Aluminum based types of hydrophobic coatings for Engineering Materials: A Review

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ABSTRACT

Today's coating applications allow for the employment of a wide range of techniques and substances to safeguard products and structures from chemical and chemical harm. Coatings are now widely utilized in manufacturing across the globe to boost productivity and cut costs, both of which are crucial for maintaining the industry's profitability. Materials with coatings are stronger than those without coatings. Strong and hard metals, ceramics, bioglass, polymers, and plastic materials are just a few of the alternatives available to designers for simple means of permanent protection. Coating techniques include sol-gel, thermal spray, dip coating, and spray coating. Only a few of the numerous processes that have been recorded and investigated include surface modification, thermal spray, sol-gel, and deposition by vapor, along with physical/chemical vapour deposition and electrode position techniques. The focus of the research is on different methods for creating aluminum-based hydrophobic coatings, as well as different aluminium oxide technical features, such as contact angle and optical properties, which are crucial for hydrophobic behaviour.In this review paper emphasis is being done to show the utility of aluminum oxide as nanocoating material for enhancement of hydrophobic property .Also various coating techniques is being discussed and compared showing different result as per methology .Alumium based nanomaterial properties is also being compared with other nano materials .Contact angle of diffrernt nano materials is also being compared along with aluminum oxide. In support of various hydrophobic property various properties like contact angle,Raman spectroscopy, X ray properties, hardness, and wet ability is being discussed. After the review role of aluminum oxide is found versatile and important in enhancing hydrophobic properties of materials and in real life application. Some modification in properties of aluminum oxide may also lead to conversion from hydrophobic (contact angle $>90^0$) to super hydrophobic (contact angle $>150^0$). Right now, the best method for preventing aluminium alloy corrosion is chromate, or hexavalent chromium. Anodizing is frequently used as the preferred finishing technique for aluminium components. Long-term strength, durability, and corrosion resistance can be maintained in aluminium using this coating. Because of its superior weather resistance, polyvinylidene fluoride (PVDF) resin is a manufactured coating that is frequently utilised for architectural applications. Wall claddings and aluminium roof sheets are among the most frequently coated surfaces using PVDF.As compared with hydrophobic property with respect to contact angle various result is seen as follows Lead(II) oxide114.6^0 , Iindium(III) oxide115^0 , Zinc oxide153°, Titanium dioxide 129° , Chromium(III) oxide 151^0, Alumina powder 144.50^0 and Teflon 128.40^0 etc.

Keywords: Aluminum oxide, coating technique, coating materials, coating properties hydrophobic effect.

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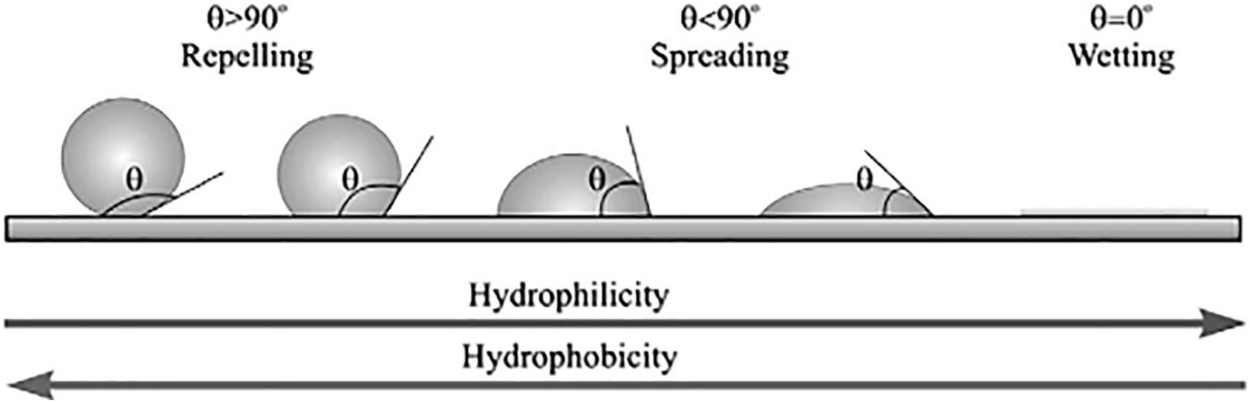
1. Introduction

In nature, there are many surfaces and materials with distinct wettability that are influenced by surface free energy and shape. According to Wenzel Cassie and Baxter, surface hydrophobicity is determined with the contact angle (CA) of liquid droplets on this surface. Many biologically varied plants and animals exhibit hydrophobic qualities in nature. In relation to prior literature, lotus leaves in nature produce a self-cleaning and super-hydrophobicity phenomenon known as the "lotus effect" that is governed by hierarchical roughness on their leaf surface. Numerous ways for creating hydrophobic surfaces have been addressed using techniques that are easy and cost-effective, but involve multiple sequential operations and different circumstances. [1].

The current work presents an overview of ultra hydrophobic surfaces with a focus on drag reduction. The following is how the review is structured. In this study, we first explain the basic theories behind behavior of wet and non-wet solid surfaces, followed by a brief review of naturally occurring super hydrophobic surfaces. Finally, we provide a succinct overview of the use of ultra hydrophobic coatings to steel, copper, magnesium, and aluminum to prevent corrosion. [2].



“Fig.1” Diagram showing water droplet shape and water contact angle (WCA) for solid surfaces along hydrophobic and hydrophilic gradients. [3]

The detailed structure of this review is as follows: The basic concepts of wettability on solid surfaces and the antifouling mechanism of superhydrophobic coatings are first described in Section 2. including electrochemical etching, micro-axis oxidation and anodizing. [4]

The contact angle is measured at the edge of the water drop where it rests. is the tangent angle of the liquid-vapor interface at the three-phase boundary. If the contact angle is less than 90^0, the ring is hydrophilic, if the contact angle is between 90^0 and 150^0, and hydrophobic if the contact angle is greater than 150^0, the hydrophobic surface can be rough or more precisely created. according to certain types of morphology. This improvement in surface wettability can be seen as an improvement in surface chemistry.

Consequently, a variety of techniques were employed to alter surface morphology and/or surface roughness. However, only electrochemical approaches seem to combine the flexibility to develop a range of surface morphologies with ease of implementation, even on very large surfaces. In fact, electrochemical processes are quite repeatable, easy to understand, and rather quick. Additionally, in contrast to the majority of other methods, electrochemical methods can produce a broad variety of surface morphologies, including hollow spheres, dendrites, flowers, cauliflowers, urchins, ribbons, tubes, rods, and sheets.[5].

In this review, we have gathered unique strategies for managing and designing structural growth of AAO of varied sizes, arrangements, topologies, geometries, and pores architectures. Changing anodization settings like current, voltage, and electrolyte type while electrochemically selfordering AAO enables access to these structures. Better control of pore organisation, along with nano imprinting techniques, has resulted in AAO nanofabrication with outstanding resolution and efficiency. The most current developments in gas-phase and wet chemical synthesis methods for surface modification and functionalization of AAO membranes have also been covered in detail. Effects of new surface modification techniques on material properties produced and the range of applications made possible by these surface modifications have been discussed, along with examples of these techniques. Complex AAO nanostructures can be fabricated with even more control over surface functionality, which should lead to the creation of novel nanostructures and nanodevices with previously unheard-of functional qualities for next-generation devices. Their applications will also be explored, with a focus on a variety of research fields, including electronics, material science, and medicine. Therefore, it is certain that AAO membranes will be crucial in a wide range of novel applications.

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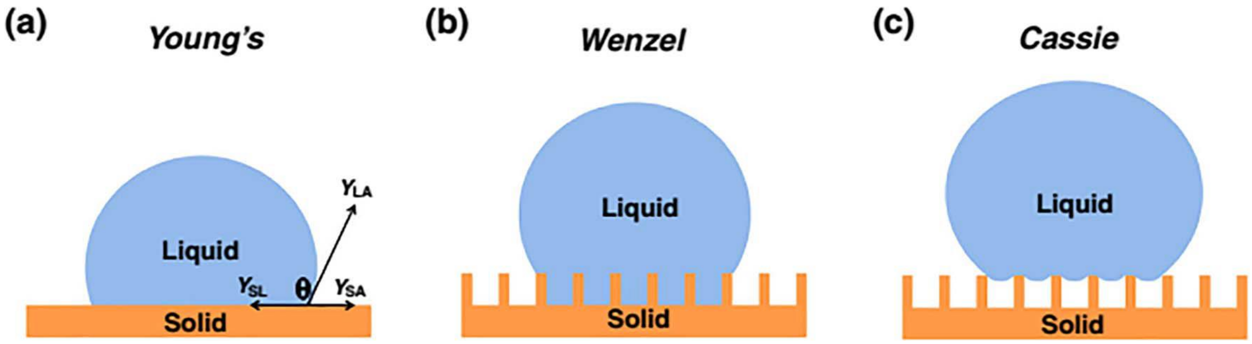
The literature assessment indicates that bio-based polymers have a great chance of taking the place of synthetic and fossil fuel-based polymers as renewable resources for applications involving paper coating. Not only can biopolymer paper coatings be flexible enough to allow for biodegradation and recycling, but many methods have been demonstrated to increase the functionality of coated paper surfaces. Review states that a completely protected bio-based paper coating might be created by carefully combining certain components (bio-based polymers and fillers) with surface structure PLA and PHB are the most promising industrially available polymers as thermoplastic materials that can be handled with continuous extrusion coating to produce a thick and continuous coating layer. More biopolymers should be applied through solvent casting and dispersion.[7].

The comprehensive application of thermoplastic biopolymers as a paper coating is still hampered by processing challenges, most of which are linked to thermal instability at melting temperatures, specific crystallization behavior, and the ensuing mechanical qualities. Typically, polymer mixing or the usage of copolymers, which have exhibited superior processing and characteristics when used as a paper coating, are used. can alleviate these difficulties.[8]. Nanotechnology, on the other hand, looks to offer a solution for overcoming the processing characteristics associated with pure biopolymers while simultaneously delivering specialised functionality to the paper coating. A variety of easily available bio-based nanofillers have intriguing features for improving the coating's barrier and mechanical properties. The most important aspect of incorporating nanofillers into a biopolymer coating is their homogenous dispersion. As a result, it is recommended that the hydrophobic interface of naturally hydrophilic nano fillers be modified: In addition to the traditional methods for chemically changing surfaces, various nanoscale technologies have been revealed and are currently being developed.[9]. Therefore, to enhance mechanical properties, thermoresponsive MFC with changeable hydrophobicity would be a good choice as a nanofiller for PHB. In addition, nanofillers can improve heat stability and serve as a nucleating agent for uniform crystallisation, which reduces brittleness in biopolymer coatings and leads to better biopolymer processing. Finally, the production of bio-based nano composite coatings on paper allows for the preservation of a mixture of favourable barrier qualities, including low oxygen and water vapour permeability and hydrophobic protection.[10].



“Fig.2” A liquid droplet on three distinct surfaces: the Cassie-Baxter model, Wenzel's model, and Young's model.[11]

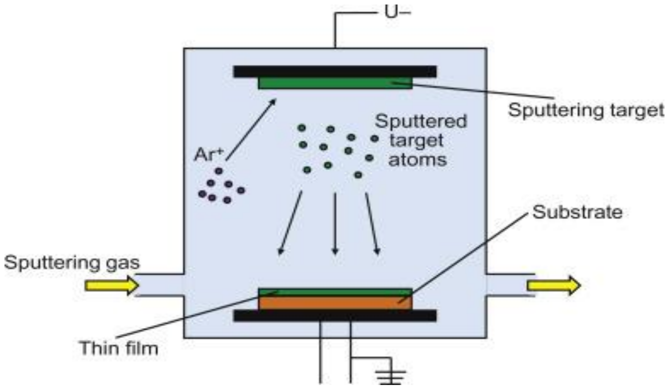
This study offers a summary of current developments in the use of ultra hydrophobic surfaces as corrosion barriers. Corrosion is a severe and pervasive problem that causes industrial plant closures, the loss of important resources, decreased production, product loss or contamination, and environmental damage. An alternative strategy to increase metal corrosion resistance is to investigate super hydrophobic surfaces that draw inspiration from nature. By reducing the area of contact between liquids and a surface, super hydrophobic surfaces can provide better corrosion prevention. Artificial super hydrophobic surfaces can be used for a variety of functions, including oil-water separation, self-cleaning, anti-icing, and, most importantly, anti-corrosion.[12].

Various techniques (such praying and dip coating) have various features for different substrates. Compared to dip coating, spray coating often has the advantages of covering a wider substrate area, greater adaptability, and recovery through simple respraying. Choosing the appropriate coating technologies for the substrates is also essential. One of the key ideas in surface science is the very hydrophobic surface. For new, significant practical applications like water collection and oil/water separation, future research in this field may focus on developing super hydrophobicity, self-healing super hydrophobic surfaces, smart responsive materials, and super hydrophobicity. These advancements could be quicker, more robust, and environmentally friendly.[13]

2. Various Techniques For Coating

2.1. Coating Produced By Vapor Deposition

These coatings, however, are more than just metal layers. Instead, complex Atom by atom, parts are deposited to create a thin, bonded metal or metal-ceramic surface layer that significantly enhances the appearance, robustness, and/or functionality of a part or product.[14].



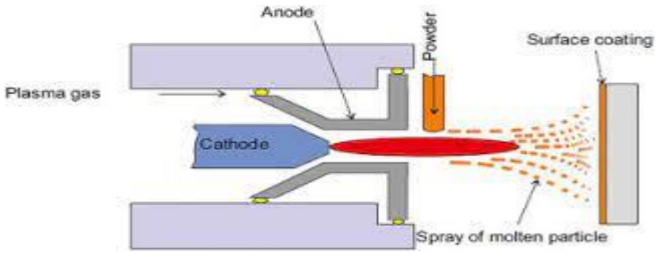
“Fig.3” Vapor Deposition coating process[14]

2.2 Phase Separation

It is possible for a well-mixed solution containing proteins and other macromolecules to spontaneously divide into two phases: one where the macromolecules are abundant, and the other where they are scarce. This phenomenon is known as separation.

2.3 Plasma Spraying

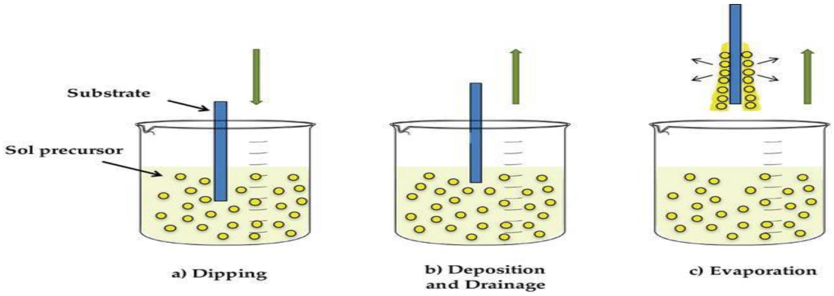
Is a coating technique in which coating material powders are injected into a plasma jet at roughly 10 000K, where they melt and are sprayed over the substrate to be coated.



“Fig.4” Plasma spraying coating process[14]

2.4 Sol-Gel Coating

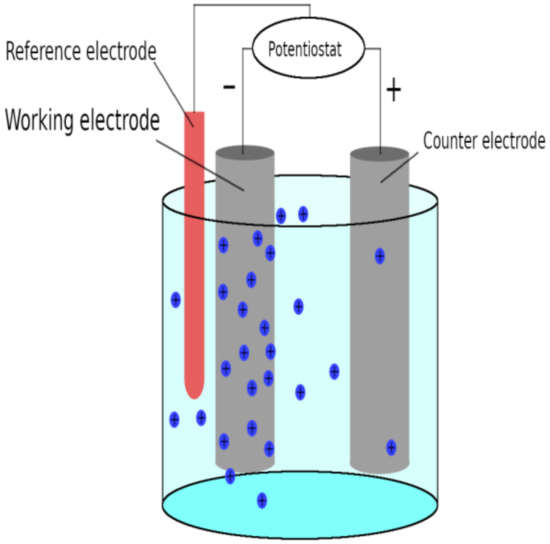
Sol-gel coatings are blended materials that display the strength of silica while also providing excellent release and smoothness without the use of fluoro polymers. The releasing or nonstick qualities of these coatings are an intrinsic feature.[15]



“Fig.5” Sol-Gel coating process[16]

2.5 Electro Chemical Depositions

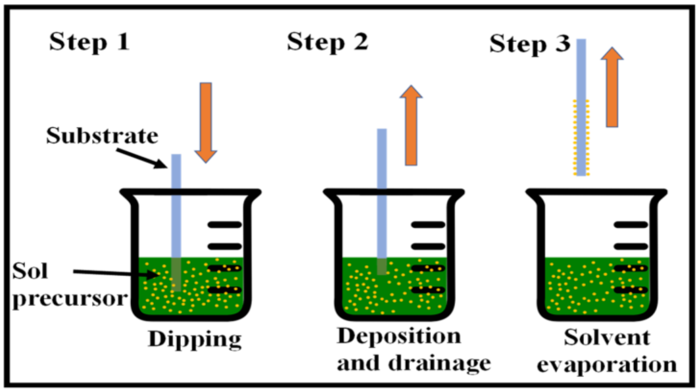
Using an electric field and a redox reaction, conducting or semiconducting materials are deposited onto a substrate (often conducting) in the process of electro deposition, sometimes referred to as electroplating. [17]**.**



“Fig.6” Electrochemical deposition coating process [17]

2.6 Solution Immersion Process

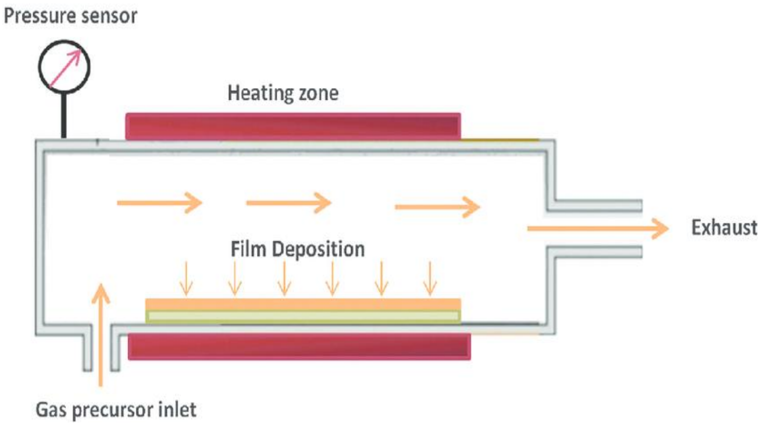
A plastic is first dissolved in a suitable solvent to create a solution for coating the substrate. Dipping, spraying, spinning, and other methods can be used to apply the solution to the substrate. The solvent is allowed to evaporate after the solution has been applied, leaving only the plastic coating behind.[14].



“Fig.7” Solution immersion coating process [15-16]

2.7 Chemical Vapours Deposition

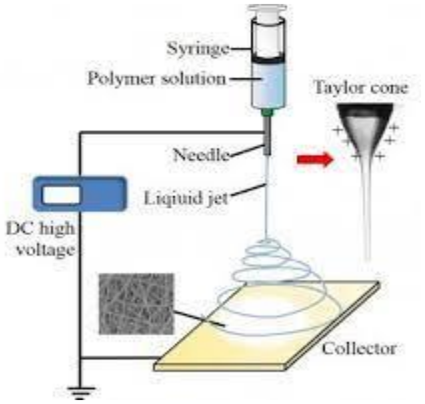
The process of chemical vapour deposition (CVD) involves the deposition of a solid material from a vapour on or near a substrate surface that is normally heated (Fig.8). Using CVD, the vapor-solid process is demonstrated. This technique is commonly used in the semiconductor industry to manufacture thin sheets.



“Fig.8” Chemical vapour deposition coating process [17]

2.8 Electro Spinning Method

Electro spinning is a simple procedure that is commonly used to create polymer nano fibers. Continuous polymer fibre fabrication at nano and micro metre sizes is a highly versatile method. This process is comparable to extrusion, however this extrusion is controlled electrically.[18]. The electro spinning raw material is subjected to a high voltage; To increase the liquid electrostatic potential, this power is needed. Liquid surface tension and electric potential are related. Therefore, the fluid volume can be changed by varying the surface tension's electric potential.[19].



“Fig.9” Electro spinning coating process[19]

2.9 Etching Method

Etching is a way of creating an extremely hydrophobic surface by roughening the surface.

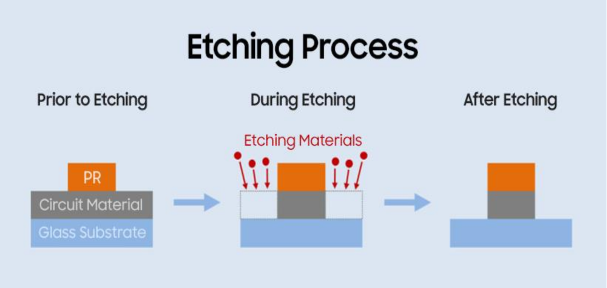
Several etching techniques can be used on the metal surface, and they can be mixed with acid to improve surface roughness. To improve the surface roughness, different etching techniques can be used in conjunction with acid. Inorganic materials can be treated using optical maser etching and plasma etching procedures.[20].

a) **Wet chemical Etching**

Solutions that are acidic or basic scrape the surface to make it rougher. [21]

(b) **Dry etching**

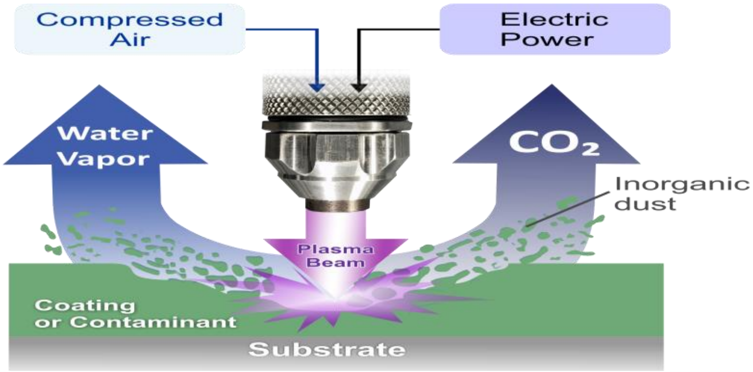
Reaction etching techniques are utilised in this plasma. In a gas discharge, reactive atoms and particles erode the surface in an anisotropic manner. [22]. Etching is a reasonably simple and straightforward procedure that may additionally used on extremely large surfaces; nevertheless, it has the drawback of utilising acids that are corrosive, including phosphoric and sulfuric acids. which renders it unsuitable for use due to environmental issues.



“Fig.10”Etching coating process [22]

2.10 Plasma Treatment

Surface plasma treatment always includes plasma etching. Surface etching caused by plasma treatment will result in considerable changes within the surface micro-nanostructure.[23]. Plasma might be an easy and efficient way to make surfaces that are hydrophobic. It is possible to raise surface energy and surface roughness simultaneously. We can easily create super hydrophobic surfaces by using oxygen plasma. However, the biggest issue with extremely hydrophobic surfaces created with the plasma process is ageing. Because the roughness of plasma-finished surfaces may be easily modified, this technology is suitable for fabricating ultra hydrophobic coatings with certain optical characteristics, where the most important factor is surface roughness.[24]



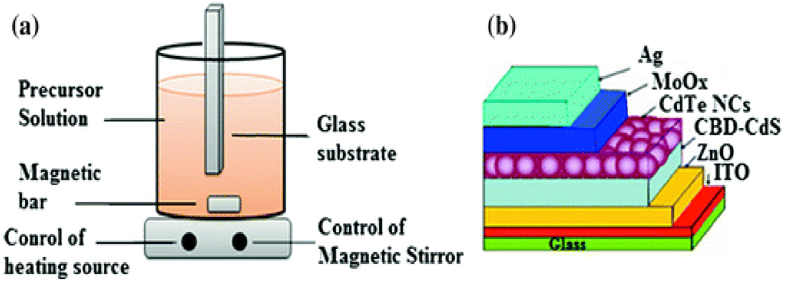
“Fig.11” Plasma Treatment coating process [24]

2.11 Layer-By-Layer (LBL) Deposition

One of the most popular techniques for creating highly hydrophobic coatings and micro- and nanoscale structures is the LBL procedure. Using the LBL process, a charged material is regularly deposited in a thin layer onto a solid or semi-solid substrate. Successive layers of opposite charge material can be stacked on top of one another to form a multilayer containing one structure with a nano-level thickness. The layer-by-layer deposition method can be used repeatedly to achieve the desired coating thickness. Nanostructures can be introduced during deposition to increase the coatings' roughness and change the way that LBL-generated coatings wet.

2.12 Wet-Chemical Method

One of the industrial methods that is most often used is wet-chemical coating because it allows for the large-scale utilisation of various materials manufacturing of ordered ultra hydrophobic coatings. The main disadvantage of this procedure is the usage of hazardous surface etching agents.



“Fig.12” Wet-chemical coating process [25]

2.13 Phase Separation Technique

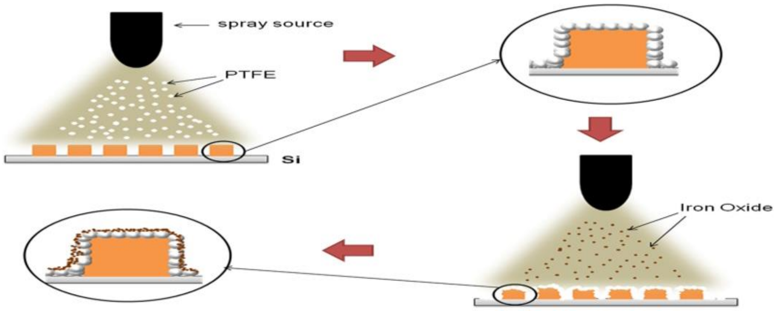
One of the easiest and least expensive approaches for generating extremely hydrophobic mesoporous polymer membranes is phase separation. It works with a restricted set of materials only. Two phases, one enriched in macromolecules and the other depleted in macromolecules, spontaneously separate from a well-mixed fluid containing proteins and other macromolecules.[25].

2.14 Imprinting Technique

Traditional imprinting techniques, such as lithography and templating, can be utilized to make super hydrophobic surfaces, which normally include a master and a replica. These tactics can be used in two different way individually and in combination with another processing technique to lessen the complexity of the synthesis procedure.

2.15 Lithography Technique

The copying of master information is the foundation of the lithography technology. Depending on the desired product, this process can provide an accurate duplicate. These approaches are divided into subclasses according to the system used, including the power supply and substrate. The most widely used lithography techniques include electron-beam lithography, soft lithography, X-ray lithography, photolithography, or optical lithography, and nanolithography.[26]



“Fig.13 “Lithography technique coating process [26]

2.16 Templating Technique

The production process of moulding and templating are essentially the same. Using a master template as a starting point, this process creates a replica using moulds that may be removed to achieve the appropriate surfaces. Although this process is less expensive, it requires more time and can only be used with a limited amount of materials.

2.17 Hydrothermal Method

One inexpensive, repeatable, and eco-friendly technique for creating a nonstructural feature in-situ on a range of metal substrates is the hydrothermal approach. This method of developing nanostructures on metal surfaces is especially effective at trapping air because it increases surface roughness at the nano-level.

“Table 1”. Several methods for creating hydrophobic surfaces have been published in the literature.

Manufacturing Process	**Remarks**	**Ref**
Separation of phases	A material is extracted from a matrix..	[25].
Plasma technique	Utilising material processing based on plasma technologies, a surface's physicochemical composition can be changed.	[24]
Method for controlling crystallisation	creating a crystal by highly structuring an arrangement of atoms or molecules.	[27].
Moist chemical reaction	An appropriate reagent-to-reagent chemical reaction that results in the formation of a solid phase	[29].
Electrochemical deposition	Electrolysis deposition is the process of applying a thin coating of salt, metal, or oxide to a surface.	[29] ,[30]
Method Template	Generating a surface texture by using a different surface as a negative template.	[31],[32].
Emulsion	Using emulsifying agents to stabilize an unstable dispersion system's dispersion.	[33]
Carving	Achieving the optimum surface by eliminating superfluous substance containing potent acids or	[34]

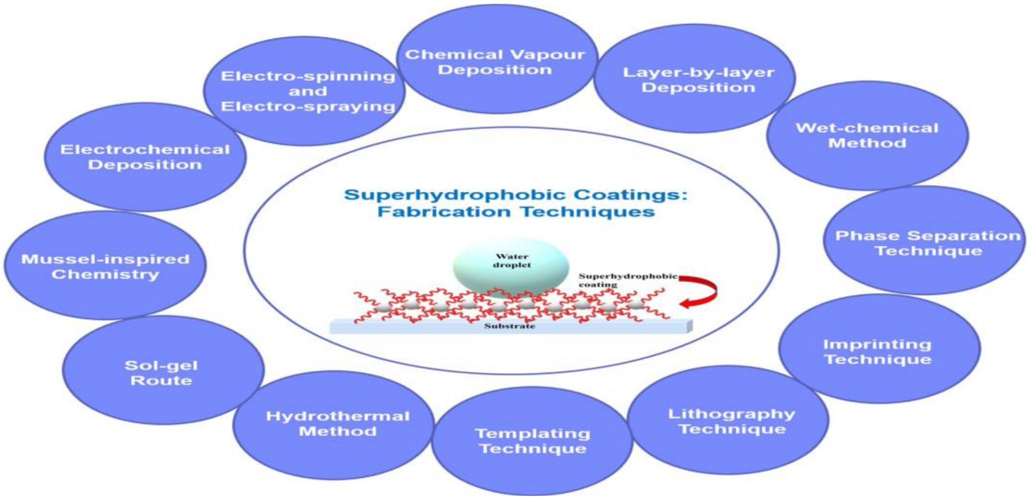
	mordants	
Sol-gel	The method of transferring colloidal fluid's (nm) particles to an already-existing surface.	[35], [36]
Immersion of the solution	Thin film fabrication largely in the liquid phase while taking into account key parameters such as reactant molar ratio, reaction duration, and temperature.	[37]
Chemical vapor deposition	A chemical process in the vapour phase deposits a solid on a surface that is hot.	[38],[39],[40]
Improved coatings that withstand corrosion	By making the surface incredibly hydrophobic, anti-corrosion coatings may be able to be formed by blocking substrate-moisture interaction.	[41],[42]
Coatings that are antireflective and transparent	For synthesis, an optically transparent and extremely hydrophobic polymer is required.	[43],[44]
Coverings that resist freezing and snow	Because of this, super hydrophobic coatings with extremely water-resistant qualities must be used.	[45]

“Table 2” . The benefits and drawbacks of hydrophobic surface preparation techniques

Procedures for	Benefits	Negative aspects	Ref

Preparation			
Sol-Gel	Surfaces with complexities	Breakability	[46]
Cold Spray	little oxidation, little degradation	High energy consumption	[47]
(CVD)	Controllable coating thickness of high quality surfaces with complexities	High temperature High cost	[48]
Deposition of physical vapour (PVD)	Superior layering Ideal for nearly inorganic substances Eco- friendly technique.	Low temperature High pressures or vacuums are necessary.	[49]
Thermal Spray Technique	There are numerous coating materials available a w ide range of substrates low price.	Difficult to prepare thick coating Low adhesion with complex surface	[50]
Polymerization in-situ	Devoid of impurities Polymers that are insoluble can be used. Miscibility is very high.	Complex processes High cost	[51]
Spin-coating	Coating of superior quality Quick dry .Thickness controllable	Small surface Smooth surface	[52]

Dip-coating	Complex surface Industrial scale Materials reusable.	Large amount of solvents Only for polymers that are soluble	[53]
Electrodeposition	Coating of superior quality Concerns about the environment Low price Manufacturing procedure is straightforward.	Environmental issues. Time consuming.	[54]



“Fig.14” The fabrication procedures for superhydrophobic coatings are depicted schematically.[55]

“Fig.15” Super hydrophobic coatings/films/surfaces possible uses[56]

3. Various Materials for Coating

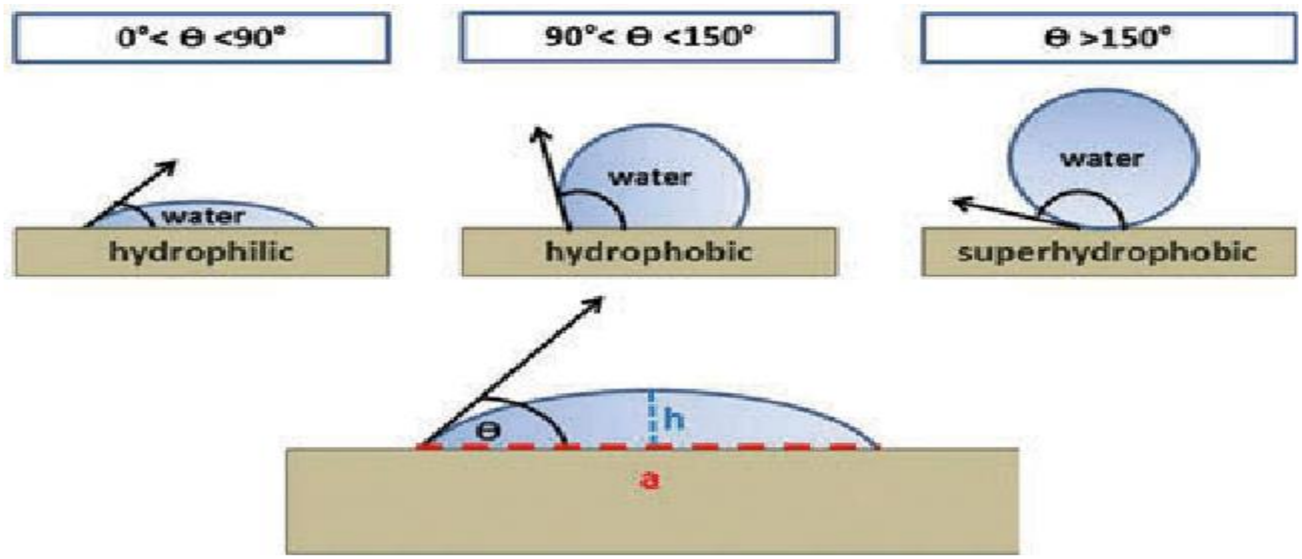
“Table 3”.Different coating materials and contact angles are used.

Coating Material	Contact Angle (degree)	Application
Poly(methylpropenoxyfluoroalkylsiloxane)	105	sealants, adhesives,
Poly(tetrafluoroethylene)	110	non-stick coating in kitchen cookware trays, etc.
Octadecanethiol	117	enhance abrasion
Perfluoroeicosane	122	highly resistant to corrosion,
Silicone	95° to 110°	resistance to heat, flame,
Acrylic	70.4 ± 0.3°	fossil fuel-based fiber.

Polyurethane	100° and 126°	enhance abrasion resistance and durability
PVC.	80°	highly resistant to corrosion, abrasion, pressure,
Phenolic	85° to 90°	immersion service for most acids, solvents, and salts
Glass	27.96	glass, stainless steel, ceramics, acrylics, wheels, and painted
Silicon	42.02	Silicone based Resins, Resin Hybridization Agents
Closed PAA	50.85	pharmaceuticals, cosmetics and paints
Solid alumina	102.83	thermal or electrical insulation
Inkjet paper	119.90	Glass bottle printing. Plastic bottle printing
FOTS on silicon	120.10	cosmetics and paints
Open PAA	46.20	pharmaceuticals, cosmetics and paints
PDMS	125.50	hair conditioners, polishes, cosmetics, damping fluids, and heat transfer fluids

Teflon	128.40	coating in non-stick cookware products such as pots and pans.
Alumina powder	144.50	abrasives and catalysts.
Black soot	154.60	pigment for inks and dyes
Copper	72.15	cookware products
Nickel sulfate	<90	steel alloys such as stainless
Chromium(III) oxide:	151	edges of knives, razors,
Aluminium(III) oxide	159	refractories, ceramics, polishing and abrasive applications
Chromium-rich pyropes	<60 degrees	corrosion resistant superalloys, nichrome, and stainless steel.
Titanium dioxide	129°	food coloring, toothpaste, face powder, inks, coatings, and papers
Zinc oxide	153°	dietary supplements, lubricants, rubbers, plastics, ceramics, glass, and cement
Iindium(III) oxide	115^0	some optical coatings, and some antistatic coatings.
Lead(II) oxide	114.6^0	lead-based industrial glass and

		industrial ceramics,



“Fig.16” Contact angle range from hydrophilic to super hydrophobic [12]

4. Required Properties for Coating

4.1 Elastic modulus and hardness tests

A nano indentation was used to determine the mechanical characteristics of materials in a small area. Mechanical characteristics were used to examine the elastic modulus and hardness of an aluminium oxide coating and an aluminium alloy substrate in a cross-sectional specimen. Elastic Modulus for AlO3 300GPa (lb/in2x106) and hardness 5500MPa.[57].

4.2 Density and thermal analysis

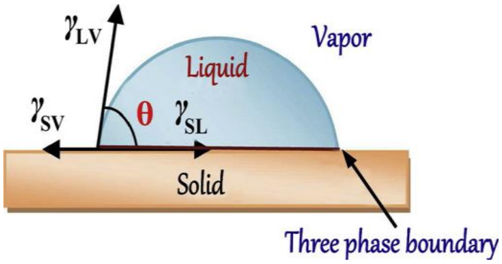
The density for aluminum oxide is 3.95g/cm3. Although Al_2O_3 is an electrical insulator, it possesses reasonably high heat conductivity for a ceramic material (30W/mK). [58]

4.3 Thermal cycling test

Thermal Cycling Testing Assures Your Equipment meets the necessary Standards. Our engineers test for thermal protection and water resistance. Also called a heat-dunk test, the thermal cycling test procedure heats the assembly to 180 degrees Celsius and then immediately dunks it into water.[59]

4.4 Wetability

Because both the adsorption and the wetting phenomena are caused by interactions between molecules of various substances, they are extremely similar. The liquid will spread across the solid's surface if the liquid molecules make greater contact with the solid's surface than the liquid does. We call this phenomena the wetness phenomenon.[60]

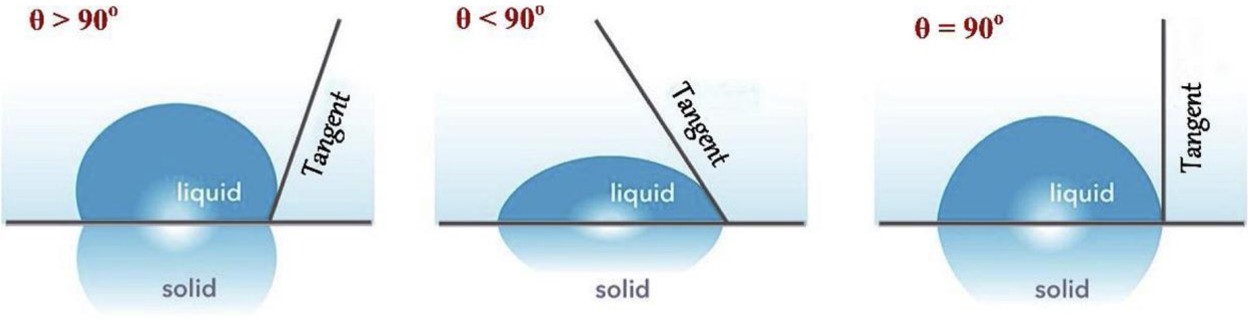


“Fig. 17”. Forces operating at a liquid's three-phase contact line with a solid surface [60]

4.5 Contact angle

The contact angle (CA) is the angle that forms between a droplet's edge and a solid surface. The CA of a liquid droplet determines both its surface tension and surface energy. The value is determined by the tangent of the liquid droplet at the solid phase surface at the three-phase boundaries and the solid, liquid, and gas phase contact point.[61]

The perimeter of a liquid droplet is defined by the limits of the three phases that make up the three separate interfaces—S-L, S-G, and L-G—solid (S), liquid (L), and gas (G), also referred to as the vapour phase. Thomas Young defined the equilibrium conditions on a perfect smooth surface in the following manner in 1805. $\gamma SG = \gamma LS + \gamma LG \cos \theta$.



“Fig.18”. Variations in a liquid drop's wetting surfaces on a smooth solid surface according to its Young's equation radius[61]

4.6 Surface roughness

Surface form and roughness can improve the materials' super hydrophobic behaviour. The super hydrophobic effect can be described using two surface roughness hypotheses. They hypothesised in the first model (the Wenzel model) that when the droplet penetrated the asperities, the surface contact area grew.

To avoid a large established contact with the support, the droplet compresses, increasing the contact angle. According to the Cassie-Baxter model, the droplet sits on top of the asperities that form the interface between the solid-liquid and solid-gas interfaces.

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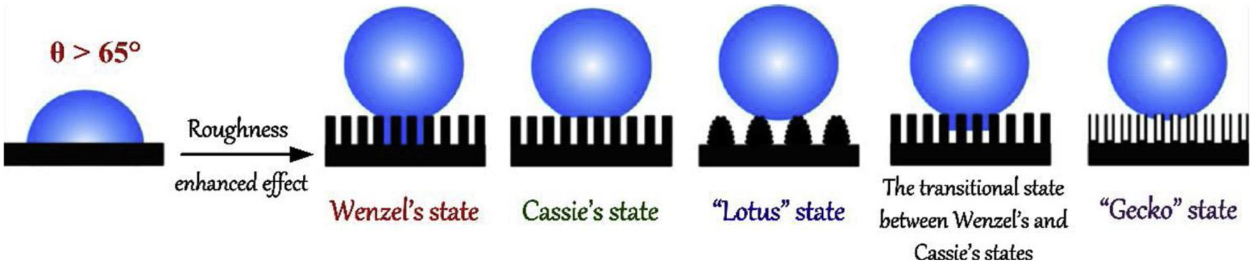

"Fig.19". Water droplets in various stages on a solid surface [62]

4.7 Energy and tension on the surface

Surface energy is the amount of energy required to enhance the interface between two different phases of a surface unit without changing their volume. The environment of volume is different from that of molecules close to the surface. In contrast to the bulk phase, they come into contact with fewer molecules. Higher potential energy molecules are found on the surface. To minimise the zone of higher energy, solids seek to shrink their surfaces .The liquid droplet that has the least surface area/volume ratio is spherical in shape. Surface tension and surface energy, in general, share the same dimension.[63]. Aluminium oxide has a specific surface energy of 0.90 J per square metre. Modulus of elasticity of aluminium oxide is 393 GPa.[59]

4.8 Visual (outward appearance)

The property of objects to reflect and transmit light determines their visual appearance. The portions of the (incident white) light spectrum that are reflected or transmitted but not absorbed determine the colour of an item. It exists as a solid and has a white appearance. It is water insoluble and odourless. This substance is most frequently found as corundum, also known as aluminium oxide, in crystalline form.

4.9 Immersion (Elevated & Reduced Temperature)

Epoxy-based coatings are commonly used for immersion grade applications. Water and other liquids cannot seep through the epoxy's densely packed, incredibly sealed layer and reach the foundation material. Pure aluminum melts around 1200° F, but aluminum oxide melts around

3600° F. If the aluminum oxide layer is not removed before welding, it causes the molten aluminum to become contaminated, which weakens the weld.[58]

4.10 Temperature & Humidity Exposure

The temperature decreases from 273 K to 373 K as a result of this increase. This indicates that when temperature rises, the range of "attractive" forces in the hydrophobic phase increases and the range of "repulsive" forces in the first solvation process diminish. The beginning of slow oxidation was seen at an oxidation isotherm of 750 °C, and after roughly an hour of exposure to air, a steady mass rise with an initial acceleration occurred at 850 °C.[64]

4.11 Salt Spray/Fog for Corrosion Resistance

Salt spray experiments are carried out in a sealed testing chamber. A sample is treated with a salt water solution using a spray nozzle. This dense fog of salt water simulates an experiment with corrosion. After a period of time determined by the product's resistance to corrosion, the appearance of oxides is inspected. Conversely, aluminium is incredibly corrosive. In contrast, aluminium oxide corrosion is caused by an incredibly hard substance that actually protects the metal from further corrosion. Additionally, aluminium oxide corrosion is less obvious than rusted iron since it resembles aluminium more (dull grey to powdery white in appearance).[65]

4.12 Refractive Index

The ability of an optical medium to bend light is indicated by its refractive index, a dimensionless number in optics. How much light is bent, or refracted, as it penetrates a material is described by the refractive index. At 632.8 nm, the extinction coefficient and refractive index of a typical sample of $Al2O3$ are 1.77 and 0, respectively.[66]

4.13 Glass Transition Temperature (Tg)

The temperature at which glass transitions (Tg) occurs is known as which molecular mobility begins to occur; below this temperature, molecular movement freezes and the elastomer becomes rigid and glassy. An elastomer's chemical structure determines its Tg. It is demonstrated that the copper-aluminum melt has a glass transition temperature of approximately 500 K. Additionally displayed are the results for pure aluminium at a temperature of about 600 K.[67]

4.14 Thermal Stability

Thermal stability is an important design feature for engineering materials that are employed at high temperatures. It is described as an alloy's resistance to ductility and toughness degradation when subjected to long-term thermal exposure. The γ-Al2O3 polymorph is stable at low treatment temperatures, below approximately 700–800 °C [10]. At temperatures above 800°C during heat treatment, the γ-Al2O3 top strategically changes into δ- and θ-Al2O3.[68]

4.15 Dielectric Strength

The electrical strength of an irritating material is characterised as dielectric strength. In a sufficiently powerful electric field, an insulator's insulating characteristics degrade, permitting the direction of charge flow. The maximum voltage needed to induce a dielectric breakdown through a material is used to compute dielectric strength. Regarding Al2O3, the dielectric breakdown happened between 4 and 5 MV/cm, and for the SiO2, it happened close to 10 MV/cm.[69].

4.16 Dielectric Constant

A material's ability to store electrical energy is gauged by its dielectric constant. It measures the degree to which a substance concentrates or retains electrical flux. The dielectric constant is the ratio of a material's permittivity to that of free space. The dielectric breakdown was in the 4–5

MV/cm range. Frenkel-Poole emission, which has the peculiar property of lowering the current at higher temperatures, was identified as the conduction mechanism by analysing the temperature dependence of the current versus electric field.[70].

4.17 Factor of Dissipation

The reciprocal of the capacitive reactance to resistance ratio of an insulating material at a certain frequency is known as the dissipation factor. It assesses an insulating material's inefficiency.[71]

4.18 Solder-through Capability

Through-hole, often known as through-hole soldering, is a method of mounting components to a PCB utilizing physical leads. The name comes from the fact that these leads are connected through holes bored into the circuit board. To retain the component in place, the leads are soldered to the opposite side of the board.[72]

4.19 UV Exposure

UV coating, also known as ultraviolet coating, is a glossy, transparent liquid coating that is applied to printed goods. This is a popular printing technique for safeguarding objects that are frequently touched during delivery. This kind of coating is applied at an average rate of Respirable dust is 5 mg/m3, and total dust is 15 mg/m3 during the course of an 8-hour workshift.[73]

4.20 Moisture & Insulation Resistance (MIR)

Moisture insulation Resistance (MIR) is the conformal coating's insulation resistance when exposed to high temperatures and humidity. A low MIR conformal coating may not be suitable for protecting a circuit board in a high moisture environment. The resistivity of aluminium varies between 2.65 and 2.82 × 10−8 Ω•m.[74]

4.21 Optical reflectance

The reflectance of a surface or optical device specifies how much light is reflected from it.. The amount of light that is projected onto a surface is equal to the product of the incident and reflected powers. How much light is transferred from a surface or optical device is determined by its transmittance. An antireflection (AR) coating can be produced by lowering surface reflection coefficients to less than 0.2%. On the other hand, a high-reflector (HR) coating can be created by increasing the reflectivity to higher than 99.99%. One option for mid-index coating materials is aluminium oxide (alumina, Al2O3), which is usually used in the 7000 to 200 nm wavelength range .[75]

4.22 Optical absorbance

The logarithm of the radiant power ratio passing through a sample from incident to transmitted is defined as absorbance. Properties of light The phrase "optical properties" refers to a variety of pigment characteristics such as scattering power, whiteness, lightening power, shade or hiding power, which are frequently reinforced by pigmented coating properties such as gloss and haze of gloss. The Ti:Al2O3 single crystal exhibits a A band of modest infrared absorption with a peak at 650 nm,

two big double-structured absorption peaks at 491 and 562 nm, and a substantial ultraviolet

absorption band at 234 nm.[76]

4.23 Hardness

The hardness of thick film coatings (the method states "thick film" is considered a minimum of 6 mm or 240 mils) is commonly assessed using an indentor-type tester that measures the resistance to indentation under a certain spring force load, whereas thin film coatings are measured using a tensile tester that measures the resistance to tensile load. While the theoretical The highest Vickers hardness of 780.4 Hv (7.65 GPa) is reached by alumina ceramic (99.0% Al2O3), with a Vickers hardness of almost 10 GPa.[77]

4.24 Flexure rigidity

The ability of a coating material to bend is denoted by its Flexural Modulus. When a force is applied perpendicularly to a coating, it measures its stiffness/flexibility. Flexural strengths of Al_2O_3/epoxy composites and sintered porous Al_2O_3 ceramics increased fast as Al_2O_3 content was increased. Flexural strength, for example, increases from 121 to 305 MPa when Al_2O_3 concentration is increased by 55%-70%.[78].

5. Conclusion and Future Scope

An overview of the literature is given in this review study on hydrophobic nanocoatings with aluminium oxide. Following that, a detailed overview of coating preparation processes and major areas of application of hydrophobic coatings is offered. Future research should concentrate on improving the endurance of hydrophobic coatings, particularly in the application of hydrophobic to superhydrophobic resistance.

An extensive discussion of various fabrication methods, such as electrode position method, various coating techniques for dip coating technique, Methods of electrospinning, sol-gel, chemical etching, and electrochemical deposition, lithography technique, imprinting technique, layer by layer deposition, phase separation method, hydroothermal method, and chemical deposition methods, was conducted. These coatings are also used to make waterproof fabrics in the textile sector. Various contact angle measurements are taken for various nonmaterials used for coating.Different physical ,thermal ,electrical properties of aluminum oxide nonmaterial is discussed like Hardness and elastic modulus measurements thermal cycling test, density and thermal analysis ,wet ability Contact angle ,Surface roughness ,Surface tension and surface energy Visual (appearance) , Exposure to Temperature and Humidity, Salt Spray/Fog for Corrosion Resistance, Refractive Index, Thermal Stability at Glass Transition Temperature, Moisture resistance, UV exposure, solder-through capability, dissipation factor, dielectric strength, and dielectric constant and Insulation Resistance are all important considerations. Optical reflectance, Optical absorbance, Hardness and flexure rigidity. The overview of the above discussed paper is to provide gist for importance of aluminum oxide in hydrophobic coating to super hydrophobic application along with various materials for operation.

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