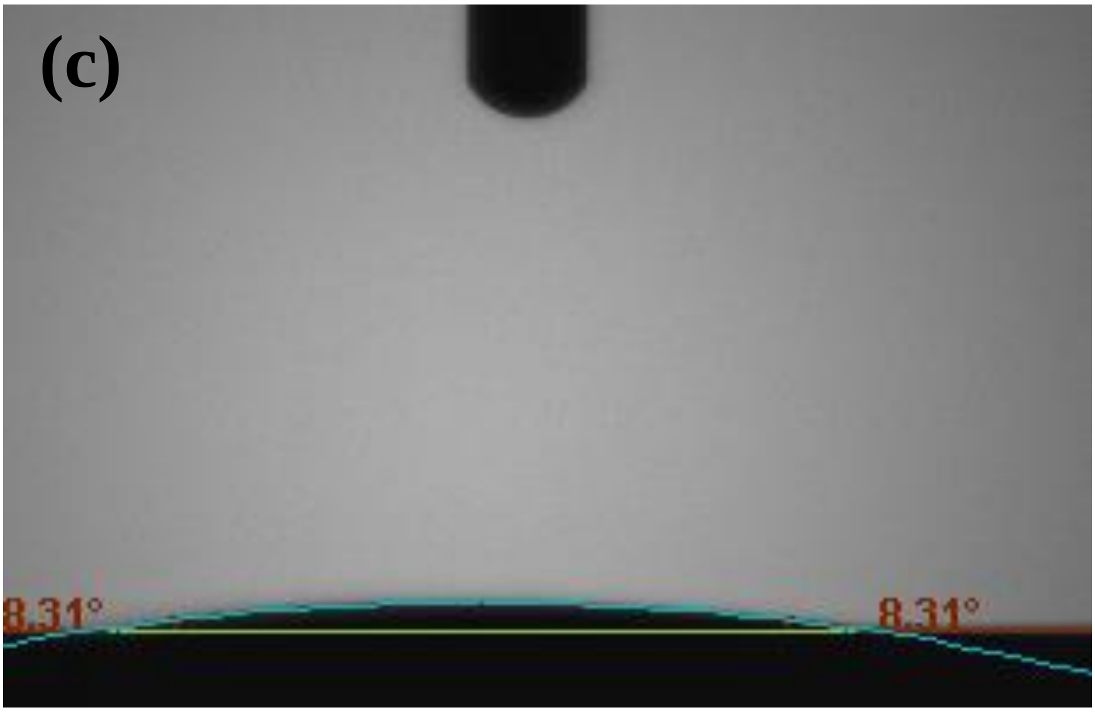


Figure 4.7: Image of Water Angle Analysis of TiO_2 Coating, (a) 5 Layers, (b) 10 Layers (c) 12 Layers.

4.4.2 Wettability of TiO_2/SiO_2 Coating

Figure 4.8 shows the image of water angle analysis of TiO_2/SiO_2 coating. Figure 4.8 (a) and (b) are referred as 5 layers and 10 layers of coating respectively. In figure 4.8 (a), it shows that 5 layers of coating has the water angle of 129.30º which has already achieved the hydrophobic characteristic. The hydrophobic surface need to have the water contact angle that is larger than 90º. Then for 10 layers, it has the water angle of 19.68º. This water contact angle is consider as hydrophilic. Although increasing the layer of coating can enhance the surface roughness which lead to better hydrophobicity, but there is a limitation of the surface roughness. As the result of increasing the layers and aggregation of coating, it may cause changes of the vertical and horizontal in morphology. Aggregation will lead to an increase in the size of vertical features, as well as a corresponding increase in the size of horizontal features. As the horizontal length scale increases, the droplet begins to penetrate the area between the roughness (Cho, Kwun Lun et al, 2010). Therefore, the 10 layers of TiO_2/SiO_2 could not achieve the hydrophobic characteristic.

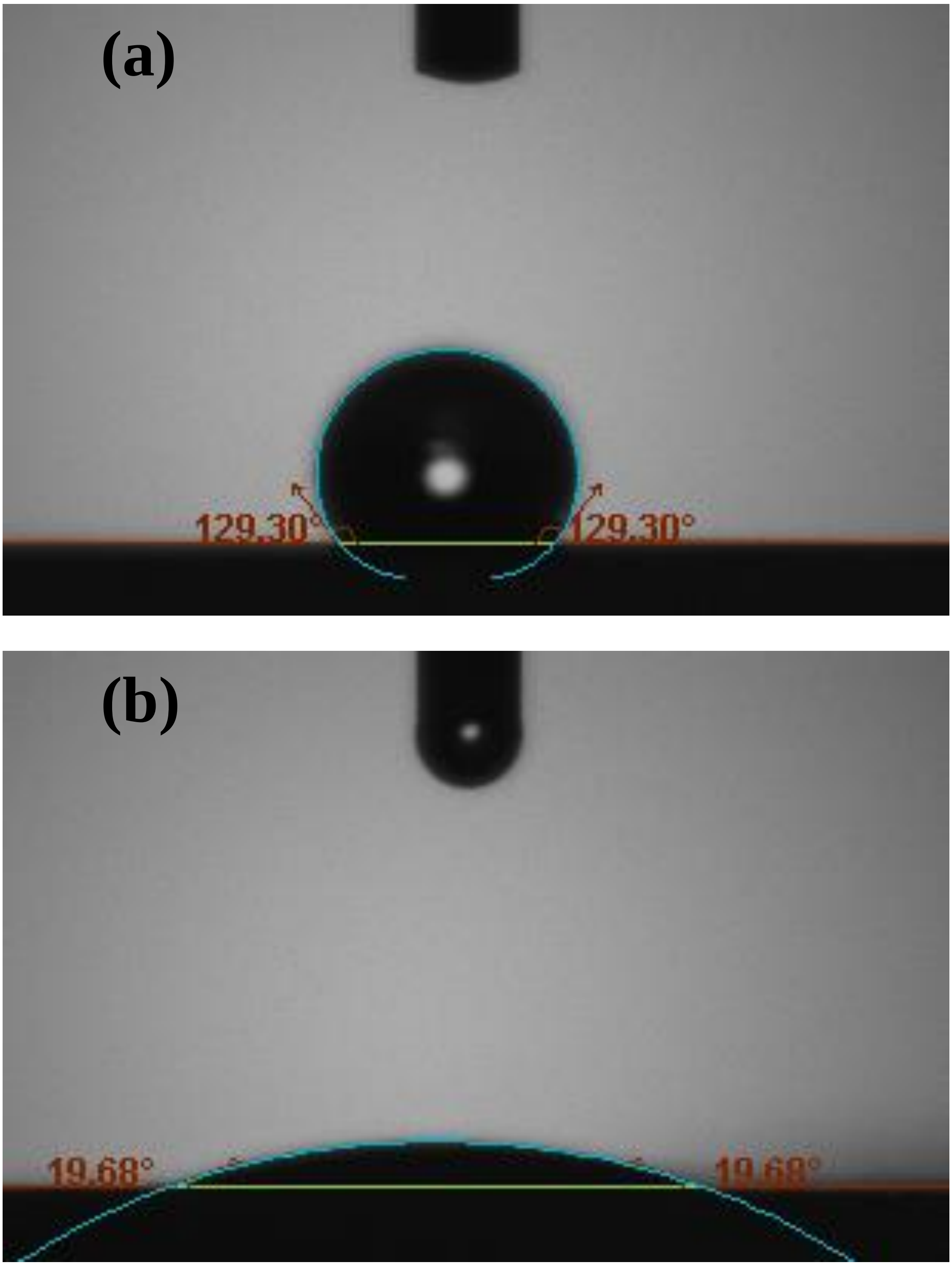


Figure 4.8: Image of Water Angle Analysis of TiO_2/SiO_2 Coating, (a) 5 Layers, (b) 10 Layers.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research, TiO_2 and TiO_2/SiO_2 were utilized as a coating that coats on aluminum fins and try to test which can achieve a superhydrophobic effect and lead to self-cleaning properties. Different numbers of layers of coating have been tried to find the optimum number of layers and improve the wettability of the coating. The aluminum fin was being roughened by using the sandpaper to remove the oxide layer which produce by the aluminum fin naturally and then dipped in a boiling coating solution. The titanium dioxide coating was then dried at the temperature at 85ºC in the oven for 30 minutes for each layer of coating and then finally calcined at the temperature of 200ºC for 6 hours. The performance of the coating was determined in the aspect of morphology properties, structure properties and wettability.

In conclusion, the morphology properties of the coating were analysed by using the Field Emission Scanning Electron Microscope (FESEM). The coating on each number of layers of coating and both TiO_2 and TiO_2/SiO_2 were all homogenous and the nanoparticles were spherical in shape. However, the homogeneity of TiO_2/SiO_2 with 5 layers of coating shows the best result in the FESEM image. Furthermore, the air pockets formed on TiO_2/SiO_2 with 5 layers of the coating were also can be seen which helps it to improve the hydrophobicity. Therefore, it is the only one that shows the best hydrophobic effect compared to the others. Moreover, the structure of TiO_2 and TiO_2/SiO_2 nanoparticles were determined by the X-ray Diffraction analysis (XRD). From the analysis, the XRD graph of TiO_2 coating after being calcined at 200ºc matched perfectly with the JCPDS Card No.: 21-1272. The synthesised titanium dioxide coating is pure anatase and in a crystalline structure. It does not consist the rutile and brookite phase due to it missing the peaks at 2Θ = 27.5º (110) and 30.8º (121) respectively. Then for the TiO_2/SiO_2 coating, it is also a pure anatase structure. The diffraction peaks that we get for anatase phase of TiO_2 are 2Θ = 25.38º (101), 37.84º

(004), 48.1º (200), 53.92º (105), 65.14º (215). Then, the diffraction peak of SiO_2 is at 29.52º by referring ICSD 98-015-5245. The for the wettability which being tested by water angle analysis, only the coating of TiO_2/SiO_2 which is 5 layers achieved the hydrophobic with the water contact angle of 129.30º. The others coating didn't achieve hydrophobic but only remain hydrophilic. This is because the size of particles of TiO2 are smaller than then particles of TiO2/SiO2, the roughness of the TiO2/SiO2 coating is greater than the TiO2 coating (Cho, Kwun Lun et al, 2010). Besides that, enhancement of the surface roughness can improve the hydrophobicity of the surface. Therefore, the aluminium fin with 5 layers of TiO2/SiO2 coating can achieved hydrophobic but TiO2 coating could not (Ahmad, N.A et al, 2013). Lastly, we can conclude that only TiO_2/SiO_2 coating with 5 layers achieved the hydrophobicity but not the TiO_2 coatings. Therefore, TiO_2/SiO_2 is a better coating material compared to TiO_2. Moreover, 5 layers of coating of TiO_2/SiO_2 bring a better effect than the 10 layers of coating which the 10 layers of coating failed to achieve the hydrophobic coating. This is due to the increasing of layers and aggregation of coating, it may cause changes of the vertical and horizontal in morphology. Aggregation will lead to an increase in the size of vertical features, as well as a corresponding increase in the size of horizontal features. As the horizontal length scale increases, the droplet begins to penetrate the area between the roughness (Cho, Kwun Lun et al, 2010). In this research, all of the objectives are attained. However, further studies and improvements are still required to improve the coating.

5.2 Recommendations

There are some recommendations are suggested for further study and research to improve and further enhance the performance of titanium dioxide coating.

1. Eliminate the oxide layer which formed by the aluminium itself by using acid or other chemical instead of sand paper to improve the homogeneity of the coating.

2. Conduct further studies using lower temperature and duration to dry the coating and calcination of the coating in order to study the effect on the performance in the aspect of morphology properties, structure and wettability.

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