Scratch and mar resistance of PU/Al_2O_3 on automotive clearcoats

By

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Scratch and mar resistance of PU/Al_2O_3 on automotive clearcoats

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Dedication

I dedicate this thesis to my Respected Parents and wife.

Acknowledgment

All gratitude and praises are to **Allah Almighty**, the Most Gracious and the Most Merciful.He is the entire source of knowledge and wisdom to mankind, who gave us health, and thoughts, and capacitated us to achieve this goal. After Almighty Allah, praises are to His **Prophet Muhammad (S. A.W.),** the most Perfect and Exalted, and an everlasting sourceof Guidance and Knowledge for humanity.

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Abstract:

In this study, polyurethane was combined with experimentally synthesized nano-alumina particles to form coatings. Nano alumina was synthesized by the sol-gel method. The polyurethane's scratch and abrasion resistance was greatly increased by the inclusion of nano-alumina, making it appropriate for use in automotive applications. The appropriate dispersion and functionalization of nano-alumina particles inside the polyurethane matrix were achieved by careful consideration of the coating's production process, which was detailed in detail. The properties and efficiency of the nano-alumina coatings were confirmed using a variety of characterization techniques, including XRD, FTIR, SEM, and contact angle analysis. XRD analysis showed the formation of nano alumina by specific peaks and card number was matched using expert high score. In comparison to non-functionalized particles, the research findings showed that functionalizing nano-alumina with stearic acid improved stability, hydrophobicity, and scratch resistance. XRD and FTIR data showed successful functionalization of nano alumina with steric acid. When used on a mild steel substrate, the resulting polyurethane-nano alumina coating showed good dispersion and greatly increased abrasion resistance and water repellency. The scratch tests revealed that the coating offered reliable defense, particularly against fine abrasives. The successful incorporation of the nanoparticles was confirmed by the SEM examination, which produced visible proof of the uniform distribution of nano-alumina particles within the polyurethane matrix. The well-adhered and compact coating structure was also visible in the SEM images, demonstrating the close interfacial bonding between the polyurethane and functionalized nano-alumina.

Keywords: Coatings, Nano alumina, Polyurethane, Hydrophobicity, Scratch Resistance.

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Chapter 1:

1 Introduction

Coatings play an essential role in modern society, serving as protective layers applied to various surfaces to enhance their performance, aesthetics, and durability. From buildings to electronics, vehicles to medical devices, coatings are omnipresent in our daily lives. This essay delves into the world of coatings, exploring their definition, types, applications, and the crucial reasons why they are indispensable in diverse industries.

Coatings, in a general sense, refer to a layer or film applied to a substrate to provide specific properties or functionalities. These coatings can be classified into three primary categories: protective, decorative, and functional coatings. Each type serves distinct purposes, and the selection of the appropriate coating depends on the desired outcome and the nature of the substrate.[1]

Coatings are essential components in a wide range of industries, offering protection, aesthetic enhancements, and improved functionalities to various surfaces and materials. The significance of coatings extends beyond the superficial appearance and contributes significantly to the longevity, efficiency, and sustainability of products and structures. As technology advances and environmental concerns grow, the development of innovative coatings will continue to play a pivotal role in shaping a safer, more durable, and aesthetically pleasing future.[2]

1.1 Types of Coatings:

1.1.1 Protective Coatings:

These coatings are designed to safeguard substrates from various environmental factors, such as corrosion, abrasion, chemical exposure, and UV radiation. Protective coatings are commonly used in industries like automotive, marine, aerospace, and construction, ensuring the longevity and reliability of coated objects.[3]

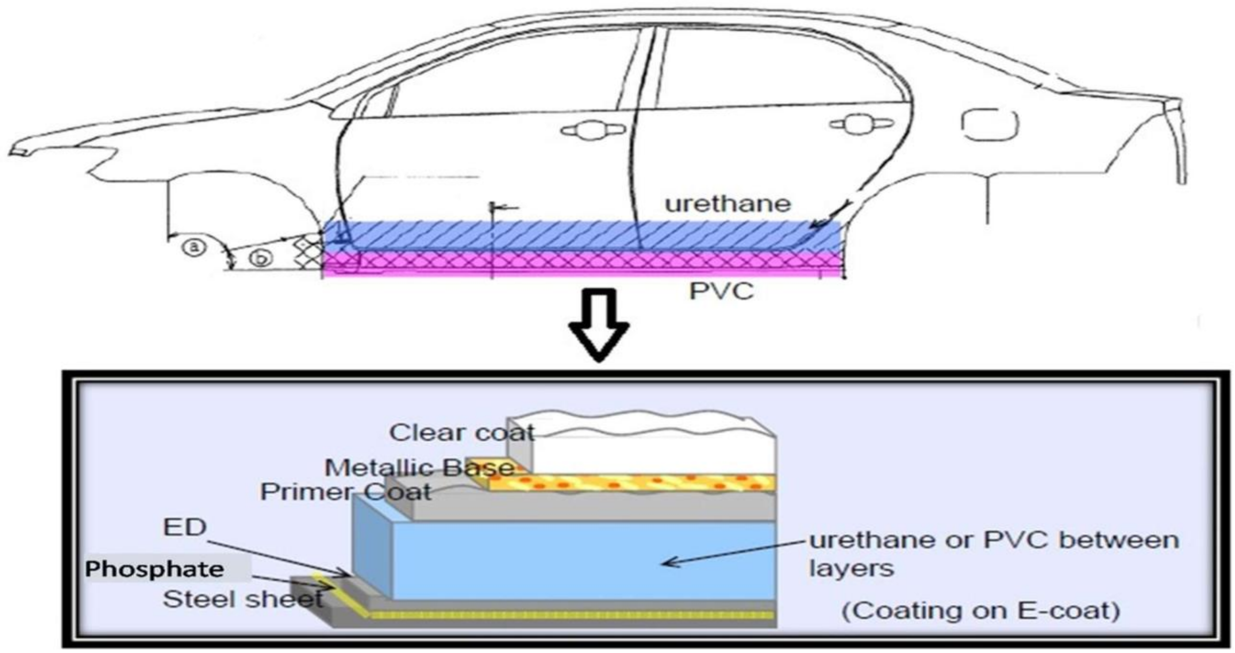

Figure 1.1 Protective paint process for automotive body

Protective coatings are a specialized type of coating designed to shield substrates from a wide range of environmental threats and extend their service life. These coatings act as a barrier between the substrate and the external environment, protecting the underlying material from deterioration and damage caused by factors such as corrosion, abrasion, chemical exposure, and UV radiation.

1.1.1.1 Corrosion Protection:

Corrosion is a natural electrochemical process that occurs when metals react with their surroundings, leading to their gradual degradation. Protective coatings, particularly in industries like automotive, marine, and aerospace, are crucial in preventing or mitigating the effects of corrosion.[4]

For example, in the automotive industry, vehicles are frequently exposed to harsh weather conditions, road salts, and moisture, which can lead to corrosion of metal components. By applying protective coatings to the metal surfaces, the coating forms a barrier that prevents corrosive substances from reaching the metal, thus reducing the risk of rust and corrosion-related damage.

Similarly, in the marine industry, where structures and vessels are constantly exposed to saltwater, protective coatings provide an essential line of defense against the corrosive effects of seawater and the marine environment. Without adequate protection, ship hulls, offshore platforms, and other marine structures would suffer from accelerated corrosion, compromising their structural integrity and safety.[5]

1.1.1.2 Abrasion Resistance:

Abrasion occurs when a surface is subjected to repeated friction or rubbing, leading to the wearing away of material over time. Protective coatings with abrasion-resistant properties are employed in industries where surfaces are susceptible to wear, such as manufacturing equipment, mining machinery, and construction tools. In manufacturing processes involving metal-to-metal contacts, such as in the production of steel or aluminum products, wear-resistant coatings help reduce the wear rate and extend the lifespan of critical components. This results in lower maintenance costs and less frequent replacement of parts, improving overall operational efficiency and productivity.[6]

1.1.1.3 Chemical Resistance:

In industries where materials are exposed to aggressive chemicals, protective coatings with chemical resistance properties are vital to preventing chemical reactions and material degradation. Chemical exposure can lead to surface deterioration, structural damage, and compromised performance of equipment and infrastructure.[7]

For instance, in the chemical processing industry, where corrosive chemicals are commonly handled, equipment such as storage tanks, pipelines, and reactors are coated with chemically resistant coatings to safeguard against chemical attacks and leaks. Likewise, in laboratories and medical facilities, protective coatings are used on surfaces and equipment to prevent chemical spills and ensure the safe handling of hazardous substances.[8]

1.1.1.4 UV Radiation Protection:

Ultraviolet (UV) radiation from the sun can cause photodegradation and fading of materials, particularly in outdoor applications. Protective coatings with UV-resistant properties are used in various industries to preserve the appearance and functionality of coated objects.[9]

In the construction industry, buildings and infrastructure exposed to direct sunlight require UV-resistant coatings on their surfaces to prevent color fading, surface chalking, and material degradation. Moreover, in the automotive sector, vehicles with outdoor exposure need UV protection to prevent damage to paint, plastics, and other exterior components.[10]

Protective coatings play a vital role in safeguarding substrates from environmental factors that can compromise their integrity and performance. By providing a protective barrier against corrosion, abrasion, chemical exposure, and UV radiation, these coatings ensure the longevity and reliability of objects in industries like automotive, marine, aerospace, and construction. In essence, protective coatings serve as a defense mechanism, allowing industries to maintain the quality and durability of their products and infrastructure, leading to enhanced safety, reduced maintenance costs, and increased operational efficiency.

1.2 Decorative Coatings:

As the name suggests, decorative coatings are used primarily to enhance the appearance and aesthetics of surfaces. They are widely employed in architecture, interior design, and artistic endeavors to add color, texture, and patterns to objects.

Decorative coatings are a diverse and creative category of coatings, specifically formulated to elevate the visual appeal and aesthetic qualities of surfaces. As the name implies, these coatings serve a primarily decorative purpose, transforming mundane objects into visually striking works of art. Their versatility and capacity to add color, texture, and patterns make them indispensable in a multitude of industries, including architecture, interior design, and artistic endeavors.

1.2.1.1 Architecture:

In the field of architecture, decorative coatings are extensively used to beautify buildings' exteriors and interiors, giving them distinct and captivating appearances. One of the most common applications is in exterior facades, where decorative coatings can emulate natural textures such as stone, wood, or marble, adding a touch of elegance to the building's appearance without the expense of using actual materials.[11]

Additionally, decorative coatings can be customized to complement the architectural style or historical significance of a building, allowing for the restoration and preservation of heritage structures. The ability to replicate intricate architectural details or create artistic murals on walls adds a unique charm to buildings, making them stand out in their surroundings.[12]

1.2.1.2 Interior Design:

Decorative coatings play a pivotal role in interior design by transforming ordinary spaces into extraordinary ones. These coatings provide interior designers with a vast array of options to experiment with color schemes, textures, and finishes, allowing them to create personalized environments that reflect the preferences and personalities of the occupants.

For instance, decorative wall coatings, such as textured paints, metallic finishes, or even digitally printed wallpapers, can elevate the visual impact of a room. They can add depth, warmth, and character to otherwise plain walls, turning them into focal points that tie the entire interior design together.

Furthermore, decorative coatings extend beyond walls and can be applied to ceilings, furniture, and fixtures, enhancing the overall ambiance and atmosphere of a space. For example, a ceiling adorned with decorative coatings can add a sense of height and grandeur to a room, while furniture with decorative finishes can contribute to a cohesive design theme.

1.2.1.3 Artistic Endeavors:

Artistic endeavors benefit greatly from decorative coatings, as they open up new possibilities for creative expression. Artists, whether painters, sculptors, or craftsmen, often incorporate decorative coatings into their works to achieve specific visual effects and aesthetics.

In traditional painting, artists may utilize specialized decorative paints, such as metallic or pearlescent finishes, to impart luminous and reflective qualities to their artworks. In sculpting, coatings with different textures can be applied to create lifelike representations of surfaces like skin, fur, or stone.

Furthermore, decorative coatings find applications in various crafts and DIY projects, allowing individuals to personalize and embellish everyday objects with creative designs. Whether it's upcycling furniture, customizing household items, or creating unique art pieces, decorative coatings offer an accessible and versatile medium for artistic expression.

Decorative coatings are essential components of modern design and artistic expression. Their ability to enhance the appearance and aesthetics of surfaces, along with their versatility in replicating textures and creating visual effects, makes them indispensable in architecture, interior design, and various artistic endeavors. From transforming the facades of buildings to adding a touch of elegance to interiors, and from enabling creative expression in artworks to empowering DIY enthusiasts, decorative coatings continue to inspire and elevate the visual landscape of our world. Their role in making spaces and objects more visually appealing and aesthetically pleasing remains invaluable in enhancing our daily experiences.

1.3 Functional Coatings:

These coatings are engineered to modify specific properties of the substrate, such as conductivity, adhesion, or magnetic behavior. Functional coatings find applications in electronics, optics, and medical devices, contributing to advancements in technology and innovation.

Functional coatings represent a specialized class of coatings engineered to modify specific properties of the substrate they are applied to. Unlike protective or decorative coatings, which primarily focus on surface protection or aesthetics, functional coatings serve as a means to enhance or introduce new functionalities to coated materials. These coatings play a crucial role in various industries, particularly electronics, optics, and medical devices, where precise control of material properties is essential for technological advancements and innovations.[13]

1.3.1 Electronics:

In the electronics industry, functional coatings are instrumental in enhancing the performance and reliability of electronic components and devices. One of the most common applications of functional coatings in electronics is in the realm of printed circuit boards (PCBs). PCBs are vital components used to interconnect electronic components in most electronic devices.[14]

Functional coatings are applied to PCBs to improve their conductivity and protect them from environmental factors such as moisture, dust, and contaminants. For instance, the application of a conformal coating on a PCB provides a thin protective layer that conforms to the board's contours, safeguarding delicate electronic circuits from adverse conditions. These coatings may be insulating or conductive, depending on the specific requirements of the circuit design.

Additionally, functional coatings are used in the manufacturing of electronic displays, such as LCDs and OLEDs, to enhance their optical properties, reduce glare, and improve viewing angles. Anti-reflective coatings are employed on glass surfaces to minimize reflections and maximize light transmission, resulting in clearer and more vibrant displays.

Optics:

In the realm of optics, functional coatings play a pivotal role in manipulating light to achieve specific outcomes. Coatings are applied to optical components such as lenses, mirrors, prisms, and filters to alter their optical properties and performance.

For instance, anti-reflective coatings are commonly used on lenses to reduce unwanted reflections and glare, thereby improving the clarity and contrast of images seen through the lens. These coatings are prevalent in eyeglasses, camera lenses, and other optical devices.

Another critical application is the use of dichroic coatings on optical filters, which enable selective wavelength transmission and reflection. These coatings are used in various devices, including spectroscopy equipment, laser systems, and telecommunications devices.

1.3.2 Medical Devices:

Functional coatings play a significant role in medical devices and implants, where biocompatibility and tailored surface properties are essential for successful integration with the human body. For example, orthopedic implants, such as joint replacements, are often coated with biocompatible materials to encourage bone integration and reduce the risk of rejection or adverse reactions.[15]

Drug-eluting coatings are another example of functional coatings used in medical devices. These coatings are designed to release therapeutic substances in a controlled manner, providing localized treatment at the site of the medical device's implantation. Drug-eluting stents, for instance, release medications to prevent restenosis (re-narrowing) of arteries after a coronary angioplasty procedure.

Functional coatings represent a cutting-edge area of material science and technology, focusing on modifying substrate properties to achieve specific functionalities. Their application in electronics, optics, and medical devices has led to significant advancements in technology and innovation, enabling more efficient, reliable, and sophisticated products. From enhancing the conductivity and reliability of electronic components to improving optical performance and achieving biocompatibility in medical devices, functional coatings continue to drive progress and shape the landscape of modern industries.

1.4 Importance of Coatings:

The significance of coatings extends far beyond mere surface protection or appearance enhancement. Several key factors underscore the importance of coatings in various industries:

Coatings, in their various forms, play a crucial role in modern society, influencing a multitude of industries and aspects of our daily lives. From protecting infrastructure against environmental degradation to enhancing the performance of cutting-edge technologies, coatings offer a range of benefits that contribute to the longevity, efficiency, and aesthetics of objects and structures. This essay delves into the significance of coatings, exploring their role in safeguarding surfaces, improving functionalities, and adding aesthetic value.[16]

One of the primary reasons for the importance of coatings lies in their ability to protect against a wide range of environmental factors. Protective coatings are specifically designed to shield substrates from threats such as corrosion, abrasion, chemical exposure, and UV radiation.

Corrosion, a natural process that leads to material deterioration, is a significant concern in industries like construction, marine, and automotive. Corrosion-resistant coatings act as barriers, preventing corrosive agents from reaching the substrate and ensuring the longevity and reliability of coated objects.[17]

Similarly, coatings with abrasion-resistance properties are vital in industries where surfaces are subject to wear, such as manufacturing and mining. These coatings reduce material loss, extending the lifespan of critical components and reducing maintenance costs.

Chemical-resistant coatings find applications in environments where materials are exposed to harsh chemicals, such as chemical processing plants and laboratories. By safeguarding against chemical attacks and spills, these coatings contribute to safety and operational efficiency.

UV-resistant coatings are essential for preserving the appearance and functionality of objects exposed to direct sunlight. Buildings, vehicles, and outdoor equipment benefit from UV protection preventing color fading and surface degradation caused by UV radiation.

Coatings also play a vital role in improving the performance and functionality of various materials and products. Functional coatings are engineered to modify specific properties of substrates, such as conductivity, adhesion, and magnetic behavior.

In the electronics industry, functional coatings enhance conductivity and protect sensitive electronic components from environmental factors. PCBs and electronic displays benefit from coatings that improve their performance and reliability.

Optical coatings manipulate light to achieve specific outcomes, such as anti-reflective coatings that improve clarity and contrast in lenses. These coatings find applications in eyeglasses, cameras, and various optical devices.

Medical devices and implants often incorporate functional coatings to achieve biocompatibility and controlled drug release. These coatings promote successful integration with the human body and enable targeted treatments.

1.4.1 Aesthetics and Visual Appeal:

Beyond protection and performance, coatings are instrumental in adding aesthetic value to surfaces and objects. Decorative coatings, as the name suggests, enhance the appearance and aesthetics of various materials, contributing to architecture, interior design, and artistic endeavors.

In architecture, decorative coatings can mimic natural textures and historical styles, adding elegance and character to buildings. These coatings enable creative expression, allowing architects to design unique facades and interior spaces.

Interior design benefits from decorative coatings that create visually appealing environments. Textured paints, metallic finishes, and digitally printed wallpapers enhance the ambiance and atmosphere of living spaces, reflecting personal preferences and design themes.

In artistic endeavors, decorative coatings open new possibilities for creative expression. Artists utilize coatings to achieve specific visual effects, manipulate textures, and create unique works of art in various mediums.[18]

One of the primary reasons for employing protective coatings is to combat corrosion, a natural process that can lead to the degradation of metals and materials. In industries like infrastructure, marine, and oil and gas, where exposure to harsh environments is common, corrosion-resistant coatings are essential to extending the lifespan of structures and equipment. These coatings form a barrier that prevents corrosive agents from reaching the substrate, thereby preserving the structural integrity of the coated components.

Coatings hold immense importance in a wide range of industries and applications, offering protection, enhanced performance, and visual appeal to surfaces and objects. Their role in safeguarding infrastructure, enhancing electronic and optical devices, and contributing to aesthetics underscores their significance in modern society.

From the protection of buildings and machinery against environmental threats to the improvement of electronics, medical devices, and optical equipment, coatings contribute to advancements in technology and innovation. Moreover, their role in enhancing the visual landscape of architecture, interior design, and art adds an aesthetic dimension to our surroundings, enriching our daily experiences.

As technology advances and environmental concerns grow, the development of innovative coatings will continue to drive progress, ensuring a safer, more durable, and aesthetically pleasing future. The importance of coatings in various industries and their impact on our lives make them an indispensable aspect of modern materials science and technology.

1.4.2 Enhancing Durability:

Coatings significantly contribute to the durability and longevity of objects by protecting them from wear and tear. For instance, automotive coatings not only give vehicles their desired appearance but also shield them from scratches, impacts, and environmental pollutants. Similarly, industrial machinery and equipment often undergo heavy usage, making the application of wear-resistant coatings crucial to minimize maintenance and replacement costs.

1.4.3 Energy Efficiency:

Coatings can also play a vital role in enhancing energy efficiency in various applications. In architecture, for example, cool roof coatings with reflective properties can reduce the absorption of solar heat, leading to lower indoor temperatures and decreased energy consumption for cooling purposes. Similarly, energy-efficient coatings are utilized in the manufacturing of solar panels and other renewable energy technologies, contributing to global efforts toward sustainability.

1.4.4 Biocompatibility and Medical Applications:

In the medical field, coatings have revolutionized implant technology. By applying biocompatible coatings, medical devices, and implants can better integrate with the human body, reducing the risk of rejection and inflammation. Moreover, drug-eluting coatings have been developed to control the release of medications from medical devices, ensuring precise and targeted treatment delivery.

1.4.5 Environmental Benefits:

Certain coatings have been formulated to be eco-friendly, reducing harmful emissions and minimizing the environmental impact. Water-based coatings, for instance, have gained popularity as an alternative to traditional solvent-based coatings, as they have lower volatile organic compounds (VOC) emissions, which contribute to air pollution and global warming.

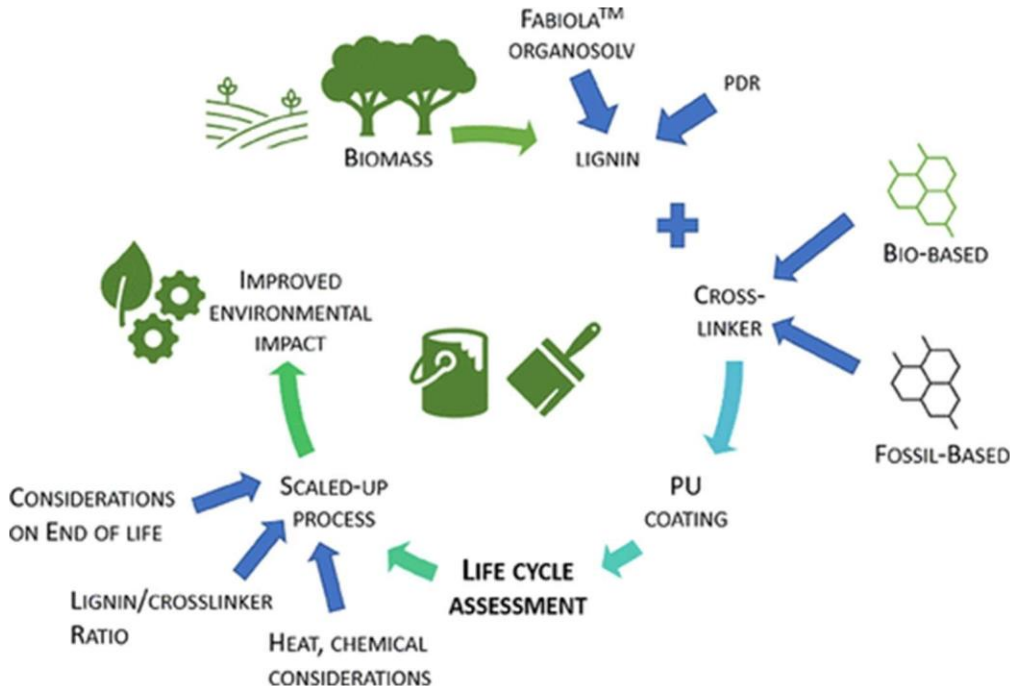

Figure 1.2 Environmental benefits of coatings

1.5 Coatings used in the automotive Industry:

n the automotive industry, coatings play a pivotal role in enhancing the overall performance, appearance, and longevity of vehicles. These protective layers are applied to various automotive components, ranging from the body panels to the engine parts, to shield them from environmental factors such as UV radiation, corrosion, abrasion, and chemical exposure. This essay will explore the significance of coatings in the automotive sector, the methods used for their application, and the materials employed to achieve superior protection and aesthetic appeal.

1.5.1 Corrosion Protection:

One of the most critical functions of automotive coatings is to protect metal surfaces from corrosion. Vehicles are constantly exposed to harsh weather conditions, road salt, and moisture, all of which can cause corrosion over time. Without appropriate coatings, the structural integrity of the vehicle may be compromised, leading to safety hazards and reduced longevity. Coatings create a barrier between the metal substrate and the corrosive elements, ensuring the vehicle's structural integrity and safety.

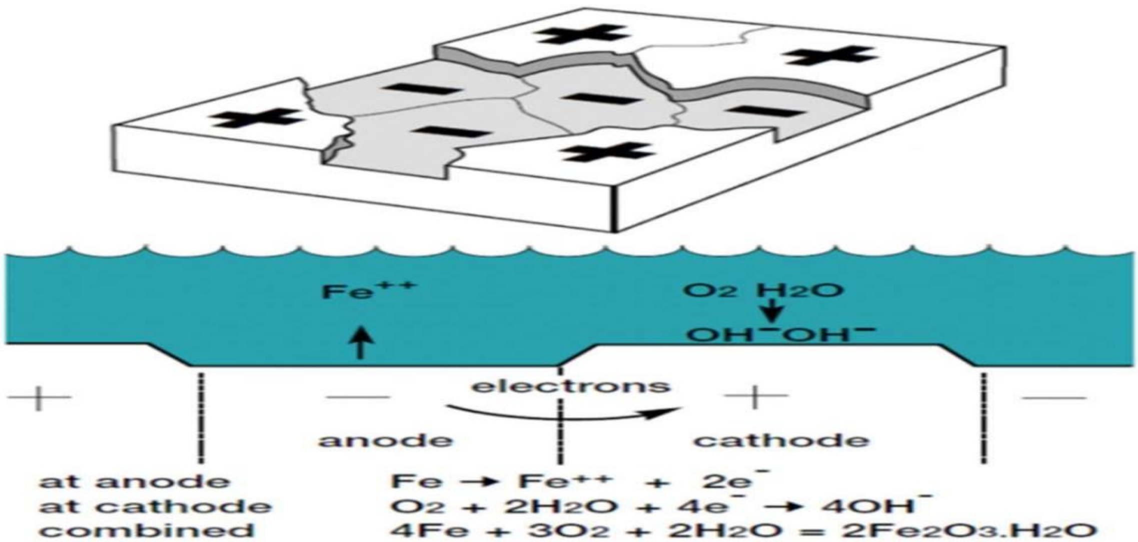

Figure 1.3 Effect of corrosion on automotive body

Its the process of gradual deterioration of metals due to chemical reactions with the environment, which poses a significant threat to the structural integrity and safety of vehicles. As automobiles navigate through varying weather conditions, road debris, and exposure to moisture, the metal surfaces of the vehicle become susceptible to corrosion. Consequently, the implementation of appropriate automotive coatings becomes paramount to safeguarding the vehicle against corrosion-induced damage.

1.5.1.1 Harsh Weather Conditions:

Automobiles are frequently exposed to a wide range of weather conditions, from scorching heat and intense sunlight to freezing temperatures and heavy rain. These extreme weather events can lead to the accumulation of moisture on the vehicle's metal surfaces, creating an environment conducive to corrosion. Without the protection of coatings, the metal can begin to react with the moisture and other corrosive agents present in the atmosphere, resulting in the formation of rust and weakening of the affected components.

1.5.1.2 Road Salt and Chemical Exposure:

In regions where road salt is used to de-ice roads during winter, vehicles are particularly vulnerable to accelerated corrosion. Road salt contains chloride ions, which are highly corrosive to metal surfaces. As vehicles drive over salt-treated roads, the salt particles can adhere to the undercarriage and body of the vehicle. Without proper coatings, the chloride ions can initiate corrosive reactions on the metal, leading to pitting, rusting, and overall structural degradation.

1.5.1.3 Moisture Accumulation:

Moisture is a primary catalyst for corrosion, and automotive coatings act as a vital barrier against its infiltration. As rainwater or condensation accumulates on unprotected metal surfaces, it can seep into tiny crevices, joints, and seams. Over time, the moisture promotes oxidation, and corrosion sets in, weakening essential components such as the frame, suspension parts, and chassis.

1.5.1.4 Structural Integrity and Safety Concerns:

Corrosion compromises the structural integrity of a vehicle, potentially leading to severe safety hazards. Critical components, such as the frame, support structures, and safety-critical parts, can become weakened by corrosion-induced degradation. In extreme cases, corrosion can even lead to the failure of essential parts, compromising the vehicle's ability to protect occupants in the event of a collision.

1.5.1.5 Coatings as Protective Barriers:

Automotive coatings serve as a robust protective barrier, shielding metal surfaces from the harsh effects of the environment. These coatings typically contain anti-corrosion additives that create a chemical resistance against corrosive agents, hindering their ability to react with the metal substrate. By forming a physical barrier, coatings prevent direct contact between the metal and external elements, effectively reducing the risk of corrosion.

1.5.1.6 Longevity and Maintenance Cost:

The presence of effective coatings on automotive surfaces contributes to the vehicle's longevity and reduces maintenance costs. By preventing or delaying corrosion, coatings extend the lifespan of various components, leading to fewer repairs and replacements. This translates to cost savings for vehicle owners over the long term.

In conclusion, the importance of automotive coatings in protecting metal surfaces from corrosion cannot be overstated. With vehicles exposed to harsh weather conditions, road salt, and moisture daily, the application of appropriate coatings becomes imperative to ensure the structural integrity and safety of the vehicle. By acting as a protective barrier, coatings shield metal surfaces from corrosive elements, reducing the risk of rust and degradation. In doing so, they contribute to the longevity of the vehicle and help mitigate maintenance costs, making them an essential aspect of modern automotive manufacturing and maintenance practices.

1.5.2 Aesthetic Enhancement:

Automotive coatings contribute significantly to the overall appearance of vehicles. A well-applied coating gives vehicles a glossy and polished finish, making them more visually appealing to consumers. The aesthetic appeal of a vehicle can influence a buyer's decision, making coatings an essential factor in the automotive industry's marketing strategy.

In the highly competitive automotive industry, aesthetics play a crucial role in attracting potential buyers and influencing their purchasing decisions. Automotive coatings, with their ability to enhance the overall appearance of vehicles, have become a key factor in the industry's marketing strategy. A well-applied coating can transform a vehicle's look, giving it a glossy and polished finish that instantly captivates consumers.

1.5.2.1 Visual Appeal and First Impressions:

The exterior appearance of a vehicle is often the first aspect that catches the eye of a potential buyer. A smooth and lustrous finish achieved through automotive coatings creates a positive and lasting first impression. The glossy appearance adds a sense of luxury, sophistication, and elegance to the vehicle, regardless of its make or model. This visual appeal can significantly influence a buyer's perception of the vehicle's quality and desirability.

1.5.2.2 Differentiation and Brand Identity:

In a market flooded with various automobile brands and models, differentiation is crucial for automotive manufacturers. Automotive coatings provide an opportunity for brands to create unique and recognizable visual identities. Brands can choose specific colors, finishes, and coatings to set their vehicles apart from competitors, making them instantly recognizable to consumers. This distinctiveness fosters brand loyalty and encourages repeat purchases.

1.5.2.3 Reflecting Technological Advancements:

As automotive technology advances, so do the capabilities of automotive coatings. Modern coatings offer cutting-edge features, such as self-healing properties that can repair minor scratches, anti-fouling capabilities to resist dirt and grime, and hydrophobic properties to repel water and maintain a cleaner appearance. These technological advancements contribute to a futuristic and high-tech image, further enhancing the vehicle's appeal to tech-savvy consumers.

1.5.2.4 Resale Value and Depreciation Mitigation:

The aesthetic condition of a vehicle significantly impacts its resale value. Vehicles with well-maintained coatings and impeccable appearance tend to retain their value better than those with visible signs of wear and tear. Automotive coatings not only protect the underlying paint but also preserve the original appearance, helping to mitigate depreciation and attract higher resale prices.

1.5.2.5 Emotional Connection and Brand Perception:

Consumers often form emotional connections with their vehicles, considering them an extension of their personalities. Automotive coatings play a pivotal role in this emotional connection. A well-finished and visually appealing vehicle can evoke feelings of pride, satisfaction, and confidence in the owner. It can also positively influence how others perceive the owner, contributing to a sense of prestige and social status.

1.5.2.6 Customization and Personalization:

Automotive coatings offer a wide range of colors and finishes, allowing buyers to customize and personalize their vehicles to suit their preferences. Whether it's a classic matte black for a sleek and edgy look or a sparkling metallic finish for a touch of opulence, coatings give consumers the freedom to create a vehicle that resonates with their style and personality.

1.5.2.7 Marketing and Advertising:

Automotive manufacturers leverage the visual appeal of well-coated vehicles in their marketing and advertising campaigns. Eye-catching images and videos showcasing vehicles with glossy coatings and reflective surfaces create a powerful marketing tool, attracting potential buyers and generating interest in the brand. These visuals are often used in print media, television commercials, online advertisements, and social media to engage with consumers effectively.

Automotive coatings play a vital role in enhancing the overall appearance of vehicles, making them visually appealing to consumers. The glossy and polished finish achieved through well-applied coatings creates a positive first impression and differentiates vehicles in a competitive market. As a key element in the automotive industry's marketing strategy, coatings influence buyers' decisions, evoke emotional connections, and contribute to a vehicle's brand identity. Moreover, coatings play a crucial role in preserving the vehicle's resale value and mitigating depreciation, making them a significant aspect of modern automobile manufacturing and marketing practices.[19]

1.5.3 UV Protection:

Continuous exposure to ultraviolet (UV) radiation can cause fading and deterioration of automotive paint and other materials. UV-resistant coatings act as a protective shield, preventing color fading and maintaining the vehicle's appearance over time. Additionally, they help retain the vehicle's value, which is essential for resale purposes.

The harmful effects of UV rays can lead to fading, degradation, and other cosmetic issues, impacting the overall appearance and value of the vehicle. UV-resistant coatings play a crucial role in mitigating these effects, acting as a protective shield that safeguards the vehicle's appearance and enhances its long-term value.

1.5.3.1 UV Radiation and its Effects:

UV radiation from the sun consists of ultraviolet A (UVA) and ultraviolet B (UVB) rays. These rays are responsible for breaking down the chemical bonds in paint and other materials exposed to sunlight. When automotive paint is exposed to UV rays, it can lead to fading, chalking, and a loss of gloss. Over time, this can cause the vehicle's color to appear dull and less vibrant, detracting from its visual appeal.

1.5.3.2 Protection with UV-Resistant Coatings:

UV-resistant coatings are formulated to counteract the damaging effects of UV radiation. These coatings contain special additives and components that can absorb or reflect UV rays, preventing them from reaching the underlying paint and materials. By creating a protective barrier, UV-resistant coatings shield the vehicle's surface from direct exposure to UV radiation, thus preserving its original appearance and colors.

1.5.3.3 Preserving Color and Gloss:

One of the primary functions of UV-resistant coatings is to maintain the vehicle's color and gloss over time. These coatings prevent the breakdown of chemical bonds in the paint caused by UV radiation, ensuring that the pigments remain stable and vibrant. As a result, the vehicle's paint retains its original hue and luster, enhancing its visual appeal and overall aesthetics.

1.5.3.4 Minimizing Material Degradation:

UV-resistant coatings not only protect automotive paint but also shield other materials used in the vehicle's construction, such as plastic trims, rubber seals, and interior surfaces. Continuous exposure to UV radiation can cause these materials to become brittle, crack, or fade. UV-resistant coatings help minimize material degradation, prolonging the lifespan of these components and maintaining the vehicle's quality and functionality.

1.5.3.5 Retaining Vehicle's Value:

Maintaining the appearance and condition of a vehicle is crucial for preserving its value, especially for resale purposes. A well-maintained vehicle with a pristine appearance, free from faded paint and sun-induced damages, will have a higher resale value in the used car market. UV-resistant coatings play a vital role in retaining the vehicle's value, as potential buyers are more likely to be attracted to a vehicle that looks newer and well-maintained.

1.5.3.6 Cost-Effective Protection:

Investing in UV-resistant coatings is a cost-effective way to protect a vehicle's exterior from UV damage. By providing an additional layer of defense, these coatings reduce the need for frequent repainting or cosmetic repairs due to sun-induced damage. This can save vehicle owners money on maintenance and ensure that their vehicles retain their visual appeal for a more extended period.

UV-resistant coatings are essential components in protecting automotive paint and other materials from the damaging effects of UV radiation. By acting as a protective shield, these coatings prevent color fading, degradation, and other cosmetic issues caused by continuous exposure to the sun. Preserving the vehicle's appearance not only enhances its visual appeal but also helps retain its value, making UV-resistant coatings a valuable investment for both vehicle manufacturers and owners. With their ability to maintain a vehicle's aesthetic appeal and protect against UV-induced damages, these coatings contribute significantly to the long-term quality and value of automobiles.

1.5.4 Scratch and Abrasion Resistance:

Automotive coatings provide a durable and scratch-resistant surface that protects the vehicle's paint and finishes from minor damages caused by rocks, debris, and other environmental factors. This protection is crucial in maintaining the vehicle's pristine appearance, especially for high-end or luxury vehicles.

Automotive coatings play a vital role in providing a durable and scratch-resistant surface, safeguarding the vehicle's paint and finishes from a wide array of potential damages caused by rocks, debris, and various environmental factors. This protection is particularly crucial for high-end or luxury vehicles, where maintaining a pristine appearance is of paramount importance to owners and enthusiasts.

1.5.4.1 Shielding against Road Hazards:

As vehicles traverse roads, they are exposed to numerous hazards that can cause scratches and damage to the paint. Small rocks, stones, and debris kicked up by other vehicles can impact the vehicle's surface, leaving unsightly marks. Automotive coatings act as a resilient barrier, absorbing the impact and minimizing the chances of scratches or chips on the paint.

1.5.4.2 Protection from Environmental Factors:

Automotive coatings protect a range of environmental factors that can harm the vehicle's exterior. For instance, tree sap, bird droppings, and acidic pollutants from industrial sources can all damage the paint if left unattended. Coatings create an additional layer of defense, making it easier to clean these contaminants without affecting the underlying paint.

1.5.4.3 Resisting Wear and Tear:

High-traffic and urban driving expose vehicles to constant abrasions and wear, especially on areas like door handles, mirrors, and the front bumper. Automotive coatings with scratch-resistant properties are designed to withstand such wear and tear, preserving the paint's integrity and minimizing visible signs of use.

1.5.4.4 Improving Longevity and Resale Value:

For high-end or luxury vehicles, maintaining a flawless appearance is essential to protect their investment and maximize resale value. Automotive coatings contribute significantly to a vehicle's longevity by preserving its pristine appearance. The reduced likelihood of visible scratches and damages helps retain the vehicle's value over time, which is particularly important for owners who may wish to sell or trade their vehicles in the future.

1.5.4.5 Enhancing Aesthetics:

High-end and luxury vehicles often feature high-quality paint and finishes that demand meticulous care. Automotive coatings play a crucial role in enhancing the aesthetics of such vehicles. The coatings' glossy and smooth surfaces complement the high-quality paint, giving the vehicle a mirror-like finish that exudes luxury and sophistication.

1.5.4.6 Minimizing Repair Costs:

Repairing scratches and damages to the vehicle's paint can be costly, especially for luxury vehicles that may have custom paint jobs or unique finishes. Automotive coatings act as a protective layer, reducing the frequency and severity of damages, which ultimately lowers repair costs and maintenance expenses for vehicle owners.

1.5.4.7 Time Efficiency in Cleaning:

The slick and hydrophobic properties of some automotive coatings make them resistant to dirt, water, and other contaminants. As a result, cleaning and maintaining the vehicle become more efficient, as these coatings repel grime and require less effort during washing and detailing.

Automotive coatings play a pivotal role in protecting high-end or luxury vehicles from minor damages caused by rocks, debris, and environmental factors. The durable and scratch-resistant surface they provide helps maintain the vehicle's pristine appearance and contributes to its longevity and resale value. Additionally, these coatings enhance the overall aesthetics of the vehicle, giving it a luxurious and refined finish. By acting as a shield against road hazards and minimizing wear and tear, automotive coatings reduce repair costs and maintenance efforts for vehicle owners, making them an essential investment for those seeking to preserve the visual appeal and value of their cherished automobiles.

1.6 Methods of Coating Application:

1.6.1 Spray Coating:

Spray coating is the most common method used in automotive manufacturing. It involves applying a liquid coating material using specialized spray guns, creating an even and smooth surface. This method allows for efficient and quick application, making it suitable for mass production.

1.6.2 Electrocoating (E-Coating):

Electrocoating, also known as electrophoretic deposition, is an immersion-based process where an electrically charged coating material is attracted to the vehicle's metal surface. This method ensures even distribution of the coating, resulting in uniform protection and coverage.

1.6.3 Powder Coating:

In powder coating, a dry powder is applied to the vehicle's surface electrostatically. The powder adheres to the substrate, and then the vehicle is heated to fuse the particles into a smooth and continuous coating. Powder coating offers excellent durability and is environmentally friendly due to the absence of volatile organic compounds (VOCs).

1.7 Materials Used in Automotive Coatings:

1.7.1 Paints:

Automotive paints consist of pigments, binders, solvents, and additives. Pigments provide color and opacity, binders hold the pigments together and adhere them to the surface, solvents facilitate proper application, and additives improve various properties like drying time, UV resistance, and flow characteristics.

1.7.2 Primers:

Primers are used as the first layer on metal surfaces to enhance adhesion between the substrate and the subsequent layers of coatings. They also provide additional corrosion protection.

1.7.3 Clear Coats:

Clear coats are transparent coatings applied over the base paint to add depth and gloss, while also protecting against UV radiation, scratches, and environmental elements.

1.7.4 Ceramic Coatings:

Ceramic coatings, often referred to as nano-coatings, are a relatively newer technology that provides exceptional protection against scratches, UV rays, and chemical contaminants. These coatings create a hydrophobic surface that repels water and enhances the vehicle's appearance.

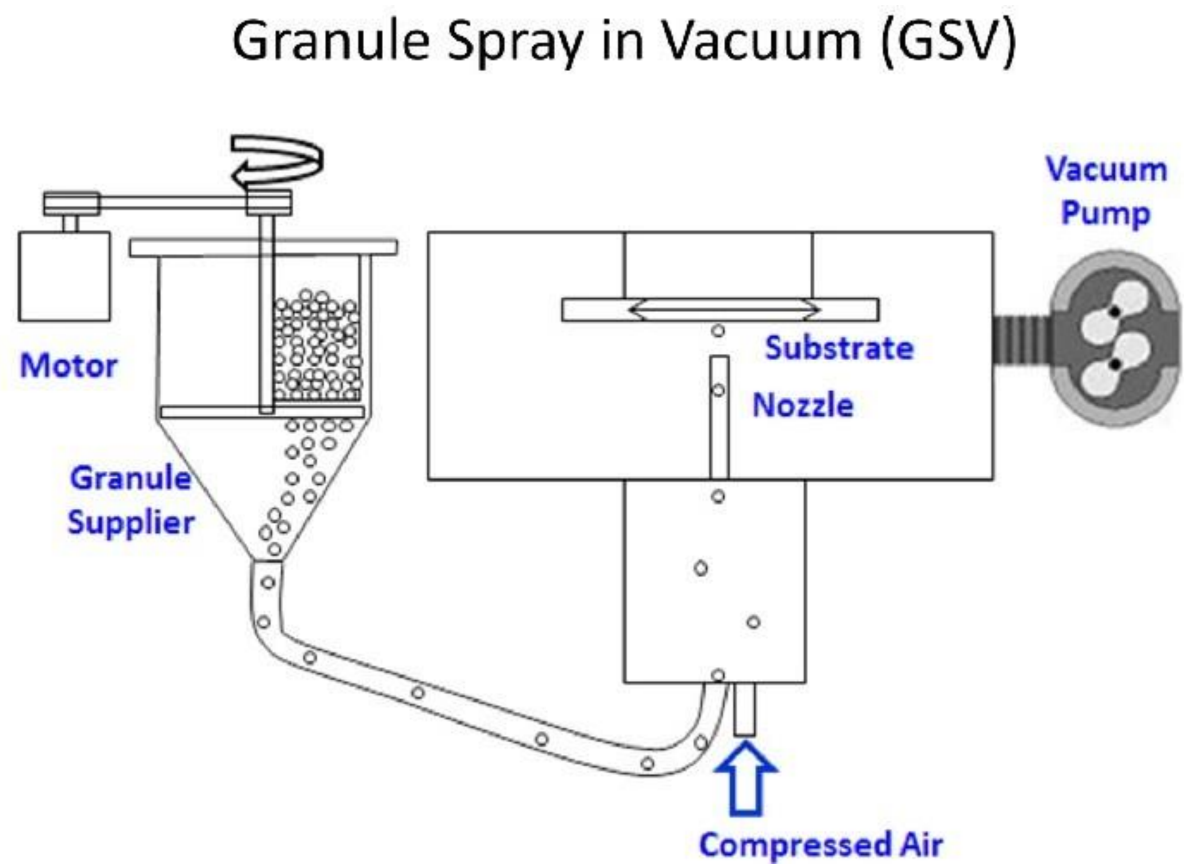

Figure 1.4 GSV method for ceramics coatings

Coatings are indispensable components of the automotive industry, offering essential protection and aesthetic appeal to vehicles. From guarding against corrosion to enhancing the overall appearance, coatings ensure that vehicles maintain their value and perform optimally over an extended period. With continuous advancements in coating materials and application methods, the automotive industry can offer consumers high-quality vehicles that are both durable and visually appealing. The importance of coatings in the automotive sector is set to remain a fundamental aspect of vehicle production and maintenance for years to come.

Chapter: 2

2 Literature Review

The automotive business first emerged almost 100 years ago. In the early stages of the vehicle paint business, brushes and varnish-type compounds are used to paint the car's body. Two coats of those varnish-based paints were used. The first coat was leveled and sanded before the second layer was applied to it, and the body's surface was polished to make it shine [20]. S.Khannaet. Al said that the usage of spray technology was established between 1920 and 1940. in the automobile paint sector. This technological advancement reduced the application and drying times and produced more equal surface finishes, which reduced the need for sanding [21]. The lacquer, created in 1923 by DuPont et al., expanded the range of paint colors available and made paint guns easier to use. However, such lacquer paints had significant drawbacks, including the necessity for 3 to 4 layers of coating to achieve the desired qualities, a relatively low level of chemical resistance, and an inability to withstand an acidic environment. Alkyd enamel paints were introduced in some automobile models in early 1930, and this marked a significant advancement in the paint business since they had extremely high surface characteristics [22]. According to Kagbi et al., the most basic type of paint is primarily composed of three elements: pigment, binder, and solvent. Some chemicals were also added to the paint to enhance its quality [23]. The ingredients and painting techniques used in the vehicle paint business have changed dramatically in recent years. Initial coating procedures were carried out manually and took weeks to complete. According to T. Sagaret. al, there have been several studies on the creation of automotive paint with specialized qualities such as faster drying times, greater corrosion resistance, color persistence, and improved environmental compatibility. Primer is the first coat, which is in charge of the adhesion and base leveling of the automobile paint; the base coat is the second coat, which gives the color to the automobile body; and clear coat is the third and topmost layer. Typically, there are three basic layers in the coating system: primer, base coat, and clear coat. The transparency of it. According to Acik et al., bio-based products must meet stringent criteria to be environmentally sustainable. Starch, cellulose, vegetable oils, sugar, and wood are among the bio-based products that are often employed. Between them, vegetable oils, which include ricinoleic acid and triglycerides, are ideal for the synthesis of a variety of polymers, including alkyds, polyamides, and polyurethanes.

Vegetable oils must be refined to create high molecular weight polymers [13]. To synthesize polymers of high molecular weight, we should modify oil and they are altered to improve responsiveness. The modification procedure that is typically used is coalition, epoxidation and transesterification, etc [24]

2.1 Introduction of Automobile Paint in the Early 1900s:

The early 1900s marked a significant revolution in the paint industry with the introduction of automobile paint. This was driven by the growing automotive industry and the need for high-quality, durable, and aesthetically appealing paints for automobiles. According to A.Gimpieriaet. al, from the outset of the paint business, both the primer and the topcoat were made from oleo resinous material or a combination of resin and oil. For painting, many coats were necessary, and the drying process took a very long period, or around two to three weeks[25]. For painting purposes, larger covered areas were needed, and the resulting paint was dull and not resistant to environmental effects [19]. Additionally, just a few distinct colors were available in the color choices. These issues in the paint business prompted researchers to create an advanced updated paint model[26]

2.1.1 Different types of oleo resinous binders:

Only the painting unit in the car sector uses a lot of energy and water and generates volatile toxic chemicals. Continuous research is being done to routinely change the paint to solve these issues. With the advent of electro-deposition in the 1940s, the automobile paint business began to improve.[27]

2.1.1.1 Use of Oleo Resinous Material:

Initially, both primer (the first layer) and the upper coat (the final layer) of paints were prepared from a mixture of resin and oil, commonly referred to as oleo resinous material. This mixture served as the binder that held the pigments together and provided adhesion to the surface.

2.1.2 Challenges of Early Paints:

a. Multiple Coats and Long Drying Time: The early paint formulations using oleo resinous material required multiple coats to achieve the desired finish and coverage. Additionally, the drying time for these coatings was very long, typically around 2 to 3 weeks, which slowed down the painting process.

2.1.2.1 Dull Appearance and Lack of Environmental Resistance:

The resultant paint had a dull appearance and lacked resistance to environmental effects. It means that the paint did not retain its shine or glossiness for a long time, and exposure to weather and other environmental factors would cause the paint to deteriorate quickly.

2.1.2.2 Limited Color Selection:

Another issue with early paint formulations was the limited range of available colors. Paint manufacturers were restricted in their ability to produce a wide variety of colors, which was a constraint in meeting customer preferences and demands.

2.2 Development of Advanced Revised Model of Paints:

To overcome the limitations of the early paint formulations, researchers and paint manufacturers worked on developing an advanced and revised model of paints. The aim was to create paints that offered improved properties such as faster drying times, better durability, enhanced color options, and resistance to environmental factors.[28]

In summary, the early 1900s witnessed a significant transformation in the paint industry with the introduction of automobile paint. However, the initial paint formulations using oleo resinous materials had several limitations, including multiple coats requirement, long drying times, dull appearance, poor environmental resistance, and limited color options. These challenges prompted researchers to work on developing improved paint formulations to meet the growing demands of the automotive and other industries.[29]

2.2.1 Painting process:

According to Mishra et al., resins, pigments, solvents, and additives are added to liquid paint and powder coating before being baked to cure the paint. Since liquid paint contains more than 40% VOC, which evaporates while drying, there is volume shrinkage in the case of liquid paint.

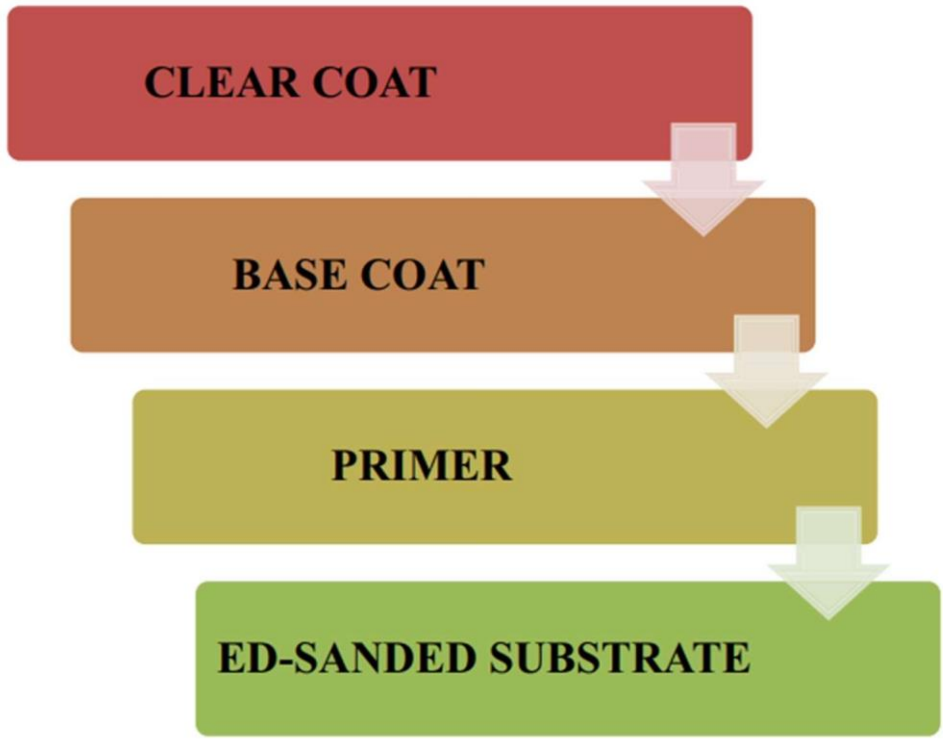

Figure 2.1 Different layers of automobile paint

The technique of painting is quite a significant aspect of the paint business. There are several procedures for painting a vehicle body.[30]

- Pretreatment
- Electrode deposition
- ED sanding
- Sealant & PVC lining
- Primer coat
- Base coat
- Clearcoat

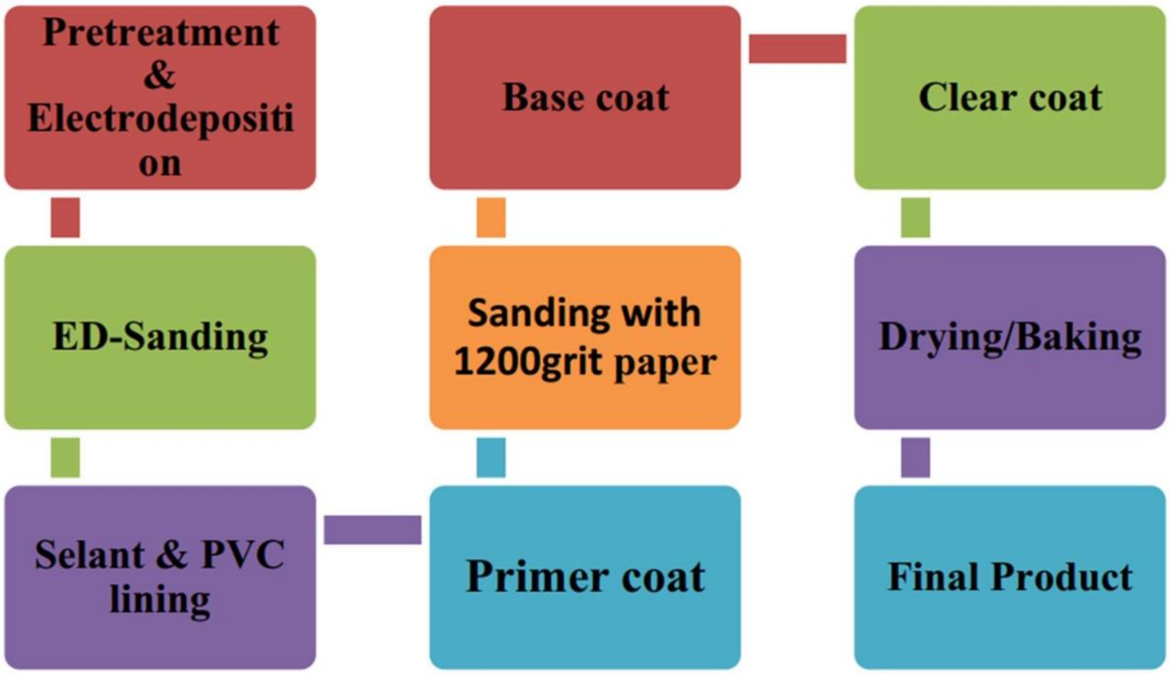

Figure 2.2 Paint processing

2.2.2 Pretreatment

Pretreatment, which is given to the automotive body by immersion or spray baths, is a crucial step in the painting process. The benefits of this approach include.

- Excellent corrosion resistance
- Higher cleanliness of metal
- Very good adhesion of the paint

Pretreatment is a critical stage in the painting process for automobiles in the automotive industry. It entails several pre-processing steps to guarantee that the vehicle's surface is spotless, slick, and prepared to accept the paint covering [31].To obtain a high-quality, resilient, and long-lasting paint finish, proper pretreatment is crucial. The steps involved in the pretreatment of automobile paint are described below:

Cleaning and degreasing: Thorough cleaning and degreasing of the surface of the car is the first stage in automotive paint preparation. By doing this, pollutants such as dirt, dust, oil, grease, and other impurities that could hinder paint adherence are removed. In this step, high-pressure water jets, alkaline cleansers, and solvents are frequently employed.

Surface Preparation: Cleaning is followed by surface preparation. It entails cleaning the surface of the car of any pollutants that could still be there, such as corrosion, rust, or old paint. To create a smooth and clean substrate, abrasive procedures like sanding, grinding, or blasting are used.

Stage of Rinsing: The vehicle is completely rinsed after surface preparation to get rid of any leftover cleaning chemicals or particles. This procedure makes sure that none of the pollutants from the earlier phases are left on the surface.

Phosphate Conversion Coating: Phosphate conversion coatings are used in several automotive paint preparation procedures. A phosphate solution is applied to the vehicle's surface, where it chemically combines with the metal to form a thin layer of protective coating. This layer offers corrosion resistance and improves the paint's adherence. After the phosphate coating, the vehicle is washed with deionized water to get rid of any extra chemicals and keep the surface clean.

Seal Stage: During various pretreatment procedures for automobile paint, a sealer may be used to increase the protective qualities of the phosphate coating and strengthen the paint adhesion even further.

Drying: To get rid of any moisture that may have remained after the pretreatment steps, the vehicle goes through a drying procedure. Drying properly is essential to avoid problems like paint flaws, fisheyes, or poor adhesion.

Following the completion of the automobile paint pretreatment procedure, the vehicle's surface is now perfectly prepared to receive the paint coating. Excellent adhesion, increased paint endurance, and corrosion resistance are all provided by the treated surface. To get the final, glossy appearance on the exterior of the car, the next steps in the automobile paint process normally comprise applying primer, paint (basecoat and clearcoat), and drying.

It's crucial to remember that while many automakers and paint shops may have unique versions of the pretreatment process, the core ideas of cleaning, surface preparation, and coating adhesion improvement continue to be crucial for obtaining a high-quality car paint finish.

2.3 Electrodeposition:

A thin layer of metal or alloy is deposited onto the surface of a conductive substrate during the electrochemical process of electrodeposition, which is sometimes referred to as electroplating or electrodeposition coating. It is frequently utilized in many different sectors for adornment, utility, and protection.[32]

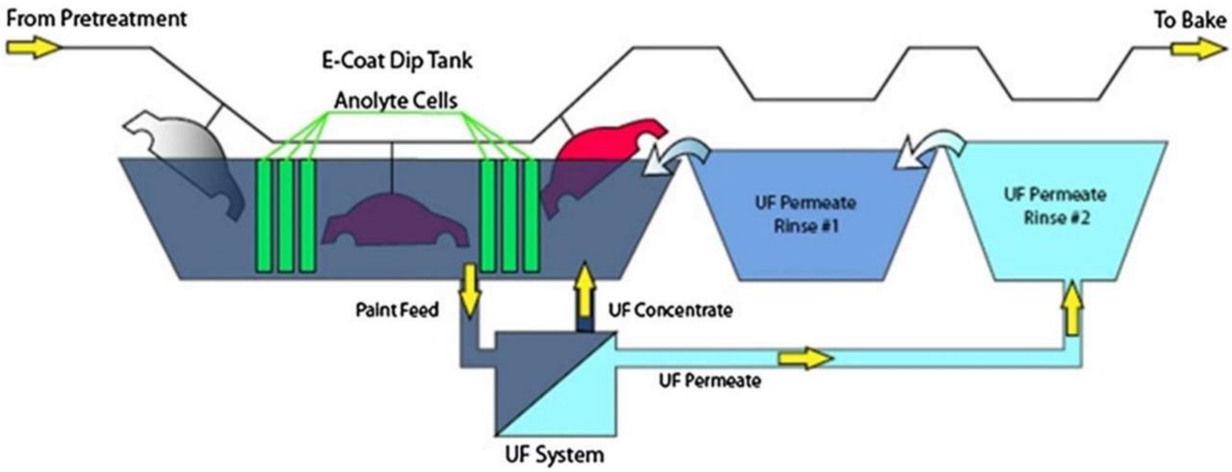

Figure 2.3 Electrode deposition tank

The method is based on the electrolysis concept, in which an electric current is used to move metal ions from an anode to a cathode through an electrolyte. As a consequence, a metal coating is created on the cathode surface. A thorough description of electrodeposition is provided below:

2.3.1 Electrodeposition Principle:

Metal ions must move through an electrolyte from an anode to a cathode for electrodeposition to occur. The cathode is the substrate that needs the metal coating, whereas the anode is generally formed of the metal to be deposited. The electrolyte, which is a mixture of metal salts dissolved in a suitable solvent, is present in an electrolytic bath in which both the anode and the cathode are submerged.

2.3.2 The procedure for electrodeposition:

Surface preparation: The substrate's surface needs to be carefully cleaned to get rid of any debris, oil, or oxide coatings before the electrodeposition procedure. For the deposited metal layer to adhere and be homogeneous, proper surface preparation is essential.

Electrolytic Bath: The anode and the prepared substrate are submerged in the electrolytic bath. The metal that is being deposited determines the appropriate electrolyte. Common electrolytes for copper plating, nickel plating, and chromium plating include copper sulfate, nickel sulfate, and chromium trioxide.

Electric Current Application: An electric circuit is made via the electrolyte by connecting an anode and a cathode to a direct current (DC) power source. Anode (+) and cathode (-) are the new names for the positive and negative electrodes, respectively.

Metal Ion Transfer: As soon as an electric current is provided, metal atoms from the anode disperse as metal ions into the electrolyte. Through the electrolyte, these positively charged metal ions move in the direction of the cathode.

2.3.3 Applications for electrodeposition:

A variety of applications for electrodeposition include:

Electroplating is frequently used for ornamental reasons to give goods like jewelry, watches, and home fixtures a dazzling and aesthetically beautiful finish.

Functional Coatings: Functional qualities, such as corrosion resistance, wear resistance, and hardness, are added to surfaces by electrodeposition [33]. For instance, to improve their toughness and attractiveness, automobile components are frequently electroplated with zinc, nickel, or chromium coatings.

Printed circuit boards (PCBs): Copper is electrodeposited onto the conductive tracks and through holes of the board during the electroplating process, a crucial stage in the production of PCBs.

Semiconductor Manufacturing: Electrodeposition is a technique used in semiconductor manufacturing to produce metal contacts and interconnects.

Electroforming: it's a specialized kind of electrodeposition used to produce very accurate complicated metal pieces and molds.

Electrolytic Capacitors: A conductive layer is created on the anode of the electrolytic capacitor using the electrodeposition process.

2.3.4 Benefits and Things to Think About:

Excellent control over the uniformity and thickness of the deposited coatings is provided via electrodeposition.

- Deposition of different metals and alloys with specific characteristics is possible.
- The method is scalable for mass manufacturing and somewhat cost-effective.

- To reduce the environmental effect of the process chemicals and byproducts, proper waste management is required.

In conclusion, electrodeposition is a flexible and popular electrochemical method that is essential in producing ornamental, practical, and protective coatings for a wide variety of applications in several sectors.

2.4 Ed sanding:

The surface of a coating that has been placed using the electrodeposition method can be leveled and smoothed using the post-treatment technique known as electrodeposition (ED) sanding. To enhance the look and finish of the paint finish on car bodies and parts, this procedure is frequently used in the automotive industry [34]. While the ED method employs the electrochemical application of a paint layer and provides great coverage and corrosion resistance, it occasionally produces an uneven or rough surface texture.

The following steps comprise the ED sanding procedure:

2.4.1 Surface Evaluation:

The coated surface is thoroughly examined to find any flaws, such as orange-peel texture, surface roughness, or other anomalies, before beginning the ED sanding process.

2.4.2 Grit Selection:

A suitable grit size of sandpaper is chosen for the sanding procedure based on the assessment. The amount of material removal and surface smoothing is influenced by the grit size, which also defines how coarse the sandpaper is.

2.4.3 Wet or Dry Sanding:

Both dry and wet sanding methods may be used to complete ED sanding. Wet sanding includes introducing water or a sanding solution to the coated surface to minimize friction and avoid heat accumulation during sanding, as opposed to dry sanding, which uses sandpaper without any liquid or lubricant.

Cleaning and polishing: After the surface has been sanded to the appropriate smoothness, it is carefully cleaned to get rid of impurities and sanding dust. To further improve the sheen and look of the surface, polishing may also be done.

Final examination: The coated surface is subjected to a final examination following the ED sanding and polishing procedure to make sure the appropriate degree of smoothness and quality is achieved.

To get the best results from ED sanding while protecting the underlying paint, knowledge is a must. To achieve a consistent and aesthetically pleasing finish, proper surface preparation, careful grit selection, and controlled sanding procedures are required. Manufacturers may provide premium vehicle paint finishes that satisfy consumer expectations and follow industry standards for appearance and surface by utilizing ED sanding.

2.5 Sealant & PVC lining:

A sealant is a substance that is used to cover openings, cracks, or voids to stop the entry of dust, water, air, or other materials. It is intended to act as a wall between two surfaces and offers airtight or waterproof protection. Sealants are often used in building, manufacturing, automotive, and other sectors. They can be obtained in a variety of forms, such as liquid, paste, or foam.

Various Sealants:

Silicon Sealants:

Sealants made of silicone are strong and adaptable. They are suited for both indoor and exterior applications due to their remarkable flexibility and ability to resist a broad variety of temperatures. The usage of silicone sealants in bathrooms, kitchens, and external seams is widespread.

Polyurethane Sealants:

These sealants have great adherence to a variety of surfaces and high tensile strength. They are frequently employed in automotive and construction applications.

Water-based and simple-to-use acrylic sealant:

They are appropriate for interior uses and are frequently employed to close gaps around windows and doors.

Butyl Sealants:

Butyl sealants have good adherence to metals and glass and are quite flexible. They are frequently employed in the creation of metal roofs, curtain walls, and automotive applications.

Latex Sealants:

Latex sealants adhere well to porous surfaces and are paintable. They are frequently used to seal cracks in concrete, plasterboard, and wood.

Applications:

Various tools, including caulking guns, brushes, and automated machinery, are used to apply sealants. To guarantee optimal adhesion, the surfaces that will be sealed must be dry, spotless, and free of dust and oil. The sealant is applied, and after curing, it creates a flexible barrier that offers protection.

PVC lining:

The process of adding a PVC coating or lining to the interior of a container, tank, or building is known as PVC (Polyvinyl Chloride) lining. The underlying substrate is shielded against chemical corrosion, abrasion, and other types of harm using PVC liner. In industrial environments where the containment of harsh chemicals or liquids is necessary, it is frequently utilized.

Lining Process:

Surface Preparation: The surface of the container or structure has to be meticulously cleaned and ready before the PVC lining is applied. To ensure that the PVC liner adheres properly, any corrosion, coatings, or debris must be removed.

Application of Primer: In some instances, a primer is used to increase the adherence of the PVC lining to the prepared surface.

PVC Application: Several techniques, including troweling, rolling, and spraying, are used to apply the PVC lining to the surface. The necessary coverage and consistent thickness are carefully achieved.

Curing and Drying: Depending on the kind of PVC used, the PVC lining goes through a curing or drying process after being applied. The PVC can create a robust and protective barrier thanks to this technique.

Quality examination: The PVC liner is put through a quality examination to look for any flaws or blemishes once it has dried or cured.

Advantages of PVC Lining:

- Excellent chemical resistance makes PVC lining ideal for handling corrosive compounds.
- It has high abrasion resistance, preventing damage to the underlying surface.
- When compared to employing corrosion-resistant metals or other lining materials, PVC lining is more affordable.
- It is simple to use and may be used to line intricate structures and designs.

To offer protection, stop leaks, and increase the lifespan of structures and equipment, sealants and PVC lining are crucial in many sectors. These materials are essential to maintaining the integrity and performance of a variety of applications, whether they are used to seal seams and gaps in construction or to line containers and tanks for chemical containment.

2.6 Primer Coat:

A primer is an essential part of the paint application process in the automobile industry. Before the basecoat and clearcoat layers, a specially designed coating is put on the surface of the car. In the automobile paint system, the primer performs several crucial roles that improve the final paint finish's general quality, tenacity, and look [35]. Let's explore the specifics of automotive primers and their importance in the process of painting automobiles:

2.6.1 Surface Preparation:

The vehicle's surface has to be thoroughly cleaned and prepared before applying the primer. To ensure that the primer and the following paint coats adhere properly, the surface is thoroughly cleaned to get rid of any debris, wax, grease, and other impurities. Additionally, at this phase, any flaws like dents, scratches, or rust spots are fixed.

Adhesion:

Promoting adhesion between the substrate (the metal or plastic surface of the vehicle) and the ensuing coat of paint is one of the primer's main purposes. The danger of paint peeling, flaking, or chipping is reduced because of the specific adhesion promoters and bonding agents included in primers, which also guarantee that the paint clings firmly to the surface[36]

Corrosion Protection:

Automotive primers are intended to act as a barrier against rust and corrosion. They provide a sealed coating that acts as a barrier against moisture, salt, and other elements that might eventually cause corrosion on the metal surface. To increase the lifespan of the vehicle's body and structural elements, corrosion resistance is essential.

Surface Levelling:

Primer aids in surface leveling and fills up microscopic flaws such as minuscule scratches or pits. This guarantees a smoother, more level surface for the succeeding paint applications, producing a premium, perfect finish.

Enhancing Colour:

Some primers are tinted or contain special colors, which can improve how some paint colors seem when finished. Applying lighter or metallic paint colors requires the use of tinted primers in particular.

Paint Adhesion Testing:

To guarantee that primer is compatible with the basecoat and clearcoat layers, paint adhesion testing is frequently used in the manufacture and refinishing of automobiles. The long-term effectiveness and longevity of the paint system are ensured by proper adhesion testing.

Types of primers:

There are several kinds of automobile primers, each of which is created to work with certain applications and surface materials. Typical kinds of automotive primers include the following:

Epoxy Primer: Epoxy primers are renowned for their superior adherence and resistance to corrosion. They are frequently applied to bare metal surfaces to prevent corrosion and strengthen the binding between ensuing paint applications.

Water-based acrylic primers: They are appropriate for use on a variety of materials, including plastic and fiberglass. They provide strong adhesion and dry quite quickly.

Etching Primer: Etching primers are made to help paint adhere to materials like galvanized steel and aluminum that are challenging to paint. To strengthen the connection between the primer and the substrate, they chemically etch the surface.

High-build primers are used to cover major flaws and offer more surface leveling. They are particularly helpful for fixing body panels that have substantial flaws or damage.

Application of Automotive Primer: Spray guns are frequently used to apply automotive primer. Professional auto body painters evenly and precisely coat the prepared area with primer. Before applying the basecoat and clearcoat, the primer must first dry or cure.

In conclusion, automotive primers are essential components of the vehicle paint system because they offer adhesion, corrosion resistance, surface leveling, and color amplification. They are a crucial phase in the painting of automobiles because they make that the final paint finish is robust, aesthetically pleasing, and able to endure a variety of environmental difficulties.

2.7 Base Coat:

The base coat is an essential part of the paint system used in the automobile industry to give cars their color and visual appeal. After the primer and before the clear coat, it is the second coat of paint that is applied to the surface of the vehicle [23]. The base coat gives the vehicle the required color and aesthetic, and together with the other paint coats, it improves the paint's endurance, weather resistance, and overall finish quality. Let's delve more into the base coat in car paint:

2.7.1 Colour and look:

The base coat's main job is to give the vehicle the desired color and look. It has the pigments and dyes needed to make the many tints and colors of automobile paint. To meet various consumer preferences and market expectations, automakers provide a broad choice of base coat colors.

2.7.2 Paint Layer Sequence:

Primer, base coat, and clear coat are the layers that make up the normal vehicle paint system. The base coat is sprayed onto the body panels of the car after the surface has been cleaned and primed. The clear coat is applied next, acting as a shield to increase the paint's resilience and shine.

2.7.3 Metallic and Pearlescent Finishes:

Different finishes, including as metallic and pearlescent effects, can be produced using base coats. Small metallic particles included in metallic base coats give them a glittering effect when exposed to light. Special pigments used in pearlescent base coats provide a subdued, iridescent effect, giving the paint a three-dimensional look.

2.7.4 Waterborne and Solvent-Based Base Coats:

Solvent-based and aqueous base coatings are the two primary categories. Organic solvents are used as carriers for the pigments and resins in solvent-based base coatings. While using water as the carrier, waterborne base coatings are more ecologically friendly and adhere to stringent VOC (Volatile Organic Compounds) laws.

2.7.5 Coverage and Concealing Power:

Base coats are made to properly cover the primer and create an equal and constant color over the surface of the vehicle. They are also made to have good coverage and concealing power. Base coatings of superior quality reduce color fluctuations and flaws in the finished paint finish.

2.7.6 Flash and Cure Times:

After the base coat has been sprayed, it passes through a "flash time," which enables the solvents to dissipate and the paint to partially firm up. This stops the clear coat from blending during application with the base coat. The base coat is ready for the clear coat to be applied after the flash time [37]. The entire paint system then dries and gradually acquires its ultimate hardness and durability.

2.7.7 Professional Application:

Professional automotive painters often use spray guns to apply the base coat since it demands both ability and accuracy. To achieve perfect and consistent color dispersion, proper application procedures, including gun settings, spray angles, and evenness, are essential.

2.7.8 Protection from Clear Coat:

While the base coat adds color and look, it lacks the sturdiness and weather resistance needed for long-term defense. To increase the overall durability and gloss of the paint finish, a clear coat is sprayed over the base coat to provide extra protection against UV radiation, environmental pollutants, and small abrasions.

In conclusion, the base coat is an important part of the automotive paint system that gives cars their color, look, and aesthetic appeal. Base coats that are applied correctly are followed by a clear coat to provide a long-lasting, high-quality paint finish that improves the appearance and shields the outside surfaces of the car from the elements.

2.8 Clear coat:

The clear coat, sometimes referred to as the topcoat or finish coat in the automobile industry, is a transparent layer of paint placed over the base coat. It is the last layer in the vehicle paint system and is extremely important for safeguarding the base coat underneath, improving the overall look, and giving durability and weather resistance [38]. Let's examine the clear coat in further depth as it pertains to car painting:

2.8.1 Protective Layer:

The clear coat's main purpose is to provide a layer of protection on top of the base coat. In terms of environmental variables including UV radiation, dampness, pollution, road debris, and small abrasions, it offers strong and sturdy protection. The protective qualities of the clear coat assist in preventing base coat fading, chipping, and deterioration over time [39].

2.8.2 Gloss and Depth Enhancement:

Because clear coatings have a high refractive index, light may be bent and scattered by them. By enhancing the shine and depth of the paint finish, the clear coat gives the car a glossy and attractive look [40]. This result produces a fascinating and multi-dimensional look and is particularly noticeable in metallic and pearlescent base coats.

2.8.3 Chemical resistance:

Clear coatings are designed to be chemically resistant, preventing damage to the paint surface from exposure to corrosive chemicals, bird droppings, tree sap, and other corrosive materials. This chemical resistance supports long-term maintenance of the vehicle's look and the integrity of the paint.

2.8.4 Environmental Resistance:

Automotive clear coatings are made to endure a range of environmental elements, including UV radiation, high humidity, and severe temperatures. Because of its resilience to weather, the clear coat won't deteriorate or become yellow over time from exposure to sunshine.

2.8.5 UV Protection:

The clear coat acts as a UV barrier to keep damaging ultraviolet rays from penetrating the base coat and deteriorating the color. UV defense is crucial to preserving the paint's original shade and looks over the course of a vehicle's life.

2.8.6 Resistance to Scratches:

The clear coat offers a certain amount of scratch resistance, helping to shield the paint from small dings and swirl marks even if it is not scratch-proof. The integrity and beauty of the clear coat may be further preserved with routine maintenance and cautious handling.

2.8.7 Professional Use:

Spray guns are frequently used by professional car painters to apply clear coatings. To achieve a smooth and even clear coat finish, proper application procedures, such as the right gun settings, spray patterns, and evenness, are essential. The clear coat is often applied following the base coat's drying and curing to the desired amount of tackiness, or "flash time."

2.8.8 Curing and Final Appearance:

The clear coat must cure after application so that it can harden and connect with the base coat beneath. The sheen and clarity of the clear coat increase as it dries, giving the paint finish its final, polished appearance [40].

2.8.9 Maintenance and Lifespan:

To maintain the clear coat's lifespan and look, regular care is required. This includes washing, waxing, and avoiding harsh cleaning techniques. The clear coat may help preserve the vehicle's paint condition and attractiveness for many years with proper care.

In conclusion, the clear coat, which offers protection, gloss improvement, and weather resistance, is an essential part of the automobile paint system. The final coat is what gives the paint finish its luster and toughness, adding to the overall appeal and resale value of the car. The automotive paint is guaranteed to remain vivid and aesthetically pleasing for the lifetime of the vehicle with a properly applied and maintained clear coat.

2.9 Scratch and Mar resistance by nano alumina:

Researchers like P. Carriere and others have shown that alumina-based nanoparticles are excellent for enhancing coating properties including scratch resistance and surface hardness. Aruna added that these small alumina particles have advantageous qualities including high strength, heat resistance, and the capacity to produce exceptionally water-repellent surfaces [41]. Additionally, they are reasonably priced.

L. Chen and others also emphasized the affordability and accessibility of these tiny alumina particles. They strengthen a coating without affecting its shine, recoatability, or transparency. A tougher coating is more resistant to wear, corrosion, and environmental factors including erosion.

According to Sinha and others, including these particles can boost a According to researchers like Sinha and his team, adding minute alumina particles can increase a coating's resistance to rust and UV radiation as well as its physical strength without degrading its clarity or transparency. The scratch and mark resistance of a polymer material increases when these alumina particles are incorporated into it. By altering the motion of big molecules nearby, alumina and silica particles can also aid in raising the temperature at which a coating transforms from a solid to a liquid.

2.10 Effect by concentration:

Specifically, 0.1, 0.2, and 0.3 percent by weight of alumina particles were used in Sinha and his team's experiments. They found that the material got stronger the more particles they added. According to researchers like Sinha and his team, adding minute alumina particles can improve corrosion and UV resistance. Another team of scientists, under the direction of Yusori, tested four different concentrations of alumina particles: 0.25%, 0.5%, 0.75%, and 1%. They discovered that introducing 0.25% of alumina particles raised the material's bending capacity by 7%. More than this quantity, nevertheless, actually lessened these qualities, primarily because of clumping. Regarding the material's hardness, they saw a similar trend [42].

To strengthen the microscopic alumina particles used in paint, the industry mixes them with a range of other substances. Alkyds, epoxy, acrylic, and polyurethane are some of these materials.

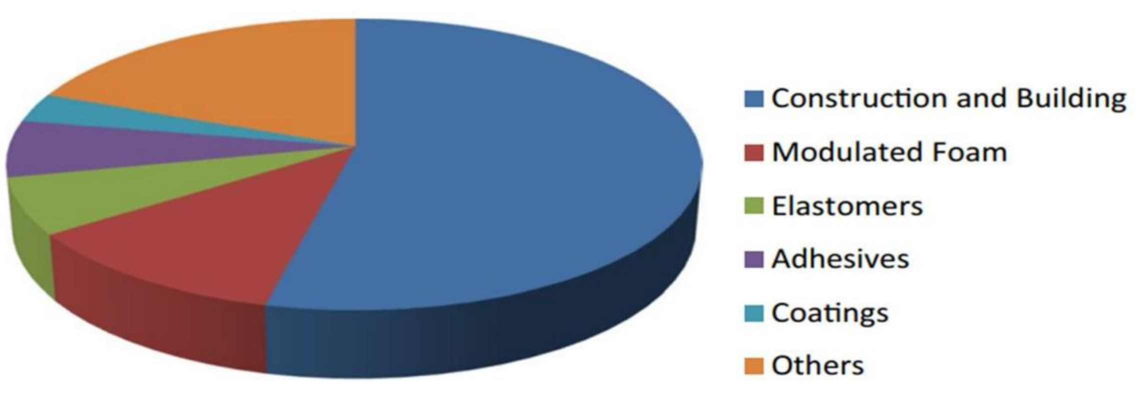

Figure 2.4 Different applications of polyurethane

2.10.1 Polyurethane-based polymer matrix:

Epoxy, a kind of plastic that solidifies when heated, is utilized in a variety of applications because it has numerous advantageous characteristics. It is robust, doesn't shrink much, and is resistant to corrosion, chemicals, and solvents. Epoxy, however, also has significant drawbacks. Its polar characteristics and high surface energy may restrict its use. Due to these qualities, it is less ideal for coatings that must reject substances like dirt, water, and other things. Tiny alumina particles were mixed with epoxy to produce an extremely water-repellent covering. This was accomplished utilizing a two-layer technique in which an epoxy coating was covered with a solution containing alumina particles on top of it. The alumina particles utilized ranged in size from 5 to 15, and they were relatively tiny[43].

2.10.2 Acrylic-based polymer matrix:

These are frequently used as waterproof coatings. They are unique because they have excellent thermal and physical qualities as well as strong water resistance. Zhang and his colleagues discovered that the structure of the substance alters when they added microscopic alumina particles, ranging in size from 4 to 60 nanometers, which significantly increases the material's resistance to scratches. They employed techniques including in-situ polymerization, ultrasonic dispersion, and high-speed stirring to incorporate the alumina particles into the substance.

2.10.3 Alkyd-based polymer matrix:

A form of plastic called alkyd is created from polyols and organic acids. It is frequently used for things like paints, varnishes, and casting molds. Small alumina particles (30-300 nanometers in size) can increase the material's overall toughness and corrosion and UV resistance. Utilizing techniques like sol-gel, in-situ polymerization, or ultrasonic procedures, these particles are incorporated into the plastic. The alumina particles often need to be adequately functionalized to obtain the optimal characteristics, frequently with the aid of silane coupling agents.

For instance, Alexander and his colleagues discovered that stearic acid may be used to functionalize the particles, making the coating extremely water-resistant. Similarly to this, Barron and his colleagues investigated how to further enhance the coating's water repellency by functionalizing alumina particles with highly branched carboxylic acids.

Alumina has a hardness of 9 on the Mohs scale, which makes it a desirable material for hardening coatings, according to Ahmad and his coworkers. Additionally, Said and his colleagues discovered that adding alumina particles to paint may considerably boost the paint's fire resistance, improving the fire resistance by roughly 45% and allowing the paint to endure temperatures of up to 800°C for two hours.

2.10.4 Production Methods of Alumina:

These alumina particles may be produced using a variety of methods, including ball milling, sol-gel, pyrolysis, sputtering, hydrothermal processing, and laser ablation. The most popular techniques are sol-gel and laser ablation. The process of hydrolysis and condensation required to convert the oxime-modified aluminum Isopropoxide precursors into a sol is shown in the accompanying figure. This is then rinsed, aged to create a gel, and dried to create legends. The alumina nanoparticles are created by sintering the legends after that [44].

Ahmet and his colleagues investigated the results of adding nano-silica or nano alumina to a polyurethane matrix. They discovered that adding nano additives like alumina or silica significantly improves the coating's thermal and mechanical properties. They also discovered that adding 1 weight percent of nano alumina or nano silica increased the polyurethane matrix's tensile strength by about 50% or 41%, respectively. W. Su and his colleagues discovered that the hardness, rupture strength, and fracture toughness were all greatly improved by the addition of merely 0.5 weight percent of nano alumina to the matrix. The link between the alumina particles and the polymer matrix is strengthened when alumina particles are added, increasing the material's strength and mechanical qualities[45]. Better wear and scratch resistance are the effects of this. Aluminum is particularly helpful in situations where it is exposed to corrosive substances because it naturally develops a protective thin oxide covering.

Chapter 3

3 Experimentation

3.1 Synthesis of materials of scratch-resistant and hydrophobic coatings:

Recent years have seen a tremendous increase in interest in the creation of hydrophobic and scratch-resistant coatings due to their wide range of uses in several sectors. These coatings are widely sought-after for applications ranging from the electronics and automotive sectors to the architectural and aerospace professions because they provide greater protection for surfaces against scratches, abrasions, and water damage [46]. This article seeks to examine in depth the processes and essential components used in the synthesis of hydrophobic and scratch-resistant coatings.

Introduction:

To extend the life and enhance the performance of surfaces, scratch resistance, and hydrophobicity are desired qualities in many applications. The danger of water-induced damage, corrosion, and discoloration is reduced by hydrophobic coatings, which reject water. Scratch-resistant coatings guard against damage brought on by mechanical wear and tear [47]. Combining these two characteristics can result in durable, multipurpose coatings with a wide range of uses.

Materials Used:

Several materials are used in the creation of hydrophobic and scratch-resistant coatings. Important elements include:

Silica Nanoparticles:

Due to their durability and resistance to abrasion, silica nanoparticles are frequently utilized as the main scratch-resistant agents [48].

Fluorinated Compounds:

Fluorinated compounds are added to the coating formulation to provide hydrophobicity. Due to the low surface energy of these substances, water beads up and rolls off the surface.

Binders and polymers:

They are crucial elements that keep the nanoparticles and other additives bound together, maintaining substrate adherence and giving the coating mechanical strength.

Synthesis Process:

Preparing the Coating Solution:

The coating solution must be prepared as the initial step in the synthesis. A solvent is used to produce a combination of the binder, silica nanoparticles, and fluorinated chemicals. The compatibility of the chosen solvent with the binder and other additives is key. Ethanol, isopropanol, or a mixture of solvents to maximize viscosity and evaporation rate are common solvents.

Mixing and Dispersion:

To produce a uniform distribution of nanoparticles and fluorinated chemicals, the coating solution is vigorously mixed and dispersed using various procedures. To dissolve agglomerates and guarantee adequate dispersion, high-speed mechanical stirring or sonication is frequently used.

Curing and Coating Application:

The coating solution is mixed, then allowed to cure for a certain amount of time. During this time, the chemical reactions between the components take place, creating a stable coating formulation. By using regulated heating or UV exposure, the curing process may be sped up.

Depending on the individual application and the substrate type, the coating is applied to the substrate using a variety of processes such as dip coating, spray coating, spin coating, or roll-to-roll coating.

Characterization and Testing:

The coating is thoroughly characterized and tested after application to make sure the intended qualities are met. Key testing consists of:

Testing for Scratch Resistance:

To verify the coating's level of scratch resistance, a series of tougher pencils are pressed against it by ASTM D3363 standards.

To obtain the necessary qualities, materials must be carefully chosen and combined during the creation of scratch-resistant and hydrophobic coatings. These coatings are widely used in a variety of sectors and increase the durability and water and scratch resistance of surfaces. Future advancements in coating technologies will probably result from ongoing research and development in this area.

3.2 Synthesis of nano alumina:

To give diverse surfaces water-repellent qualities, nano alumina particles are used in the creation of hydrophobic coatings. These coatings are used in sectors including construction, automotive, aerospace, electronics, textiles, and textiles where greater durability and water resistance are essential [49]. Hydrophobic coatings that include nano alumina provide increased scratch resistance, UV protection, and self-cleaning properties, among other advantages. Here is an example of how nano alumina particles are utilized to create hydrophobic coatings.

Nano alumina particles are scattered inside the coating formulation to produce a stable suspension. Dispersion in Coating Formulation. Nano alumina has a large surface area and tiny particle size, which promotes greater dispersion and more uniform particle distribution in the coating. The hydrophobic characteristics are equally distributed over the coated surface thanks to this homogeneous dispersion, ensuring consistent water repellency.

Nano alumina particles are extremely strong and hard, providing reinforcement and scratch resistance. They serve as strengthening agents when added to hydrophobic coatings, raising the coating's general hardness and scratch resistance. This lengthens the lifespan of the coating by helping to shield the underlying substrate from harm brought on by abrasive wear and environmental conditions.

Formation of Micro- or Nano-Scale Surface Roughness:

Nano alumina particles, when dispersed throughout the coating, can produce micro- or nano-scale surface roughness [45]. This roughness increases the region in which water droplets come into touch with the surface, decreasing their stickiness and facilitating easier roll-off. This phenomenon, sometimes referred to as the "lotus effect," endows the coating with superhydrophobic properties.

Binders for Hydrophobic Coatings:

In the coating formulation, hydrophobic polymer binders are frequently coupled with nano alumina particles. The nano alumina particles are held together by these binders, which also serve as a matrix to promote strong adherence to the substrate. The polymer binder's hydrophobic properties also add to the coating's overall water repellency.

Hybrid Coatings:

In some circumstances, fluorinated chemicals and other hydrophobic nanoparticles, such as nano alumina particles, are mixed to produce hybrid coatings. Different hydrophobic materials can work together synergistically to improve the coating's water-repellency and other desired qualities.

Nano alumina particles can also offer underlying surfaces UV protection by reflecting or absorbing damaging UV light. Additionally, water can pick up debris and pollutants as it rolls off the surface due to the superhydrophobic surface generated by the integration of nano-alumina. This coating's self-cleaning feature aids in maintaining its cleanliness and debris-free condition.

Depending on the substrate and the intended use, hydrophobic coatings made of nano alumina can be applied via spray spraying, dip coating, spinning coating, or roll-to-roll coating.

To sum up, nano alumina particles are essential for the creation of hydrophobic coatings because they improve water repellency, scratch resistance, UV protection, and self-cleaning qualities. They are useful additions in coating formulations because of their distinct properties, which enable the construction of robust surfaces with a higher level of protection from environmental elements and water-induced damage.

3.2.1 Methods used in the synthesis of nano alumina:

A versatile substance utilized in the creation of different nanoparticles, nano alumina is also known as tiny aluminum oxide or alumina nanoparticles. It performs an essential role as a constituent or support substance in several nanoparticle production techniques. Nano alumina is the perfect material for the creation of nanoparticles because of its distinctive qualities, including its large surface area, thermal stability, and chemical inertness. The following are some typical procedures for using nano alumina in the manufacture of nanoparticles:

3.2.1.1 Template-assisted synthesis:

Nano alumina can serve as a scaffold or template for the development of other nanoparticles during template-assisted synthesis. This process involves depositing or adsorbing the necessary precursor ingredients onto the surface of nano alumina particles. The required nanoparticles are then produced from the precursors via a chemical or thermal method. The nano alumina template can be eliminated when the synthesis is complete, leaving behind the nanoparticles in the appropriate size and form [50].

3.2.1.2 Sol-gel Method:

The production of metal oxide nanoparticles, including silica, titania, and zirconia, among others, is frequently carried out using the sol-gel process. In the sol-gel procedure, nano alumina acts as a precursor substance. Metal alkoxides are hydrolyzed and condensed throughout the process, which produces a sol or gel. It is possible to create mixed metal oxide nanoparticles by employing nano alumina as one of the precursors [45].

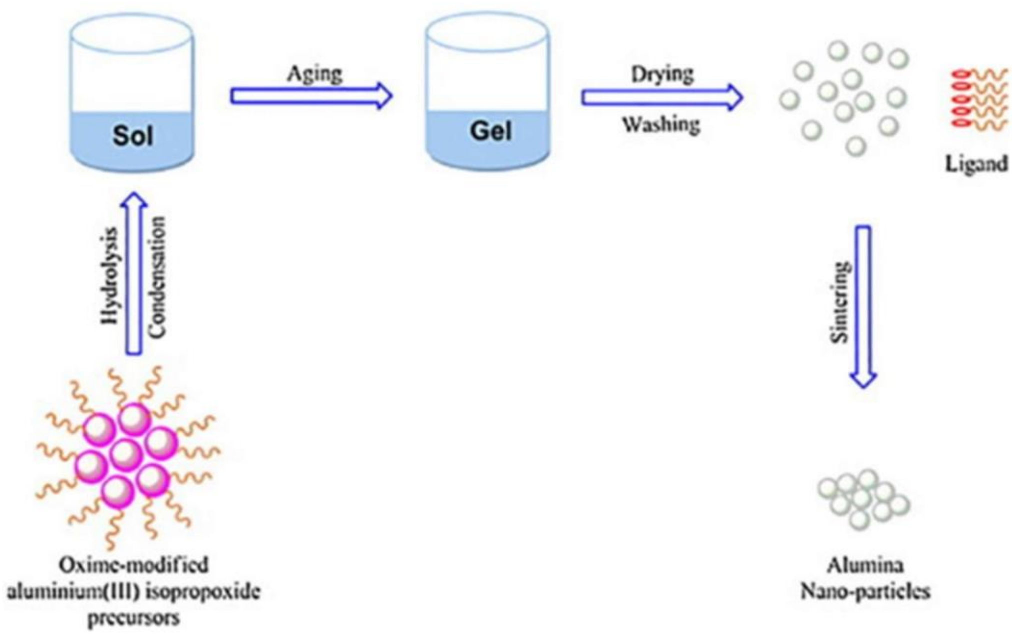

Figure 3.1 Sol-gel method for synthesis of nano alumina

3.2.1.3 Impregnation Technique:

Nano alumina is used as a support material in the impregnation process to disseminate or impregnate other active metallic species or compounds. The manufacture of supported metal nanoparticles or catalysts is frequently done using this technique. Nanoalumina's large surface area and porosity make it an ideal substrate for the deposition of active species, which produces well-dispersed nanoparticles [51].

3.2.1.4 Co-Precipitation Process:

In the co-precipitation process, nano alumina and metal ions are both precipitated at the same time. During the co-precipitation, the pH and temperature may be adjusted to produce nanoparticles of different compositions and sizes. To improve the qualities of the nanoparticles, further processing or modification might be used.

3.2.1.5 Combustion Synthesis:

To create heat and reactive species, a combination of metal precursors, fuel, and oxidizer is ignited. In this procedure, nano alumina may function as both an oxidant and a precursor. Exothermic reactions produce high temperatures upon ignition, which leads to the creation of nanoparticles. The creation of other metal oxide nanoparticles may be aided by the nano alumina's involvement in redox processes.

3.2.1.6 Flame Spray Pyrolysis:

This technique involves spraying precursor solutions into a high-temperature flame, which causes quick evaporation and chemical reactions. In this procedure, nano alumina can be employed as a precursor substance to create nanoparticles. Precursor concentration and flame conditions can be adjusted to produce nanoparticles with specific qualities.

Overall, because of its special features, nano alumina plays a crucial position in the creation of nanoparticles by serving as a template, support material, precursor, or taking part in chemical processes. Due to its adaptability, it serves as a valuable ingredient in a variety of nanoparticle manufacturing processes, aiding in the creation of a wide variety of sophisticated materials with a variety of uses.

3.3 Synthesis of nano alumina by Sol-gel Method:

3.3.1 Materials :

Nitric acid, hexadecyl trimethylammonium bromide (C16TMABr), and aluminum isopropoxide (AIP) are utilized as starting materials in the production of nano alumina. These materials were obtained from the Merck Company and utilized directly after purchase without further purification.

Aluminum Isopropoxide (AIP):

$Al(OCH(CH_3)_2)_3$ is the chemical formula for aluminum isopropoxide, which is frequently referred to as AIP. It has a strong smell and is either a colorless liquid or a white solid. AIP is frequently used as a precursor in the sol-gel method to create aluminum oxide (alumina) nanoparticles. In the presence of water and acids, AIP undergoes hydrolysis and condensation processes in which aluminum hydroxide species are formed, which are then converted into aluminum oxide nanoparticles [52].

Hexadecyl trimethylammonium bromide (C16TMABr):

is a cationic surfactant that is also known as cetyltrimethylammonium bromide (CTAB) or as hexadecyl trimethylammonium bromide. It has the chemical formula $C_{16}H_{33}(CH_3)_3NBr$, which indicates that it is a quaternary ammonium compound. As a template or surfactant, C16TMABr is commonly employed in the production of nanomaterials, including nano alumina. During the sol-gel process, the surfactant's positive charges interact with negatively charged species, encouraging the creation of certain nanostructures with regulated pore sizes and shapes.

Nitric Acid:

Strong mineral acid known as nitric acid has the chemical formula HNO_3. It is a colorless liquid that has a strong odor and is extremely corrosive. Nitric acid is employed as an acid catalyst to speed up the hydrolysis and condensation processes of the precursor aluminum isopropoxide during the production of nano alumina. Nitric acid's presence aids in regulating the pace of these reactions and affects the nano alumina particles' resultant pore structure and shape.

The Merck Company is a well-known provider of chemicals and lab reagents, offering top-notch supplies for academic and commercial endeavors. The Merck starting materials were employed "as received" by the researchers in the synthesis procedure, which means that no additional purification or alterations were made to the compounds. When the starting ingredients are pure and fulfill the criteria needed for the planned synthesis, this strategy is frequently used in research since it eliminates the need for extra purification stages and streamlines the experimental procedure.

Overall, the sol-gel approach is used to synthesize nano alumina utilizing a mixture of aluminum Isopropoxide, hexadecyl trimethylammonium bromide, and nitric acid. They are excellent for a variety of applications in catalysis, adsorption, and other domains connected to nanotechnology because these starting materials allow for the controlled creation of nanoscale alumina particles with certain pore properties.

In this work, aluminum Isopropoxide (AIP) was used as a precursor and a cationic surfactant in an acidic media to create nanocrystalline-alumina utilizing the sol-gel technique. To produce the biggest pore diameter and maximum pore volume in the resultant -alumina support, the researchers sought to optimize the sol-gel parameters. They used the response surface method (RSM) to carry out this optimization and looked at the impacts of three different variables: the pH of the solution, the water/AIP molar ratio, and the template/AIP molar ratio. With the use of the Box-Behnken design, each variable was examined at three separate levels.

In the sol-gel process, a sol (a colloidal solution of nanoparticles) is transformed into a gel (a three-dimensional network of linked particles) by condensation and hydrolysis processes. The process allows for fine control over the final material's composition and structure, making it possible to modify features like pore volume and diameter.

The cationic surfactant was utilized by the researchers to alter the nanocrystalline-alumina's surface characteristics, which can affect the pore structure and improve its stability and activity as a support material.

The following three factors were examined:

the pH of the Solution:

The form and size of the -alumina nanoparticles are greatly influenced by the pH of the sol-gel solution. The impact of changing the pH within a specified range on the pore volume and diameter was examined. They discovered that getting a big pore diameter and high pore volume for the -alumina support required a maximum pH value of 6.5.

Water/AIP Molar Ratio:

The water-to-aluminum isopropoxide molar ratio is crucial for regulating the pace of hydrolysis throughout the sol-gel procedure. To achieve the correct pore structure, a sufficient water-to-AIP ratio is required. The researchers investigated how this ratio affected the size and volume of the resultant pores.

Template/AIP Molar Ratio:

The quantity of cationic surfactant utilized about the aluminum isopropoxide precursor is known as the "template/AIP molar ratio." The creation of pores and the total surface area of the -alumina support can both be impacted by the presence of a template, such as a surfactant.

The researchers carried out trials with different combinations of the three factors using the Box-Behnken design, and based on the data they collected, they created a mathematical model to forecast the ideal circumstances for generating the biggest hole width and highest pore volume.

The researchers determined the expected ideal conditions: a pH value of 6.5, a template/AIP molar ratio of 0.8, and a water/AIP molar ratio of 90, after analyzing the data and using the response surface approach.

They carried out one further experiment under the assumed ideal circumstances to verify the hypothesis. The findings of this experiment demonstrated that the -alumina sample produced under these circumstances had the largest pore volume and pore diameter measurements of 1.76 cm3 g-1 and 17.03 nm, respectively, among all the samples produced for the research.

Overall, this study showed that the sol-gel method in conjunction with the response surface method is a useful strategy for enhancing the synthesis of nanocrystalline alumina with particular pore characteristics, which can be useful as a support material in various applications, such as membranes, catalysts, and adsorbents. The discoveries open the door for customized materials with desirable qualities by helping to understand and manage the sol-gel process.

3.3.2 Sample Preparation:

The usual sol-gel preparation procedure for synthesizing nano alumina is described in full below, comprising the phases of hydrolysis, peptization, condensation, and calcination:

Dissolution of Hexadecyl trimethyl Ammonium Bromide (C16TMABr) with Aluminum Isopropoxide (AIP):

In a typical preparation, a certain volume of water is obtained, and hexadecyl trimethyl ammonium bromide and aluminum Isopropoxide are dissolved in it. Water and C16TMABr are chosen to have molar ratios of 80 and 0.8, respectively, to AIP. To achieve the appropriate nano alumina characteristics during the sol-gel process, these ratios are essential for managing the hydrolysis and condensation processes.

Hydrolysis:

After dissolving AIP and C16TMABr in water, the hydrolysis process is started. After being heated to 80°C, the reaction mixture is vigorously stirred for 30 minutes. Aluminum Isopropoxide is attacked by water molecules during hydrolysis, which causes it to undergo hydrolysis and give rise to aluminum hydroxide species.

Peptization:

The mixture is put through peptization once the hydrolysis stage is finished. Nitric acid (10 wt%) must be added to the mixture and vigorously stirred for the mixture to undergo peptization. Peptization is used to bring the mixture's pH down to about 4.5. The colloidal solution is stabilized at this pH level, which also regulates the size and dispersion of the nano alumina particles. Nitric acid is also used to help in the clearance of surplus.

Condensation:

Condensation is the next process, and it starts when the solvent is removed from the reaction mixture. By heating the reaction mixture, a three-dimensional network of linked nanoparticles is created because of the evaporation. The mixture is dried for 15 hours at 110 °C in the oven to speed up the condensation process.

Calcination:

The dried sample is then heated to a high temperature during the last step of calcination, which removes the surfactant (C16TMABr) and transforms the precursor particles into the required gamma alumina crystallite phase. The sample is calcined for 5 hours at 650 °C, which is hot enough to destroy the organic surfactant and speed up the phase change to gamma alumina.

Nano alumina with the required gamma crystallite phase, a regulated pore structure, and other customized features is the result. This nano alumina substance is currently prepared for further uses in a variety of industries, including catalysis, adsorption, and as a substrate for other nanomaterials.

3.4 Polyurethane- nano alumina synthesis:

For coating automobile surfaces, a homogenous mixture of nano alumina and polyurethane must be created. Nano alumina can be added to polyurethane to improve coating qualities like hardness, abrasion resistance, and thermal stability [53]. A thorough procedure for making the mixture is provided below:

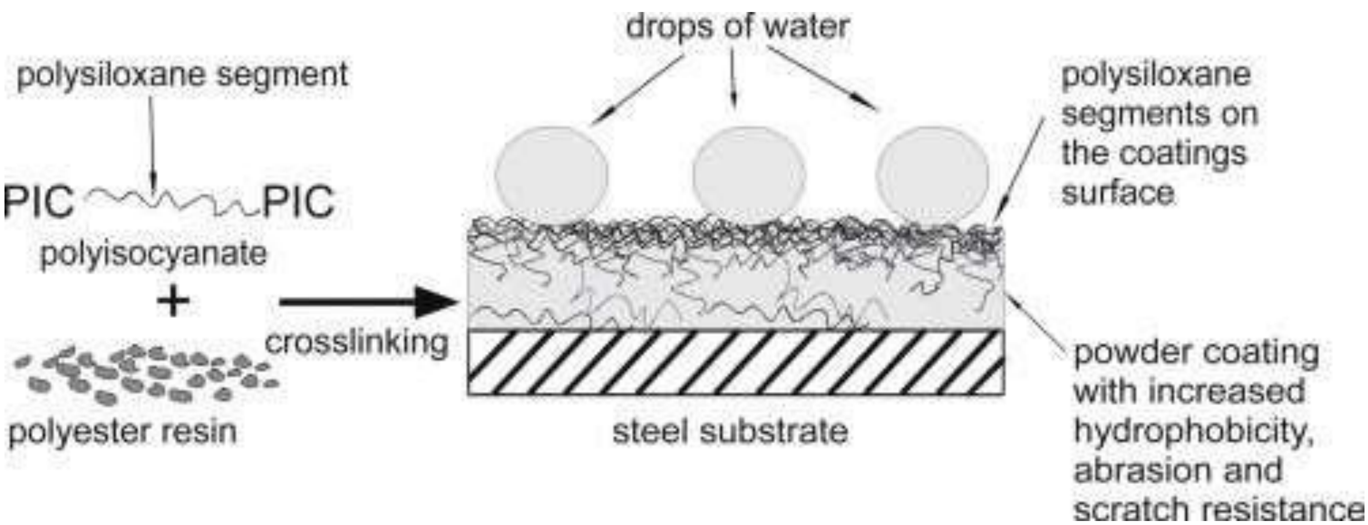

Figure 3.2 Polyurethane coating for hydrophobic applications

3.4.1 Materials required:

A two-component polyurethane system consisting of a resin and a hardener/catalyst is known as polyurethane resin.

Aluminum oxide nanoparticles, also known as nano alumina particles, are frequently found as a powder.

A clean, dry container that can hold the necessary amount of the mixture is a mixing container.

Mechanical stirrers or high-shear mixers are used for stirring.

Solvent: If necessary, a suitable solvent to change the mixture's viscosity.

Gloves, safety glasses, and a well-ventilated space are all necessary safety equipment when handling chemicals.

3.4.2 Step-by-Step Methodology:

3.4.2.1 Getting Ready and Safety Measures:

Put on the required safety equipment to ensure your safety when handling and mixing.

Work in an area with good ventilation or a specialized lab that is suited to handle chemicals.

3.4.2.2 Measurement and Weighing:

The manufacturer's recommended ratio should be followed when measuring the desired amount of polyurethane resin and hardener. For the best drying and coating qualities, the manufacturer often provides this ratio [54].

Using the appropriate proportion of reinforcement as a guide, weigh the nano alumina powder. Depending on the final coating's intended qualities, the precise amount might change. Nano alumina is typically added to polyurethane resin in tiny amounts (e.g., 1-5% by weight).

3.4.2.3 Nano Alumina Pre-mixing

The tiny alumina particles should be put in a different container.

(Optional) Think about pre-dispersing the nano alumina particles in a suitable solvent if they have a propensity to aggregate. This process can enhance dispersion and guarantee a more homogeneous polyurethane mixture.

3.4.3 Polyurethane with Nano Alumina Addition:

Add the pre-weighed nano alumina particles (or, if using a solvent, the nano alumina dispersion) to the polyurethane resin and hardener container.

Make sure the parts are thoroughly combined and the nano alumina particles are dispersed equally throughout the polyurethane.

3.4.3.1 Combining the Ingredients:

For full mixing of the polyurethane, hardener, and nano alumina, use a mechanical stirrer or a high-shear mixer. To prevent adding air bubbles to the mixture, the mixing operation should be carried out at a controlled speed.

3.4.3.2 Gas removal (Optional):

Degassing can be done to get rid of air bubbles if they are introduced during mixing. By putting the combination in a vacuum chamber and applying a vacuum for a predetermined period, this can be accomplished.

3.4.3.3 Adjusting the viscosity (optional):

The viscosity of the mixture may need to be adjusted depending on the application technique and necessary coating thickness. To attain the correct viscosity, a compatible solvent may be added if necessary.

3.4.3.4 Application:

When the combination is prepared, you can use a suitable application technique, like spraying, brushing, or dipping, to apply it to the vehicle surface.

For the polyurethane coating to work at its best, abide by the manufacturer's instructions for curing times and environments.

It's important to remember that the precise type of polyurethane resin, hardener, and nano alumina employed may affect the preparation process's specifics. To ensure the best outcomes and safety during the preparation process, always refer to the manufacturer's instructions and safety data sheets for the specific components.

3.5 Coating PU/nano alumina on Mild steel substrate:

3.5.1 Getting Mild Steel Sheets Ready:

Mild steel sheets in the necessary thickness and size were purchased from the market.

The sheets were examined for any rust, pollutants, or surface flaws. For a smooth coating surface, they were cleaned and sanded as necessary.

3.5.2 Small Round Circles Cut into:

The mild steel sheet was meticulously sliced into smaller circular shapes with a diameter of 1 inch each using a cutting device (such as a metal cutter or a laser cutting machine).

Out of the larger mild steel sheet, 46 pieces were created.

initial application

Each 1-inch circle's surface was cleaned to get rid of any dust or debris before applying the primer.

The circles of mild steel that had been prepared received a priming coat. The performance of the coating as a whole is enhanced by the primer, along with adhesion and corrosion resistance.

It's possible that the primer used was a special kind made for metal surfaces, ensuring strong adhesion and shielding the steel from corrosion.

3.5.3 Effect of even and uneven coat on automotive:

There are various advantages to applying an even coat of paint or protective coating to an automotive surface. It adds to the aesthetic appeal of the car by giving it a uniformly smooth finish. This contributes to a polished and appealing appearance, which might increase the vehicle's market value.

Additionally, a uniform coat provides superior defense against harmful environmental factors like UV radiation, dampness, and road debris. This increases the endurance and lifetime of the vehicle by lowering the risk of corrosion, fading, and damage to the underlying materials.

Additionally, a smooth surface provided by an even coat may marginally enhance fuel efficiency and minimize air resistance, while also making a little contribution to the vehicle's aerodynamics. On the other side, an uneven paint or coating application can have several detrimental impacts. It may result in surface flaws like streaks, sags, or patches of uneven color, which would reduce the vehicle's aesthetic attractiveness. This could create the impression of inadequate upkeep or negligence and could reduce the automobile's value on the used car market.

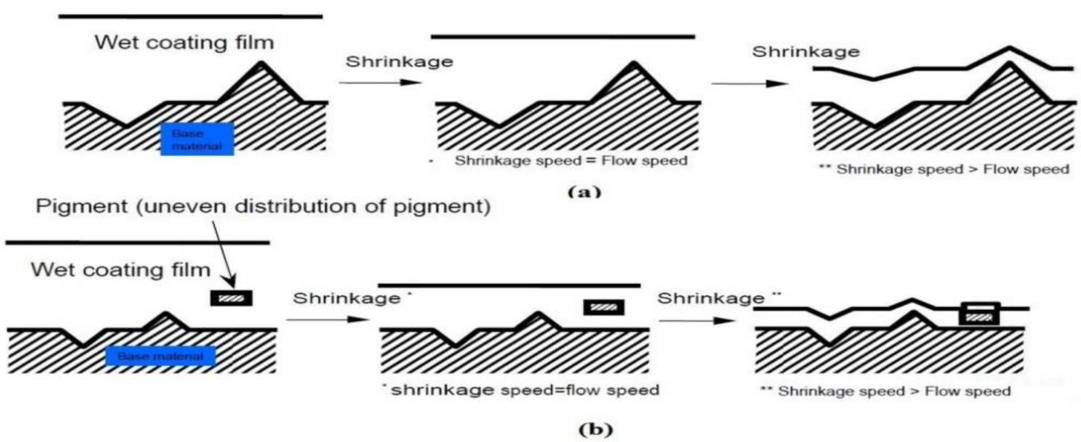

Figure 3.3 Effect of uneven coating on the substrate

Furthermore, an uneven coat could expose specific parts of the car to the weather, speeding up wear and tear or possibly the development of rust or other damage.

When a car with an even coat needs touch-ups or repainting, the procedure is typically simpler and enables a seamless color transition. Repairing or repainting an uneven coat, however, can be more difficult and frequently necessitates additional preparation work to fix the flaws and produce a consistent finish.

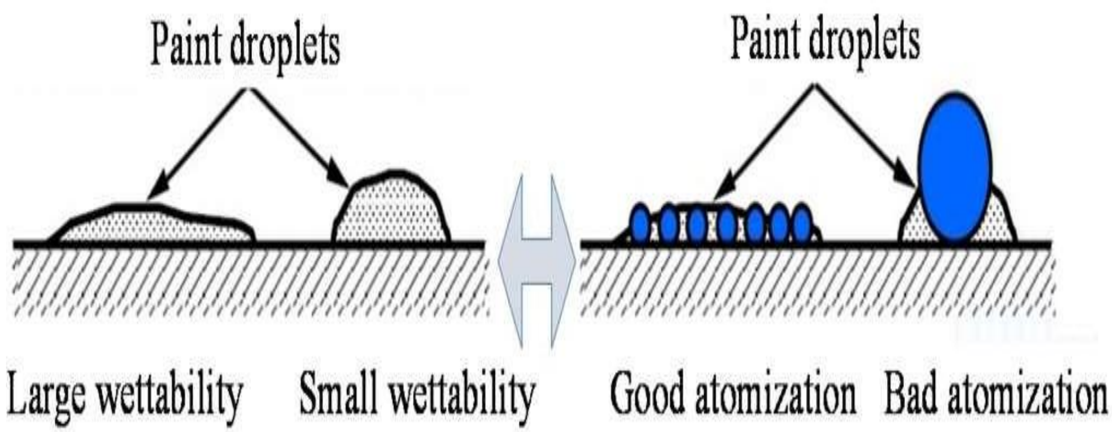

Figure 3.4 Importance of even coat on automotive body

In conclusion, it is crucial to keep an even coat of paint or protective coating on an automotive surface for both aesthetic and structural reasons, as well as to assure the vehicle's endurance and weatherproofing. The vehicle can look its best and retain its long-term worth with proper maintenance and prompt correction of any flaws.

3.5.4 Use of the Base Coat:

The base coat was applied once the primer had dried (according to the manufacturer's suggested drying time).

Given that the base coat was applied in a paint shop, it's possible that pre-mixed base coat paint was utilized.

The base coat gives the coated circles color and their primary visual appeal.

3.5.5 Application of the Clear Coat:

The clear coat (probably a clear polyurethane or acrylic clear finish) was made separately once the base coat had cured.

To create a protective and glossy layer, a clear coat was placed on top of the base coat.

The clear coat was manufactured; therefore it may have entailed following the manufacturer's directions to properly mix a clear coat resin with a hardener/catalyst in the right ratio.

3.5.6 Using spray paint:

For the clear coat, spray paint was used as the application technique.

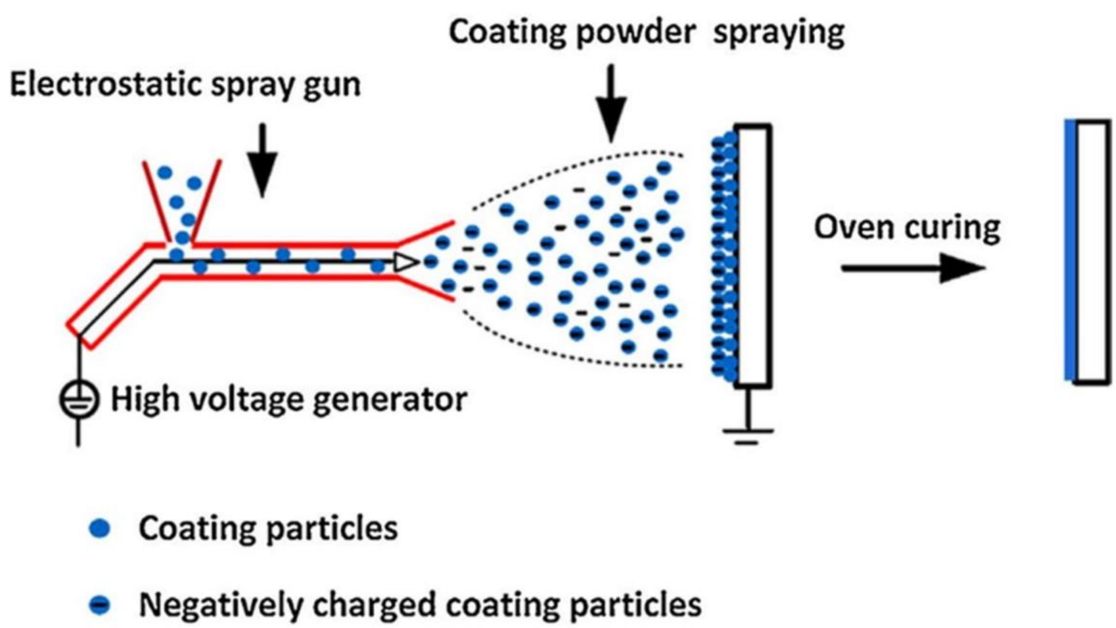

Figure 3.5 Spray coating of automobile paint on automobile body.

The clear coat was evenly sprayed over the full surface of each 1-inch circle after it had been set up on a suitable surface.

To ensure a smooth and uniform finish, care was taken to prevent the clear coat from building up or running excessively.

Depending on the scope of the project and the equipment available, a spray gun or aerosol can have been utilized for the application.

3.5.7 Drying and Curing

The coated circles were given a clear coat and then allowed to dry in a controlled environment so that the solvents could dissipate and the coating could fully cure.

It should have been done by the manufacturer's instructions. The drying and curing times vary on the particular clear coat that was used.

3.5.8 Quality Control:

Each circle covered was examined for flaws or blemishes once the clear coat had fully dried and hardened.

The coated circles' overall thickness, smoothness, and attractiveness may have been evaluated during quality tests.

After the primer, base coat, and clear coat were applied, the resulting 1-inch circles would have been prepared for use in the appropriate application, components in automotive or other projects.

Chapter 4

4 Results and discussions

4.1 XRD of Nano-alumina:

A potent method for examining the crystallographic structure of materials is X-ray diffraction (XRD). In this study, the sample's XRD pattern yields crucial details regarding its crystal structure and crystallite size.

Three primary peaks can be seen in the XRD pattern at distinct d-spacings of 0.139 nm, 0.198 nm, and 0.242 nm. The lattice structure of the material's peaks line up with its crystal planes. The numbers "one," "two," and "three" on the XRD figure represent the peaks.

The separation between consecutive crystal planes in the material is known as d-spacing. Through Bragg's law, it is connected to the diffraction angle (2). The following equation can be used to find the d-spacing for each peak:

$d = \lambda / (2 * \sin(\theta))$

where:

d stands for d spacing.

Θ is the X-ray radiation's wavelength,

The diffraction angle is [].

According to the XRD examination, the substance is in the gamma phase, which describes a particular configuration of atoms or molecules inside the crystal lattice. Materials may go through many phases as a result of variations in temperature, pressure, or other environmental conditions.

We can deduce more information about the material's qualities from the XRD results that show a gamma phase with small crystallite size, without attributing them to the presence of contaminants. Here is the updated summary:

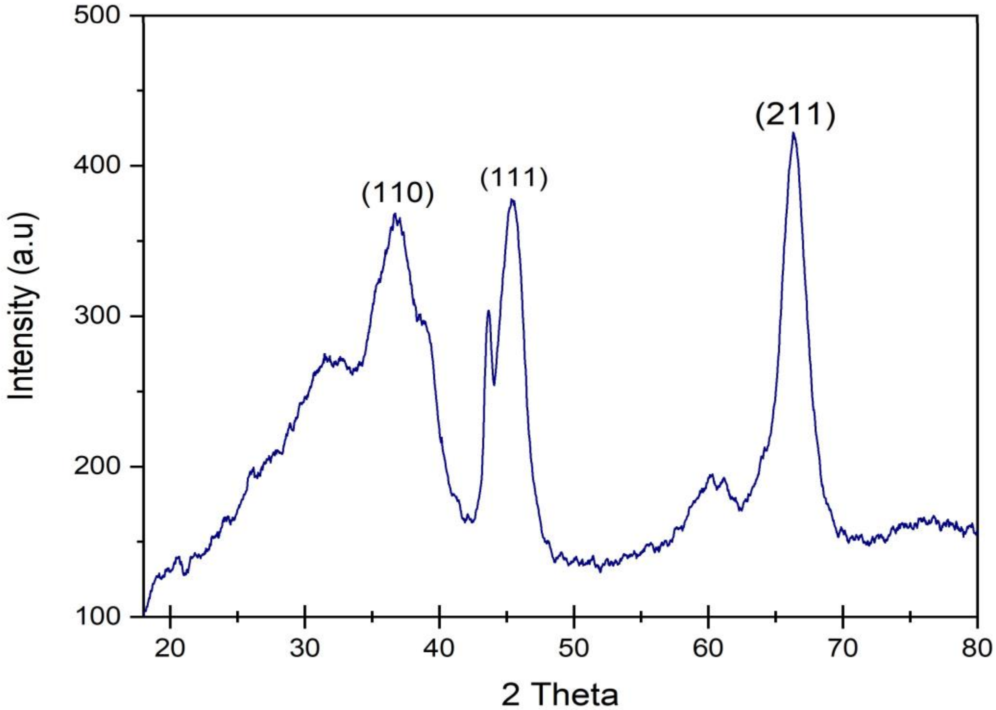

Figure 4.1 The XRD patterns of nano alumina

In the picture, peaks one, two, and three are identified, and the X-ray diffraction (XRD) analysis indicates three primary peaks at d-spacings of 0.139 nm, 0.198 nm, and 0.242 nm. These peaks demonstrate the existence of particular crystal planes inside the lattice structure of the material, demonstrating a properly organized configuration of atoms or molecules in the gamma phase [55].

The major peaks' observed broadness in the XRD pattern suggests that the material has a tiny crystallite size. Small crystallite size is not always a sign of contaminants; it can be caused by several things, including the synthesis method or processing conditions. Instead, it suggests that the crystal domains of the material are small and widely scattered.

Remarkable material qualities are linked to the rare gamma phase and small crystallite size combination. Notably, the gamma phase's existence is frequently linked to strong hydrophobic characteristics. This indicates that the substance is very water-repellent and exhibits strong resistance to interactions with water or other polar solvents.

The material's increased mechanical strength qualities are also a result of the small crystallite size. Small crystallite materials typically have better mechanical properties, such as higher hardness, tensile strength, and toughness. These improved qualities can be very helpful in a variety of applications that call for strong and long-lasting materials.

It is crucial to remember that the material's hydrophobicity and strength are inherent attributes derived from its crystal structure and crystallite size, not from the presence of impurities. Exploring potential applications in fields where mechanical integrity and water resistance are critical components requires understanding these qualities [56].

In conclusion, the material's gamma phase with its small crystallite size shows good hydrophobic and strength properties in the XRD examination. The material is promising for a variety of applications where mechanical robustness and water repellency are desirable qualities due to its distinctive properties. It is possible to learn more about the material's potential applications in other sectors by conducting additional research into its characteristics and performance.

4.1.1 XRD of functionalized nano alumina:

First, alumina nanoparticles were created and then examined using X-ray diffraction (XRD). The material's gamma phase with a small crystallite size was confirmed by the XRD pattern, which showed three primary peaks with d-spacings of 0.139 nm, 0.198 nm, and 0.242 nm. These peaks indicated the presence of certain crystal planes. The produced nanoparticles appeared to have good hydrophobic and strength properties based on the small crystallite size.

Stearic acid and 2-propanol were used to functionalize the alumina nanoparticles to increase the material's stability and characteristics. Stearic acid molecules were attached to the nanoparticle surfaces as part of the functionalization procedure. The material's stability and hydrophobicity increased as a result of the functionalization.

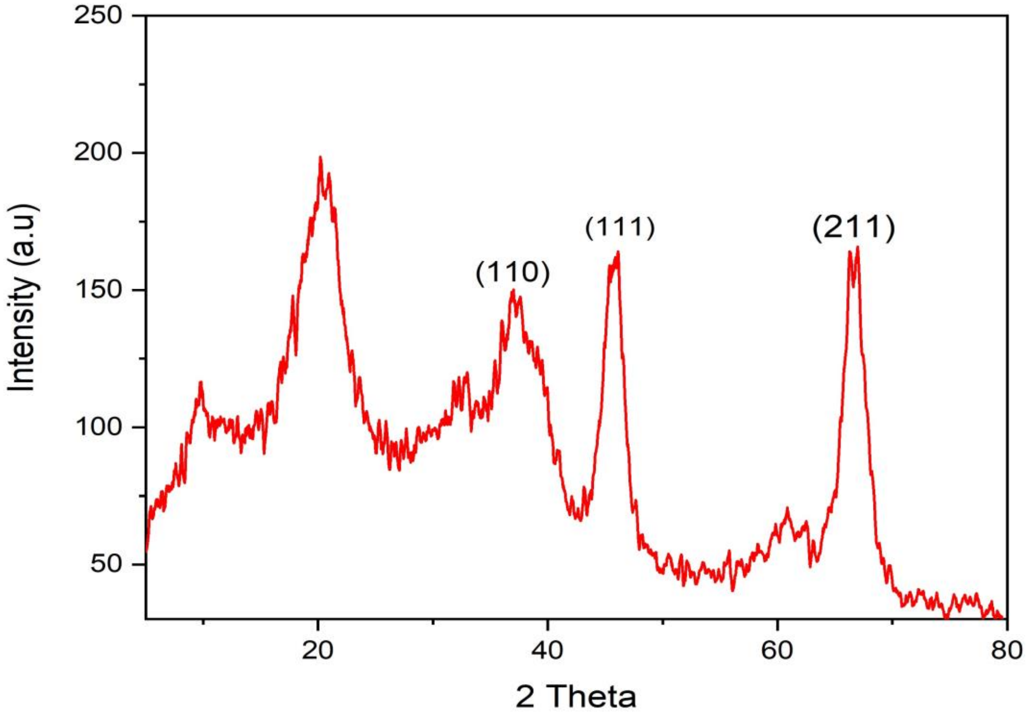

Figure 4.2 The XRD pattern of functionalized nano alumina

The functionalized nanoparticles' XRD examination revealed an extra peak at 22 degrees. The presence of stearic acid in the molecule is responsible for this new peak. This peak's presence proves that the functionalization procedure was successful and that stearic acid molecules have now been integrated into the alumina nanoparticles' crystal structure [57]. The XRD pattern demonstrated that functionalization caused the material's structure to become much more stable. The material is appropriate for a variety of applications because of its improved stability, which is essential for maintaining its long-term performance and durability. Additionally, the functionalization with 2-propanol and stearic acid made a considerable contribution to the increase in hydrophobicity. Stearic acid produced a hydrophobic coating on the nanoparticle surfaces, increasing their ability to repel water. When a material needs to withstand exposure to moisture or water, this feature is very helpful.

The functionalization method improved the material's scratch resistance in addition to its hydrophobicity. On the surfaces of the nanoparticles, the stearic acid molecules created a protective coating that lessened the impacts of abrasion and scratching. In applications where the material may come into touch with rough surfaces or encounter mechanical stress, the improvement in scratch resistance is advantageous.

Overall, stearic acid and 2-propanol functionalized alumina nanoparticles to produce a more stable structure with improved hydrophobicity and scratch resistance [57]. The functionalized nanoparticles now have interesting new applications in a variety of sectors, including coatings, paints, and surface treatments, where mechanical robustness and water repellency are crucial criteria.

4.1.2 Functionalized and non-functionalized nano alumina comparison:

Let's contrast the XRD graphs of alumina nanoparticles with and without stearic acid and 2-propanol functionalization:

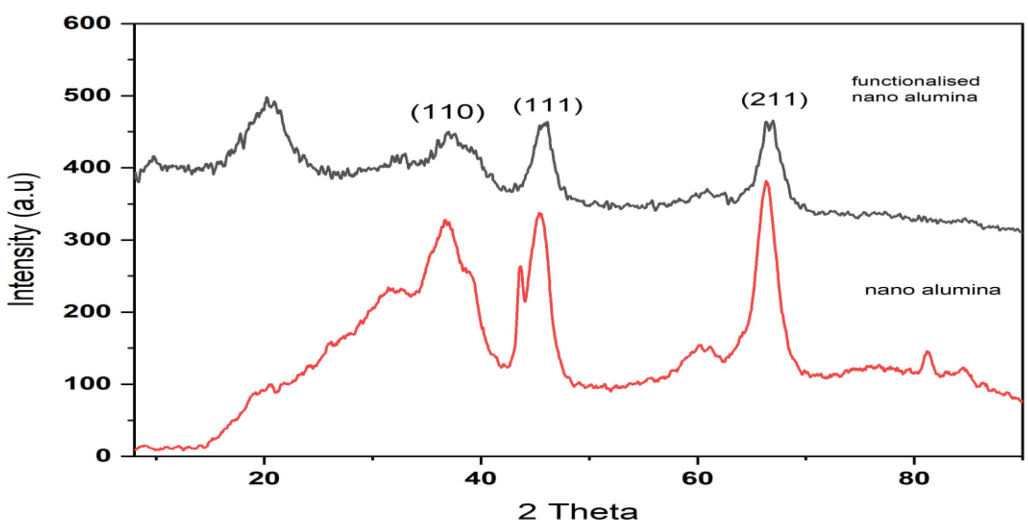

Figure 4.3 The XRD patterns of functionalized and non-functionalized nano alumina

In non-functionalized alumina, three primary peaks are visible in the XRD pattern of unfunctionalized alumina nanoparticles, with d-spacings of 0.139 nm, 0.198 nm, and 0.242 nm.

These peaks demonstrate the existence of particular crystal planes inside the lattice structure of the material, demonstrating a properly organized configuration of atoms or molecules in the gamma phase [58]. The material's crystallites may be larger since the peaks are relatively sharp and thin.

The gamma phase's presence suggests a particular configuration of atoms or molecules inside the crystal lattice.

The non-functionalized alumina nanoparticles have smaller crystallite sizes, which improve their hydrophobicity and strength. More frequently than not, smaller crystallites result in improved mechanical performance. In Stearic acid and 2-propanol-functionalized alumina nanoparticles similar to the non-functionalized sample, the XRD pattern of alumina nanoparticles functionalized with stearic acid and 2-propanol displays three prominent peaks with d-spacings of 0.139 nm, 0.198 nm, and 0.242 nm. The XRD pattern includes the three primary peaks as well as a new peak that shows up at 22 degrees and denotes the presence of stearic acid in the substance. The efficient incorporation of stearic acid molecules into the crystal lattice of the alumina nanoparticles is indicated by the new peak at 22 degrees. The more distinct peaks in the XRD pattern show that the functionalization procedure increases the material's stability. The XRD peaks are noticeably wider than in the non-functionalized sample, which suggests that the functionalization procedure has resulted in smaller crystallite sizes.

The hydrophobicity of the material is dramatically increased by the addition of stearic acid to the nanoparticle surfaces. Higher water contact angles and improved water repellency result from the existence of a hydrophobic layer, which repels water molecules. Greater mechanical integrity and defense against surface damage are provided by the functionalization of the material using stearic acid and 2-propanol.

Comparison:

Alumina nanoparticles with and without functionalization both show three main peaks at comparable d-spacings, demonstrating that the underlying crystal structure (gamma phase) is preserved. In the XRD pattern, the functionalization procedure adds a new peak at 22 degrees, demonstrating that stearic acid was successfully incorporated into the material's crystal lattice. In contrast to the non-functionalized sample, the functionalized sample exhibits wider peaks in the XRD pattern, which suggests a smaller crystallite size. The hydrophobicity and scratch resistance of the functionalized nanoparticles is improved by the reduced crystallite size. The more clearly defined peaks in the XRD pattern show that the nanoparticle surfaces with stearic acid and 2-propanol have increased stability. Overall, stearic acid and 2-propanol functionalization of alumina nanoparticles offers benefits in terms of improved stability, increased hydrophobicity, and improved scratch resistance, making the functionalized nanoparticles promising candidates for various applications in coatings, surface treatments, and other fields requiring water-repellency and mechanical durability.

4.2 FTIR analysis:

4.2.1 FTIR analysis of nano alumina:

FTIR analysis was used to analyze the surface chemistry of the nano alumina sample, which was made from aluminum Isopropoxide, hexadecyltrimethylammonium bromide (CTAB), and nitric acid. This allowed researchers to pinpoint the material's different bonds and functional groups.

When the FTIR spectrum was examined, distinctive peaks representing various kinds of bonds and functional groups could be seen [59].

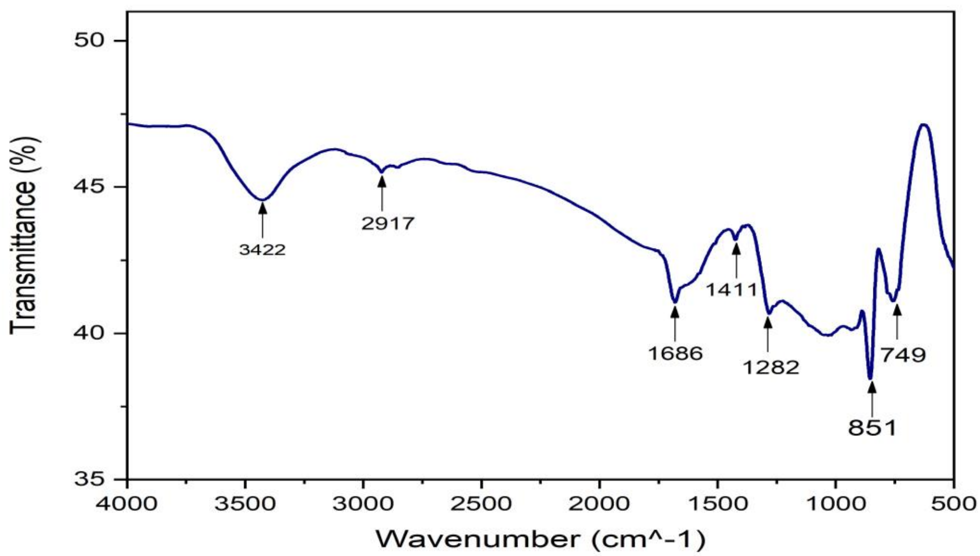

Figure 4.4 FTIR spectrum of nano alumina

The FTIR spectra clearly showed the presence of metal-oxygen bonds (Al-O), with absorption peaks seen in the wavenumber region of 749 cm^-1. These peaks demonstrated the presence of interactions between aluminum and oxygen in the alumina structure [60].

Alkoxy groups (Al-O-R) were produced as intermediates throughout the synthesis process using aluminum Isopropoxide. In the FTIR spectra, the stretching vibrations of these alkoxy groups were seen at wavenumbers of 1282 cm^-1.

The synthesis procedure involved the application of nitric acid, which resulted in the creation of carboxylate groups (RCOO-) on the nano alumina surface. The typical peaks in the FTIR spectra, which correspond to the stretching vibrations of the C=O bond in carboxylate groups, were at 1686 cm^-1. Ammonium ions (NH4+) were added to the nanoparticle surface as a result of the inclusion of CTAB during the production process. These ammonium ions' bending and stretching vibrations were picked up in the FTIR spectra at wavenumbers at 1411 cm^-1. On the nano alumina surface, organic CTAB chains with lengthy hydrophobic alkyl groups were also seen. Stretching vibrations at 2917 cm^–1 range of the FTIR spectrum were visible and corresponded to the C–H bonds in the organic chains. The nano alumina surface included hydroxyl groups (OH), as shown by the FTIR measurement. These hydroxyl groups exhibited strong stretching vibrations at 3422 cm^-1.

In conclusion, the FTIR analysis gave important information about the nano alumina sample's surface chemistry. A thorough understanding of the material's molecular structure and functional groups was made possible by the detection of metal-oxygen bonds, alkoxy groups, carboxylate groups, ammonium ions, organic CTAB chains, hydroxyl groups, and nitrate ions. The FTIR results have major implications for the future uses of nano alumina in a variety of industries and are crucial in defining it.

4.2.2 FTIR of Polyurethane:

The Fourier-transform infrared (FTIR) examination of polyurethane is described in the text you gave. FTIR is a popular analytical method that uses a sample's chemical bonds to absorb infrared light to determine the functional groups that are present in it.

Let's examine the details:

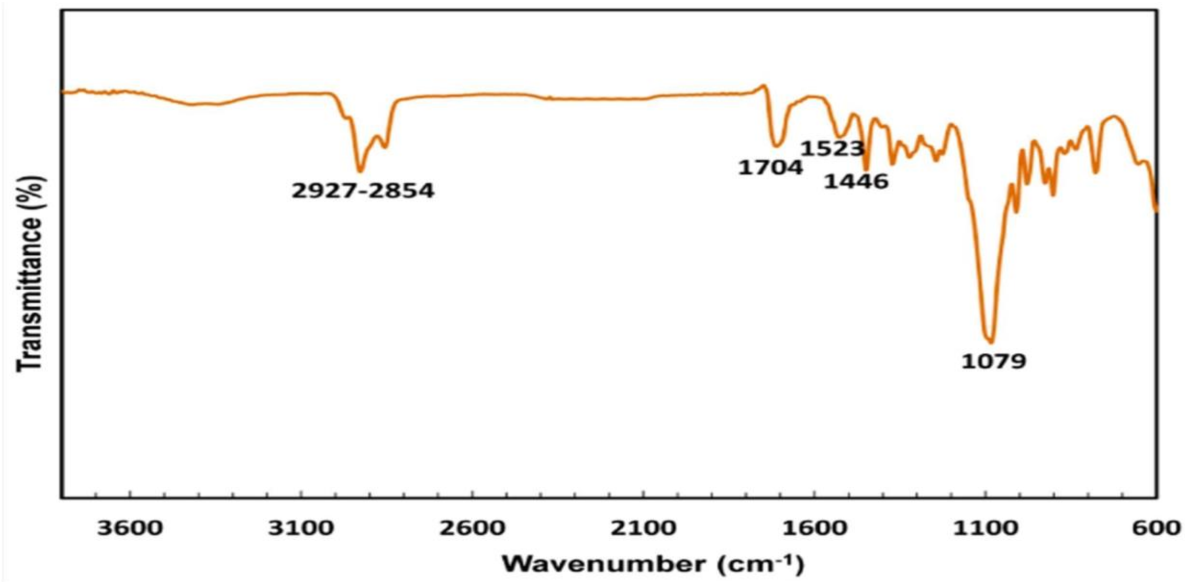

Figure 4.5 The FTIR spectrum of polyurethane

Stretching bands of -CH2 are seen (from PPG) between 2927 and 2854 cm^-1[61]. This claim means that the polyurethane sample's -CH2- group stretching vibrations were picked up by the FTIR study. The region of these vibrations, having absorption bands between 2927 and 2854 cm1, is defined by the wavenumber range (cm1) [62]. The urethane carbonyl band that was found at 1704 cm1: This section implies that the FTIR research discovered a distinctive band associated with the urethane carbonyl group. In the infrared spectrum, the carbonyl group (C=O) commonly shows up around 1700 cm^-1.The usual locations of the C-N stretching bands and the N-H bending in the plane are 1523 cm-1 and 1446 cm-1, respectively: The C-N bond's stretching vibrations and the N-H bond's bending vibrations in the molecule's plane were picked up by the FTIR analysis [63]. At wavenumbers of 1523 cm1 and 1446 cm1, these vibrations are seen as absorption bands, respectively. At 1079 cm1, the C-O-C characteristic band was located: This claim suggests the existence of a distinctive band linked to the C-O-C ether connection. In the FTIR spectrum, the ether linkage (C-O-C) often exhibits an absorption band of about 1079 cm1[62].

Overall, the FTIR analysis offers important details regarding the polyurethane sample's chemical makeup. Researchers can establish the existence of several functional groups in the polyurethane molecule, such as -CH2- groups from PPG, urethane carbonyl (C=O), C-N bonds, N-H bonds, and C-O-C ether linkages, by finding distinct absorption bands at various wavenumbers [64]. This information can be used to describe polyurethane's structure and makeup and to learn more about the chemical processes involved in its creation.

4.3 SEM Analysis:

The nano alumina SEM pictures of the material exhibited several significant properties. According to the photographs, the nano alumina particles were evenly distributed across the surface during the preparation process, showing excellent dispersion.

The nano alumina particles were found to be tiny, spherical agglomerates with an average size in the nanometer range upon closer inspection. The particles' surfaces displayed a smooth and distinct morphology, demonstrating a high degree of purity and a low level of contaminants or impurities [65].

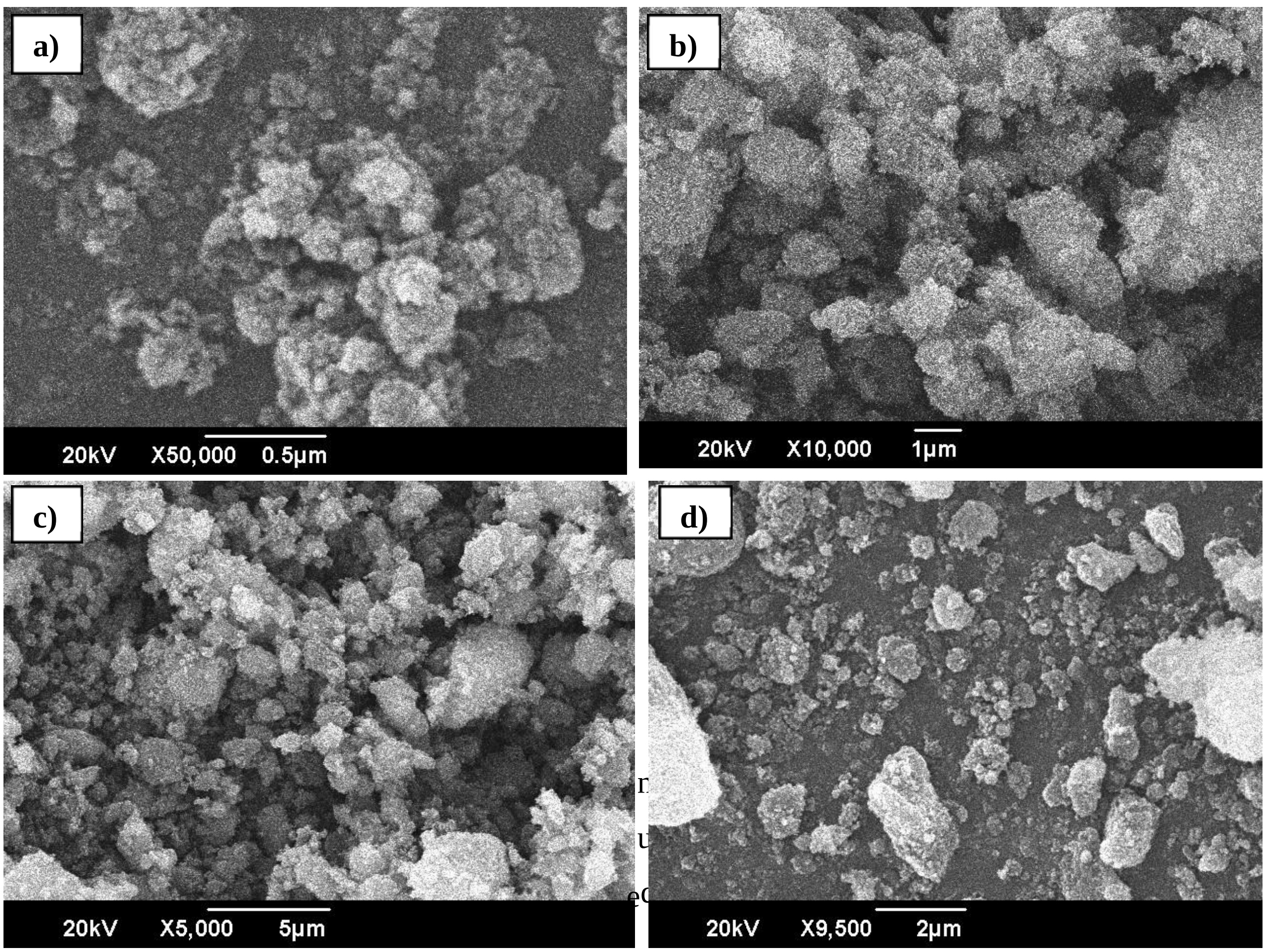

Figure 4.6 SEM images of nano alumina at different resolutions

pictures allowed for a precise evaluation of their morphology and shape. The particles' uniformity and regularity of structure point to a planned synthesis process[66].

The SEM-EDS elemental analysis further supported the identity of the nano alumina sample by confirming the presence of aluminum and oxygen.

Overall, the nano alumina SEM pictures gave detailed information on the sample's particle size, distribution, morphology, and purity. Understanding the material's properties and making the most of its prospective uses in areas like catalysis, composite materials, and biological applications depends heavily on the characteristics that have been identified [67].

4.4 Contact angle analysis:

By measuring the angle created between a liquid droplet and the material's surface, the contact angle analysis technique evaluates a material's wettability and surface energy. The contact angle study sheds light on the surface qualities and adhesion traits of the coatings when applied to mild steel substrates with various coatings[53].

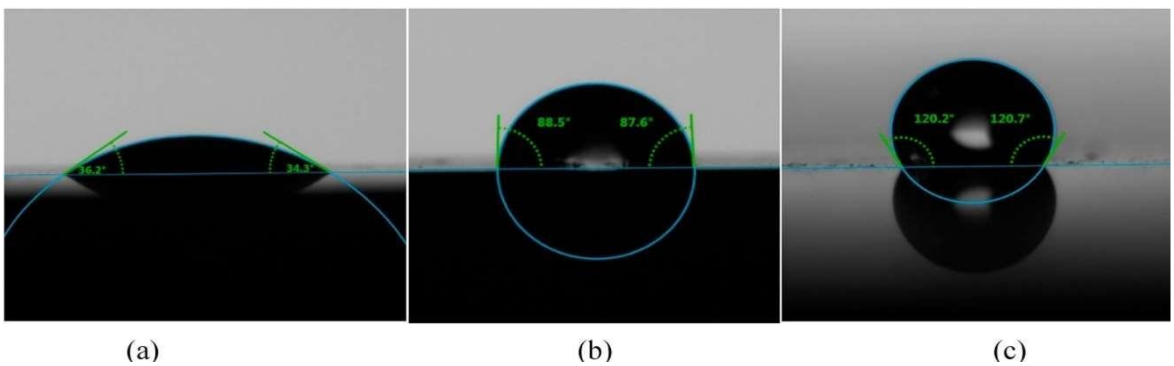

Figure 4.7 Contact angle analysis of (a) Primer-coated mild steel substrate. (b) Base-coated mild steel substrate. (c) PU/nano alumina coated mild steel substrate.

Sample 1: Primer Coated Mild Steel (Contact Angle: 36°)

The mild steel substrate coated with a primer layer had a contact angle of 36 degrees, according to the examination of contact angles. A surface with this contact angle is considered to be somewhat hydrophobic, which means that it has some water-repelling characteristics [68]. The primer coating probably provides some level of protection for the mild steel substrate and could serve as a transitional layer between coatings. The surface may be partially wettable but may be difficult for water to spread due to its moderate hydrophobicity.

Sample 2: Base-coated mild steel (contact angle: 88.5°)

The contact angle analysis showed an 88.5-degree contact angle for the mild steel substrate with the base coat applied. When compared to Sample 1, a contact angle of this size denotes a much higher level of hydrophobicity. Better surface defense and water repellency are probably provided by the base coat [69]. A higher contact angle suggests superior water resistance and probable anti-corrosion qualities since water droplets tend to bead up and interact with the surface in a limited way.

Sample 3: Clear-coated mild steel coated with PU/nano alumina

The ultimate protective layer is revealed by the contact angle analysis of the mild steel substrate covered in PU/nano alumina as a transparent coat. The formulation and the properties of the nanomaterial would determine the precise contact angle value for this sample. However, adding nano alumina to a polyurethane (PU) clear coat can greatly improve the surface characteristics.

When nano alumina particles are present, the contact angle may rise, enhancing the hydrophobicity. A larger contact angle means the coated surface will be more resistant to abrasion, moisture, and other environmental variables including pollution and toxins. The clear coat made of PU and nano alumina is anticipated to have high scratch resistance and durability, improving the general functionality and appearance of the mild steel substrate.

In conclusion, contact angle research of mild steel substrates with various coatings provides important details on the surface characteristics and functionality of the coatings. The findings can assist scientists and engineers in fine-tuning coating formulas for particular applications, including corrosion prevention, scratch resistance, and general durability under a variety of environmental conditions[54].

4.5 Scratch and Mar resistance test:

The mild steel substrate, which had a polyurethane-nano alumina clearcoat applied to it, was tested for scratch resistance by exposing coated samples to several sandpapers of increasing grit sizes to gradually amplify the severity of scratches on the substrate. This procedure sought to mimic various abrasive interactions that the coated surface might come into contact with in actual situations [70].

The preparation of the coated mild steel circular samples with a 1-inch diameter ensured a homogenous and strongly adherent polyurethane-nano alumina clearcoat.

Five different sandpapers, 180, 320, 600, 1000, and 2000, were chosen, ranging in grit size from coarse to fine. Each piece of sandpaper was firmly placed, and the force used during the test by the scratch tester was calibrated [71].

The coated side of the coated mild steel samples was placed down on each piece of sandpaper for the scratch testing. The sample was moved back and forth or linearly across the sandpaper surface under regulated and planned stress. To make scratches on the surface, a certain number of strokes (for example, 10 strokes) were repeatedly applied.

The coated mild steel samples were meticulously inspected in the right illumination after each scratch test. We looked for obvious evidence of sandpaper damage, such as scratches, on the surface [72].

Based on the degree of the scratches left by each sandpaper, the scratch resistance of the coated mild steel substrate was assessed. When utilizing the coarser sandpapers (such as 180 and 320 grit), deeper and more extensive scratches were seen. Larger abrasive particles in these sandpapers led to more substantial material removal from the coated surface during the scratch test. The coated surface, therefore, demonstrated reduced scratch resistance to severe abrasive contacts.

On the other hand, the scratches on the coated mild steel substrate were shallower and less extensive when employing finer sandpapers (such as 1000 and 2000 grit) [73]. Smaller abrasive particles in finer sandpapers result in less material removal and less harm to the coated surface. The coated surface consequently showed greater scratch resistance to minor abrasive contacts.

Each scratch test's data was recorded and analyzed to reveal important information about the coating's scratch resistance at various grit levels. The findings of this examination can be used to improve coating formulation, choose appropriate coatings for applications, and improve the overall toughness and aesthetics of coated steel surfaces used in automobiles or other applications.

4.6 Atomic Force Microscopy:

The Atomic Force Microscopy (AFM) topographic analysis was carried out to meticulously examine the surface characteristics of a Polyurethane nano alumina clearcoat that had been applied to a mild steel substrate. This process yielded several noteworthy observations.

AFM images of uncoated mild steel:

AFM images of uncoated mild steel shows comparatively rough surface. The z axis shows 462.8nm. The roughness of MS in three dimensions can be given as 21.8nm, 26.4nm and 127nm in x, y and z dimensions respectively.

Figure 4.8 2-D AFM image of uncoated mild steel

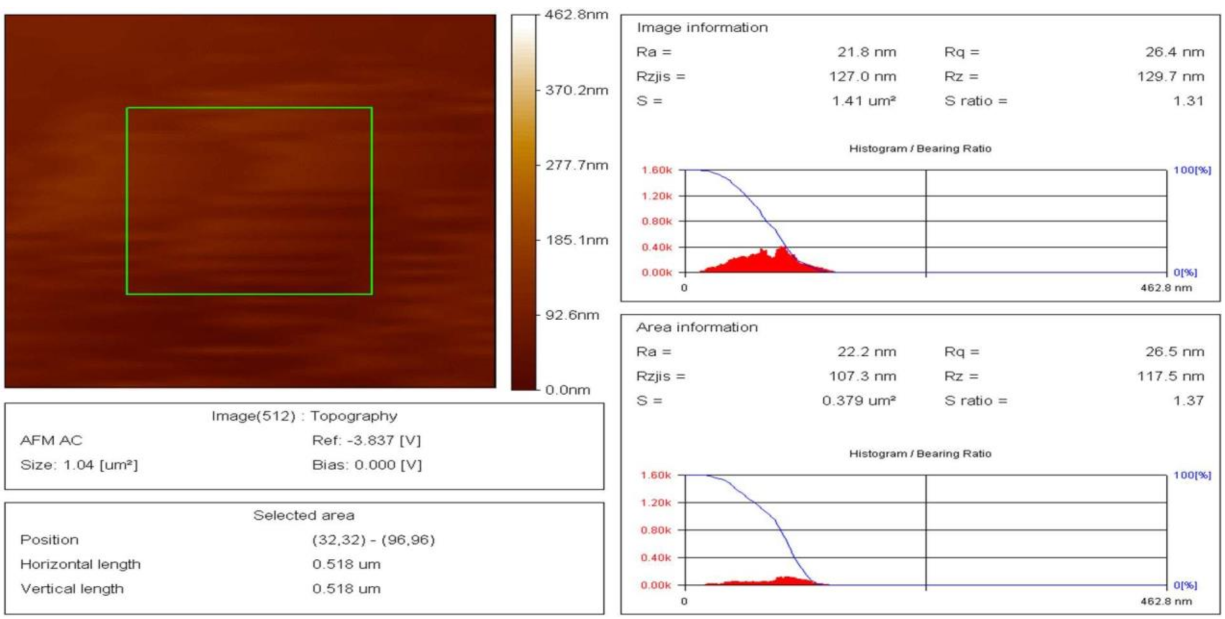

Figure 4.9 Roughness of uncoated mild steel

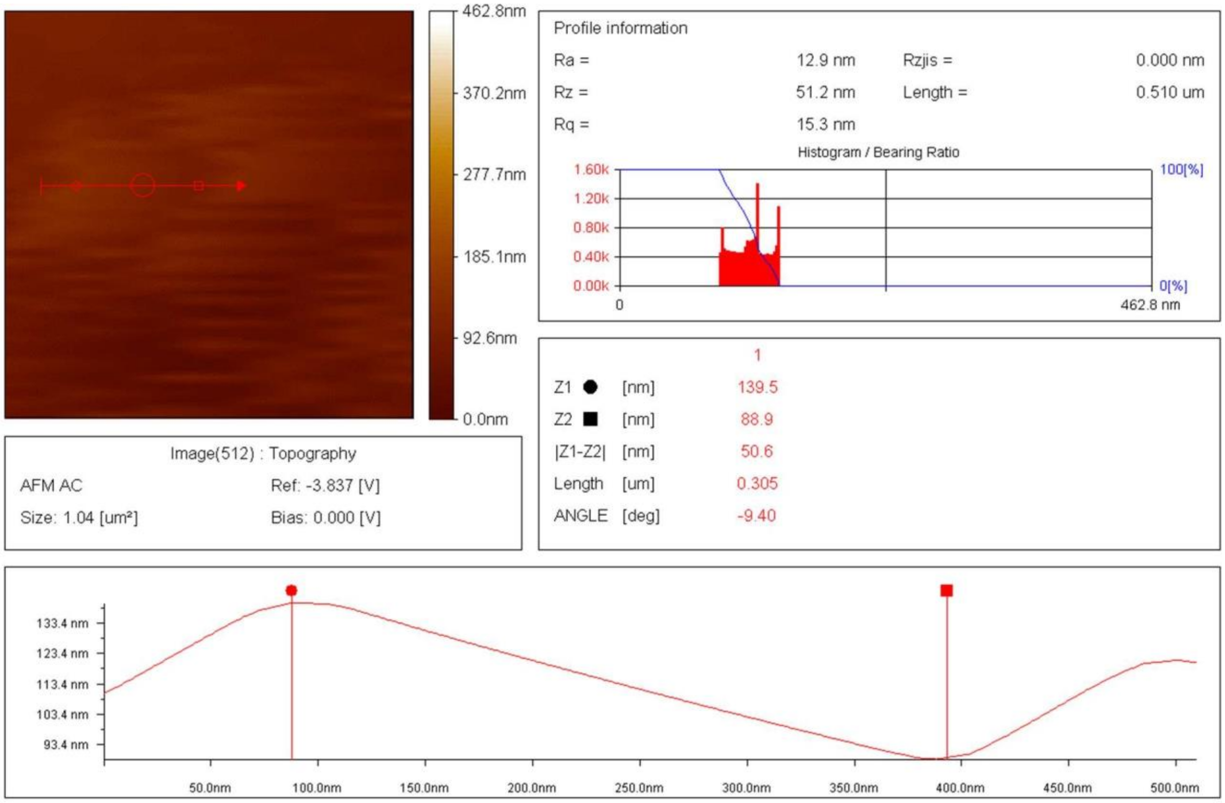

Figure 4.10 Thickness of uncoated mild steel

AFM images of primer coated mild steel:

The Atomic Force Microscopy (AFM) topographic analysis was carried out to meticulously examine the surface characteristics of primer coated MS substrate.

Figure 4.11 2-D AFM image of primer coated mild steel

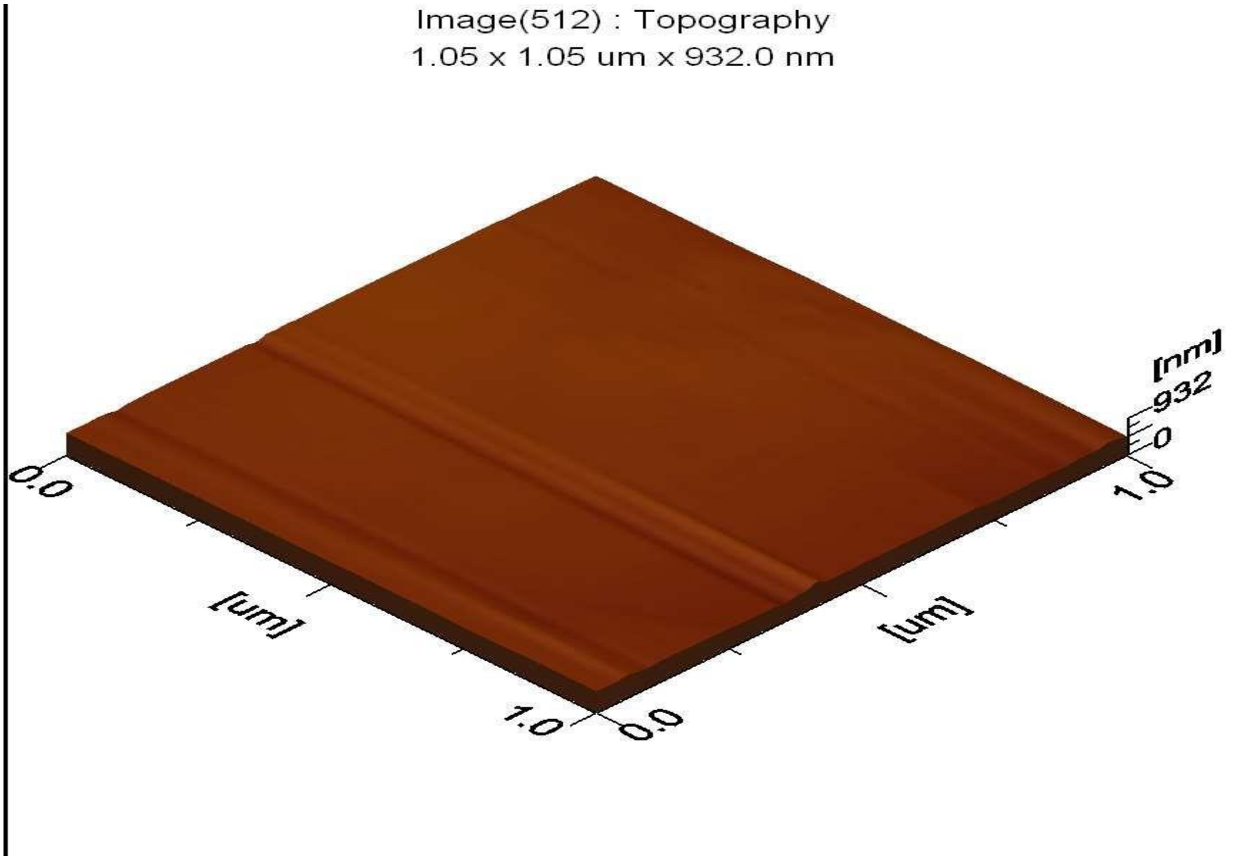

Figure 4.12 3-D AFM image of primer coated mild steel.

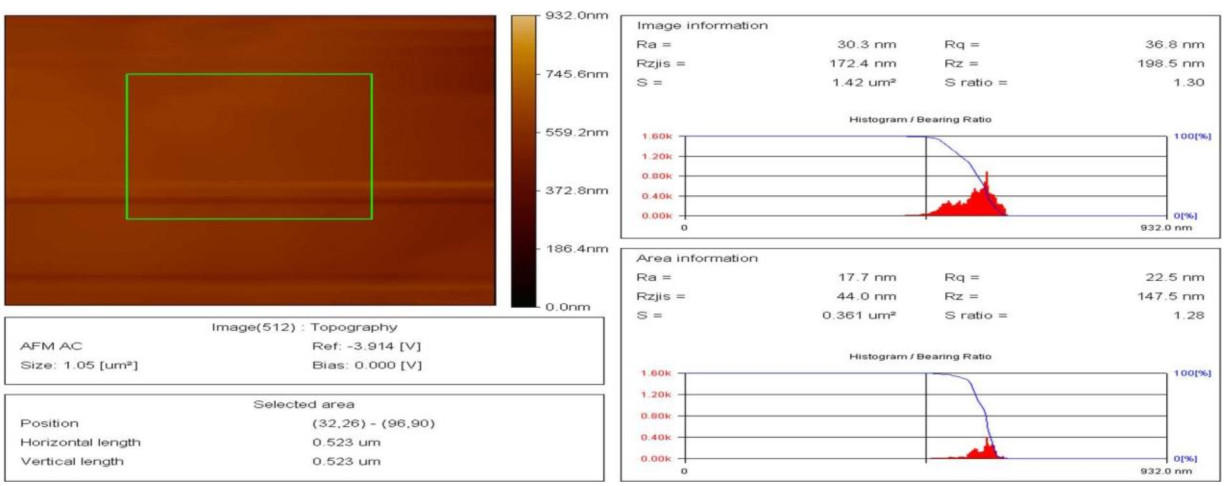

Figure 4.13 Roughness of primer coated mild steel

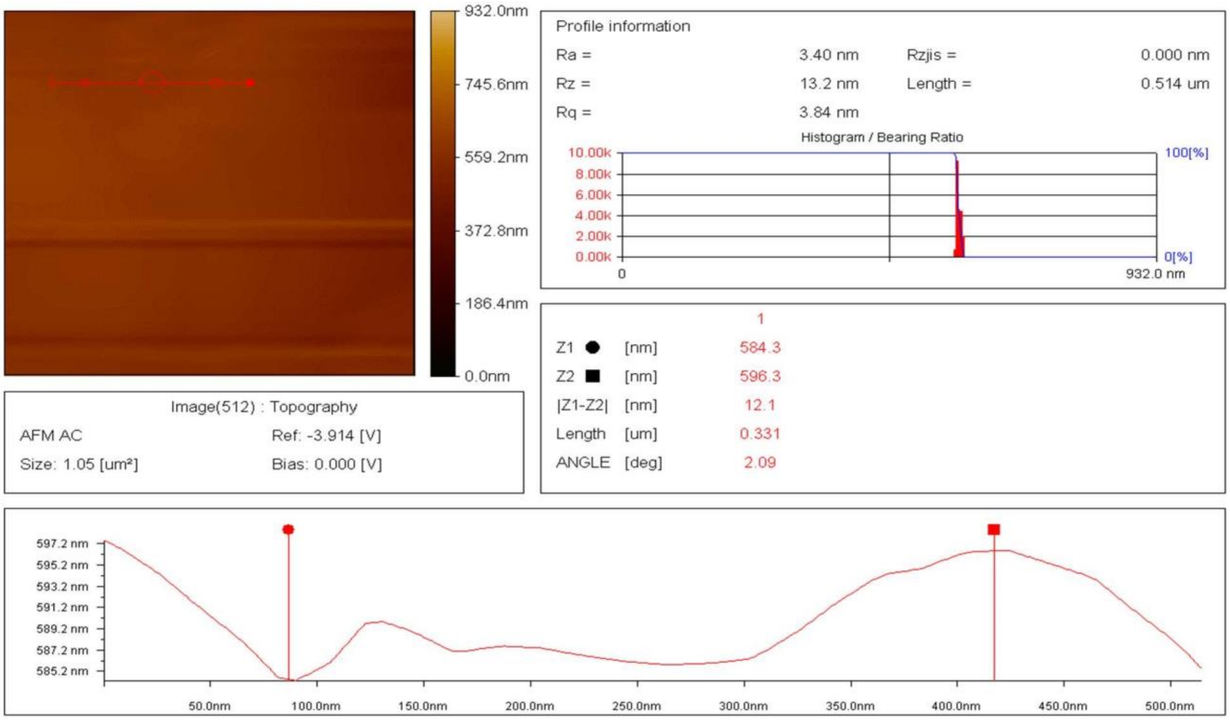

Figure 4.14 Thickness of mild primer coated mild steel.

AFM images of base coated Mild steel:

Figure 4.15 2-D AFM image of base coated mild steel.

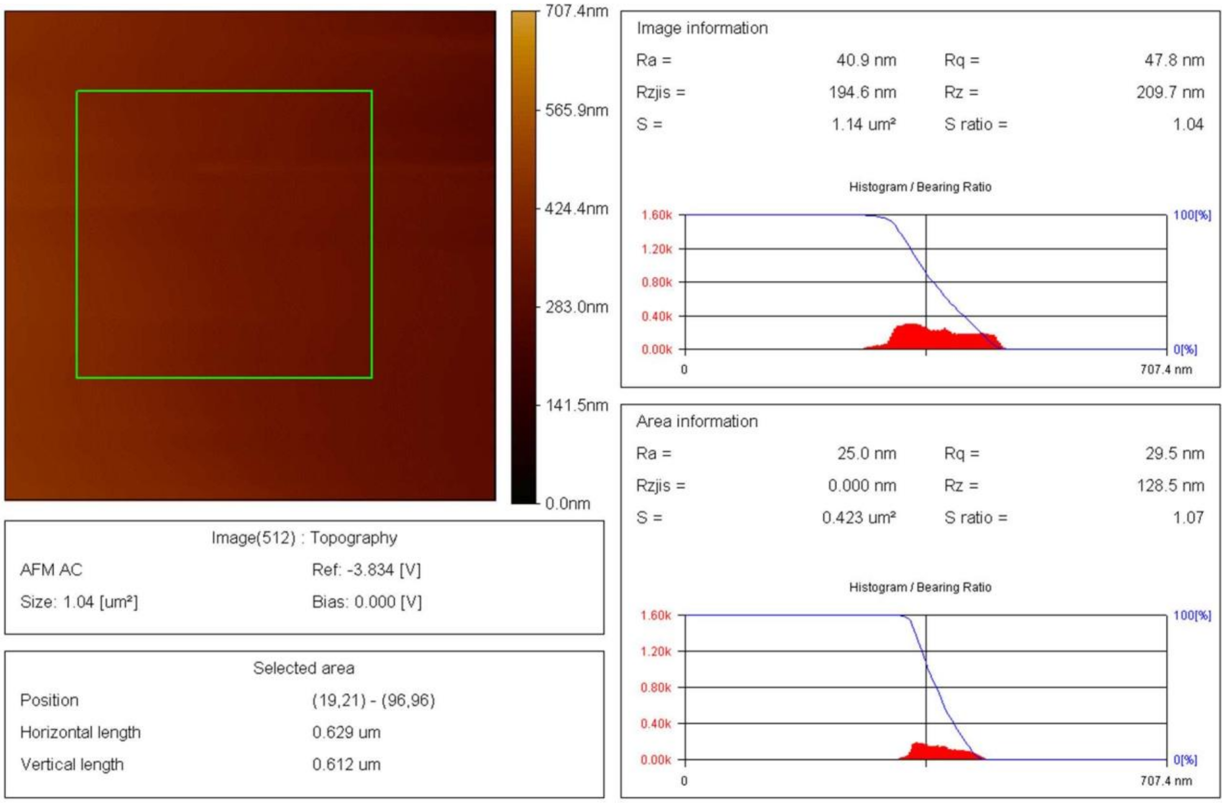

Figure 4.16 Roughness of base coated mild steel.

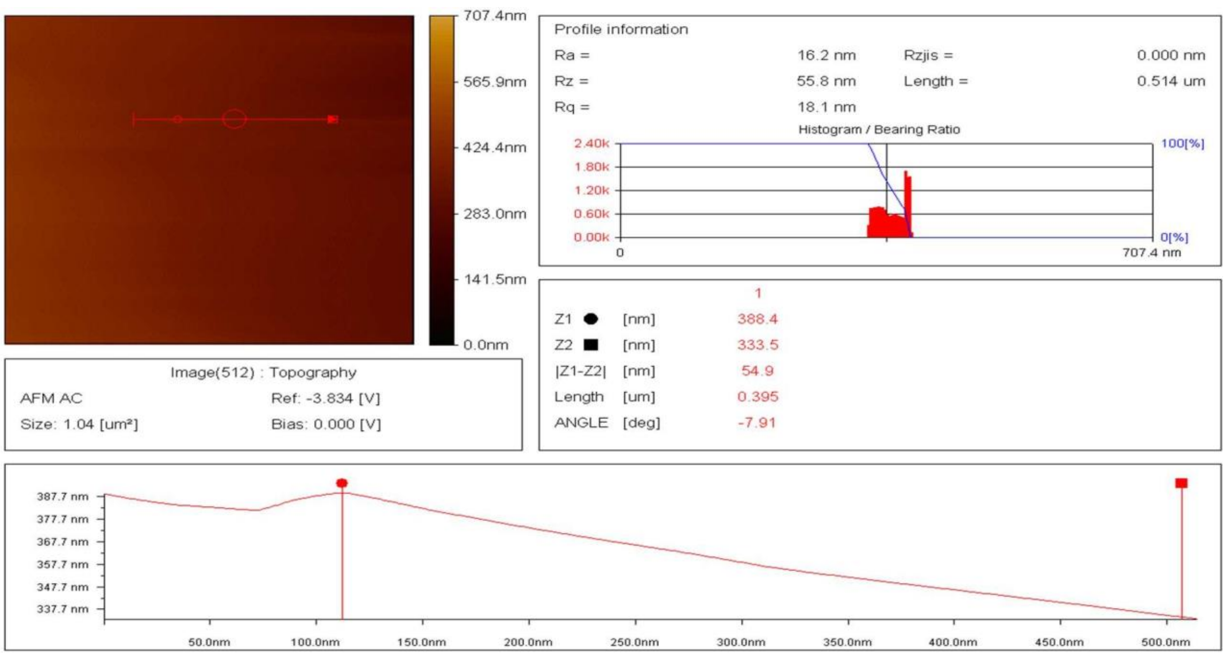

Figure 4.17 Thickness of base coated mild steel

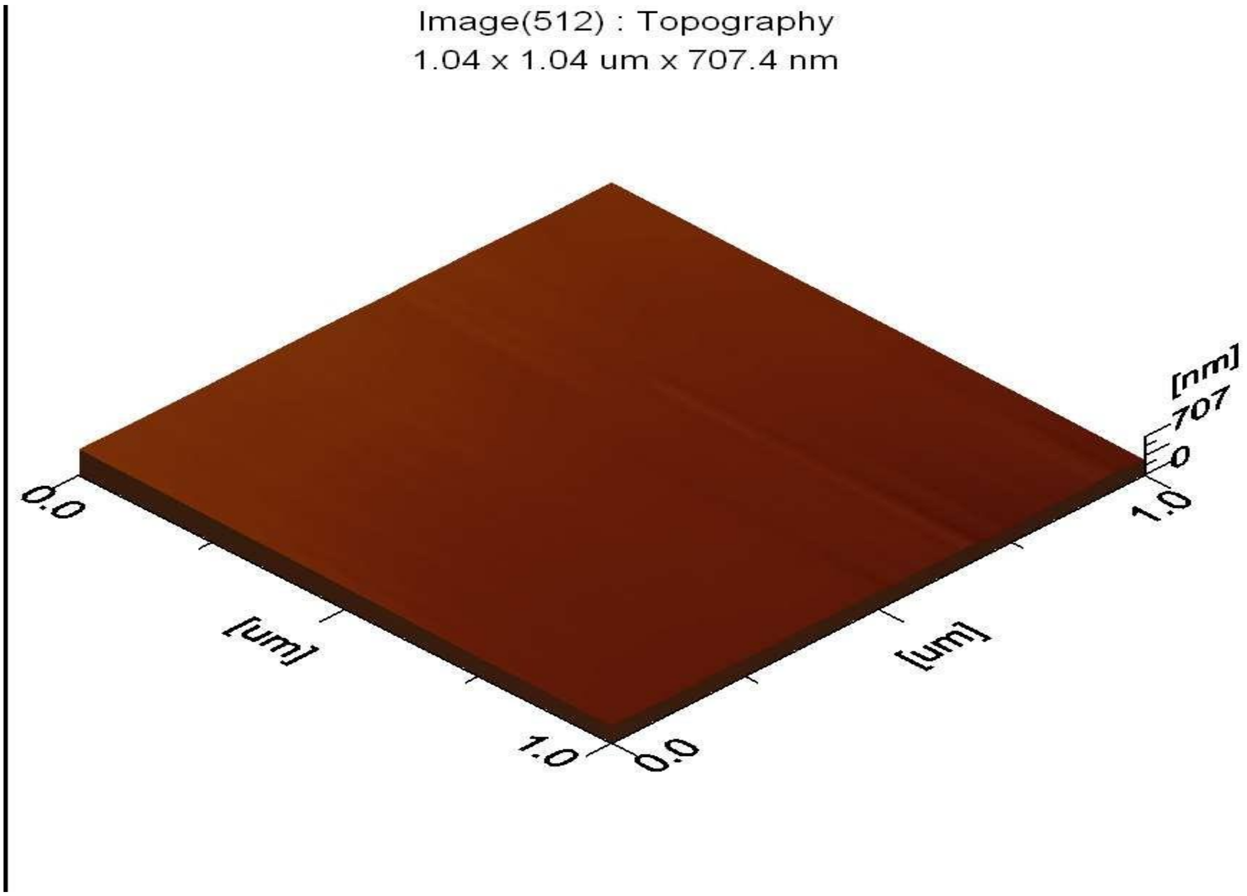

Figure 4.18 3-D AFM image of base coated mild steel

AFM images of clear coated mild steel:

The Atomic Force Microscopy (AFM) topographic analysis was carried out to meticulously examine the surface characteristics of a Polyurethane nanloalumina clearcoat that had been applied to a mild steel substrate. This process yielded several noteworthy observations:

Homogeneous Dispersion: The AFM analysis revealed that the components comprising the clearcoat were evenly and uniformly distributed across the substrate's surface. This level of uniform dispersion suggests that any particles or constituents within the clearcoat mixture were thoroughly blended, without any noticeable clustering or agglomeration. This is a crucial aspect of coating quality as it ensures that the material's properties are consistent throughout the coated area.

Uniform Distribution: The clearcoat displayed a remarkable degree of consistency in its distribution across the substrate. This means that the coating had spread evenly, without any discernible variations or irregularities in thickness. Such uniform distribution is significant for achieving a smooth and aesthetically pleasing surface finish, particularly in applications where visual appearance is essential.

Excellent Film Formation: The AFM analysis provided evidence of excellent film formation during the curing process. Film formation refers to the clearcoat's ability to create a continuous and uninterrupted layer over the substrate. In this case, the clearcoat exhibited a seamless film formation, free from any air traps or pinholes. The absence of these defects is particularly critical as air traps and pinholes can compromise the integrity of the coating, making it less effective at protecting the substrate from environmental factors such as corrosion.

Surface Roughness: The AFM measurements indicated that the surface roughness of the coated panels fell within a relatively narrow range, specifically between 11.1 nanometers and 12.6 nanometers. Surface roughness measurements are vital for understanding the texture of a coated surface. In this context, the controlled and consistent roughness within this range suggests that the clearcoat achieved a specific desired level of surface texture. This parameter can be critical in applications where friction, adhesion, or appearance requirements need to be met precisely.

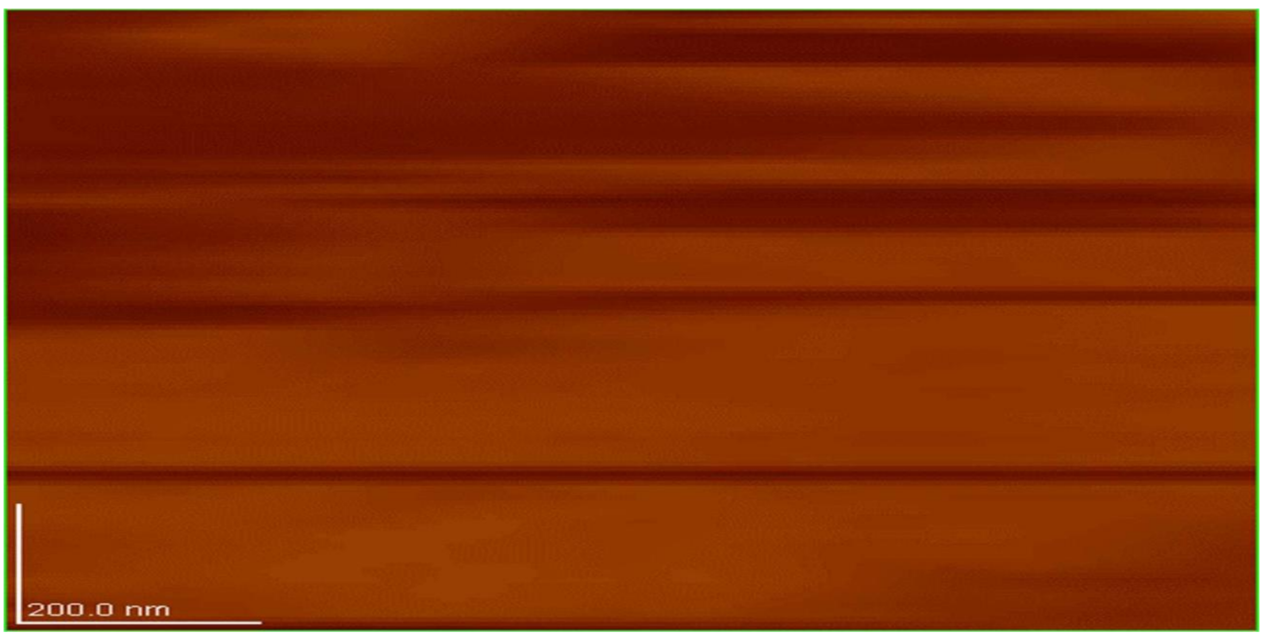

Figure 4.19 2-D AFM image of clear coated mild steel

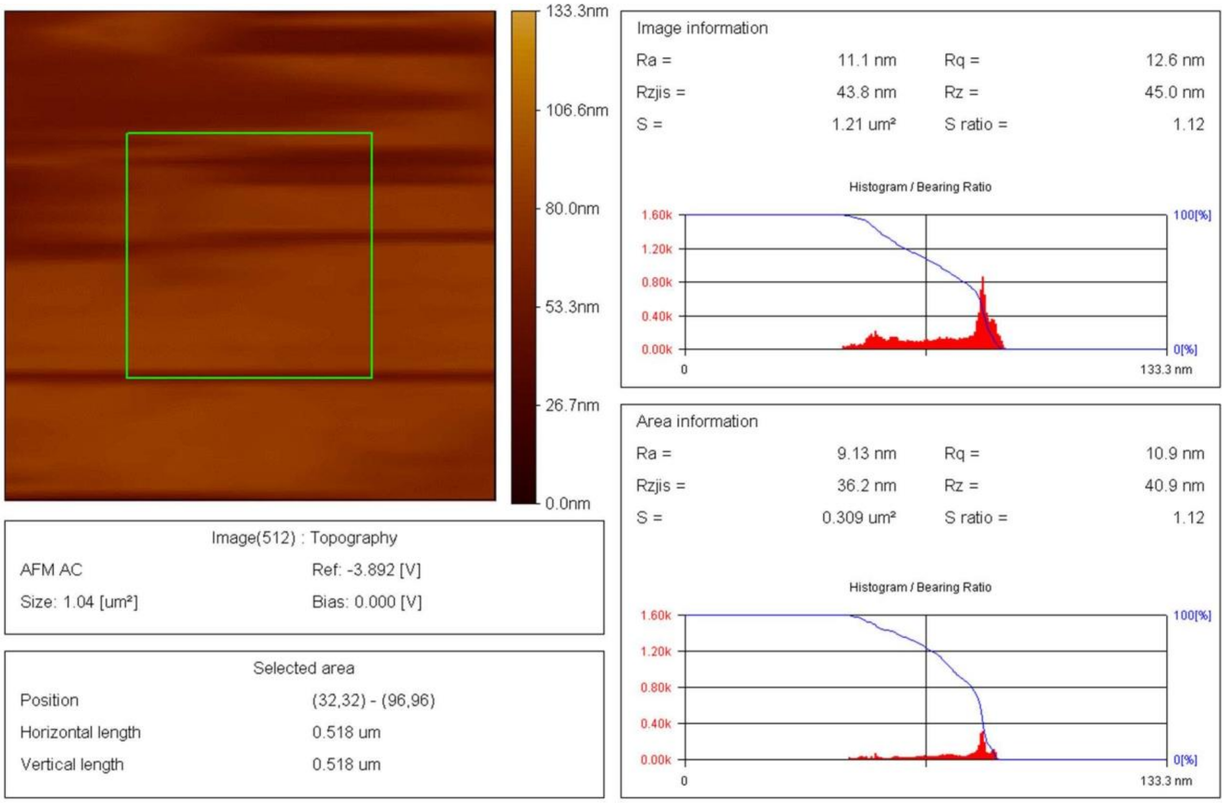

Figure 4.20 Roughness of clear coated mild steel.

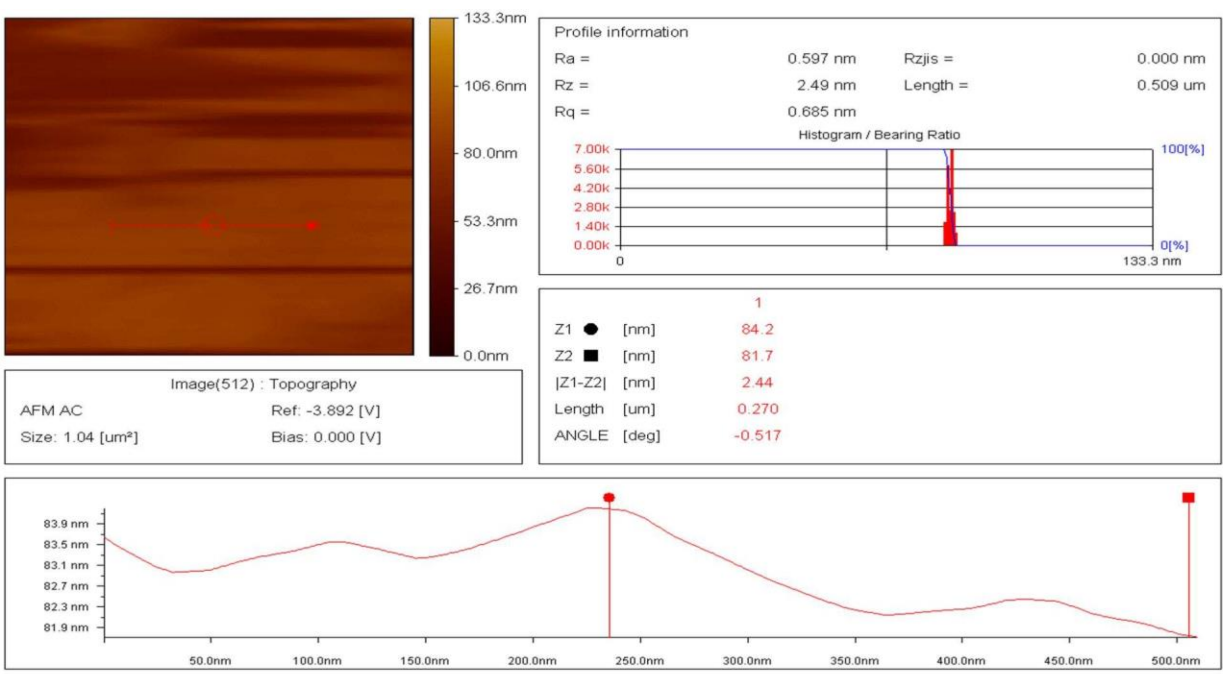

Figure 4.21 Thickness of clear coated mild steel.

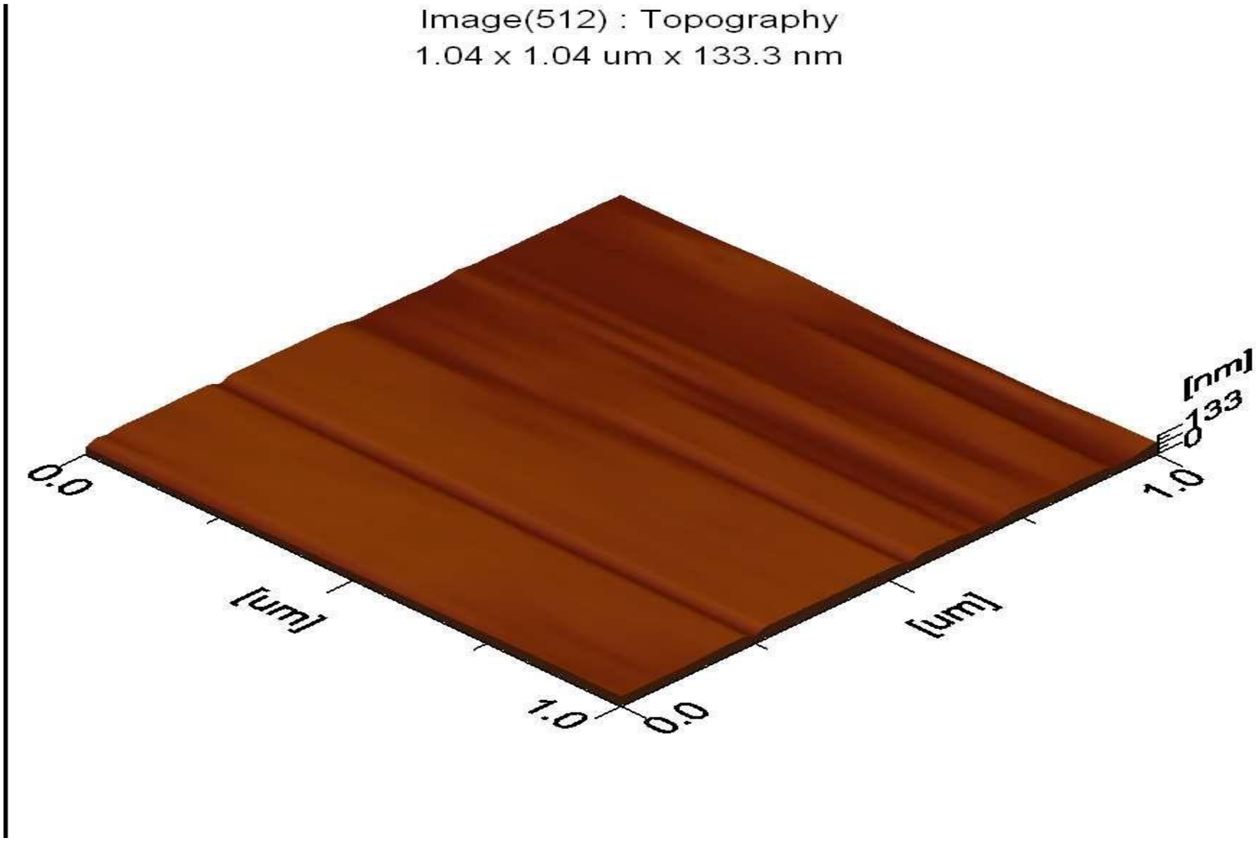

Figure 4.22 3-D AFM image of clear coated mild steel.

The detailed AFM analysis of the Polyurethane nano alumina clearcoat on the mild steel substrate unveiled a series of positive outcomes. These included the uniform distribution and homogeneous dispersion of coating components, ensuring consistency throughout the application. Additionally, the clearcoat displayed impeccable film formation without the presence of air traps or pinholes, attesting to its quality and effectiveness as a protective layer. Finally, the controlled surface roughness within a specific nanometer range highlighted the coating's ability to meet specific surface texture requirements. These findings collectively demonstrate the high quality and precision of the clearcoat application, making it suitable for various demanding applications.

Conclusion

Nano-alumina particles were created through sol gel method and then mixed with polyurethane to create coatings. The polyurethane's improved scratch and mar resistance from the nano-alumina made it appropriate for use in automotive applications. Processes for coating and synthesis were systematically described. The characteristics and effectiveness of the manufactured nano-alumina and coatings were confirmed by several characterization techniques, including XRD, FTIR, SEM, and contact angle analysis.

The outcomes showed that, in comparison to non-functionalized particles, functionalizing nano-alumina with stearic acid increased stability, hydrophobicity, and scratch resistance. The polyurethane-nano alumina coating demonstrated excellent dispersion and improved the abrasion resistance and water repellency of the mild steel substrate. The coating provided protection, especially against fine abrasives, according to the scratch tests.

With a focus on how coatings are used in the automotive sector, this thesis has offered an in-depth analysis of the development and relevance of coatings. It has looked at the development of automotive coatings from the first oleo resinous paints in the early 1900s to the modern multi-layered sophisticated paint systems. The literature review followed significant advancements in automotive finishing, such as the invention of spray-painting technology and electrodeposition coating. We went into great length about the primer's many layers and the basecoat's and clearcoat's unique functions. Nano-alumina particles were created through experimental effort and then mixed with polyurethane to create coatings. The polyurethane's improved scratch and mar resistance from the nano-alumina made it appropriate for use in automotive applications. Processes for coating and synthesis were systematically described. The characteristics and effectiveness of the manufactured nano-alumina and coatings were confirmed by several characterization techniques, including XRD, FTIR, SEM, and contact angle analysis. The outcomes showed that, in comparison to non-functionalized particles, functionalizing nano-alumina with stearic acid increased stability, hydrophobicity, and scratch resistance. The polyurethane-nano alumina coating demonstrated excellent dispersion and improved the abrasion resistance and water repellency of the mild steel substrate. The coating provided protection, especially against fine abrasives, according to the scratch tests.

5 References

1. Paul, S., *Surface coatings. Science and technology.* 1985.
2. Barbezat, G., A. Nicol, and A.J.W. Sickinger, *Abrasion, erosion and scuffing resistance of carbide and oxide ceramic thermal sprayed coatings for different applications.* 1993. **162**: p. 529-537.
3. Fotovvati, B., et al., *On coating techniques for surface protection: A review.* 2019. **3**(1): p. 28.
4. Munger, C.G., *Corrosion prevention by protective coatings.* 1985.
5. Khramov, A., et al., *Hybrid organo-ceramic corrosion protection coatings with encapsulated organic corrosion inhibitors.* 2004. **447**: p. 549-557.
6. Kotecki, D. and J.J.W.J.-I.W.R.S. Ogborn, *Abrasion resistance of iron-based hard facing alloys.* 1995. **74**(8): p. 269-278.
7. Wegmann, A.J.P.i.O.C., *Chemical resistance of waterborne epoxy/amine coatings.* 1997. **32**(1-4): p. 231-239.
8. Duecoffre, V., et al., *Emulsifiers with high chemical resistance: a key to high-performance waterborne coatings.* 1998. **34**(1-4): p. 200-205.
9. Tsuzuki, T., X.J.R.J.o.T. Wang, and Apparel, *Nanoparticle coatings for UV protective textiles.* 2010. **14**(2): p. 9-20.
10. Chiavari, C., et al., *Organosilane coatings applied on bronze: influence of UV radiation and thermal cycles on the protectiveness.* 2015. **82**: p. 91-100.
11. Reiners, G., U. Beck, and H.A.J.T.S.F. Jehn, *Decorative optical coatings.* 1994. **253**(1-2): p. 33-40.
12. Mattiello, J.J., *Protective and decorative coatings*. 1945: US Government Printing Office.
13. Hegemann, D., et al., *Design of functional coatings.* 2005. **23**(1): p. 5-11.
14. Martinu, L., et al., *Plasma-enhanced chemical vapor deposition of functional coatings.* 2010: p. 392-465.
15. Badv, M., et al., *Single and multi-functional coating strategies for enhancing the biocompatibility and tissue integration of blood-contacting medical implants.* 2020. **258**: p. 120291.

16. Sundararajan, G., D. Sen, and G.J.W. Sivakumar, *The tribological behavior of detonation sprayed coatings: the importance of coating process parameters.* 2005. **258**(1-4): p. 377-391.
17. Dasgupta, A. and J.S.J.A.j. Sirkis, *Importance of coatings to optical fiber sensors embedded in'smart'structures.* 1992. **30**(5): p. 1337-1343.
18. Scrinzi, E., et al., *Evaluation of aesthetic durability of waterborne polyurethane coatings applied on wood for interior applications.* 2011. **72**(1-2): p. 81-87.
19. Arcos, D. and M.J.J.o.M.C.B. Vallet-Regí, *Substituted hydroxyapatite coatings of bone implants.* 2020. **8**(9): p. 1781-1800.
20. Akafuah, N.K., et al., *Evolution of the automotive body coating process—A review.* 2016. **6**(2): p. 24.
21. Khanna, A.S., *High-performance organic coatings*. 2008: Elsevier.
22. Standeven, H.J.J.o.t.A.I.f.C., *The development of decorative gloss paints in Britain and the United States C. 1910–1960.* 2006. **45**(1): p. 51-65.
23. Mohanty, D., et al., *Characteristic properties of base coat of automobile paint: enhancement in scratch and abrasion resistance by nanoscale reinforcement—a review.* 2023. **80**(1): p. 185-240.
24. Acik, G., et al., *Synthesis and properties of soybean oil-based biodegradable polyurethane films.* 2018. **123**: p. 261-266.
25. Giampieri, A., et al., *A review of the current automotive manufacturing practice from an energy perspective.* 2020. **261**: p. 114074.
26. Salehi, M., et al., *The role of TiO2 nanoparticles on the topography and hydrophobicity of electrodeposited Ni-TiO2 composite coating.* 2020. **8**(2): p. 025008.
27. Casadio, F., et al., *Scientific investigation of an important corpus of Picasso paintings in Antibes: new insights into technique, condition, and chronological sequence.* 2013. **52**(3): p. 184-204.
28. Engelmann, S., *Advanced Thermoforming: Methods, Machines and Materials, Applications, Automation, Sustainability, and the Circular Economy*. 2023: John Wiley & Sons.
29. Hirsch, J.J.T.o.N.M.S.o.C., *Recent development in aluminium for automotive applications.* 2014. **24**(7): p. 1995-2002.

30. Salihoglu, G. and N.K.J.J.o.e.m. Salihoglu, *A review on paint sludge from automotive industries: Generation, characteristics and management.* 2016. **169**: p. 223-235.
31. Doerre, M., et al., *Advances in automotive conversion coatings during pretreatment of the body structure: A review.* 2018. **8**(11): p. 405.
32. Ab Rahim, N., et al. *Reducing Bits in Electrodeposition Process of Commercial Vehicle-A Case Study*. in *IOP Conference Series: Materials Science and Engineering*. 2016. IOP Publishing.
33. Nabiilah, A., et al., *Bits Reduction in the Electrodeposition Process of a Pickup Truck: a Case Study.* 2017. **11**(1).
34. Hamzah, W.A.W., et al., *Automotive Paint Production Line Blistering Improvement and Approach.* 2022. **2**(1): p. 19-28.
35. Maric, M., et al., *Synchrotron FTIR characterisation of automotive primer surfacer paint coatings for forensic purposes.* 2014. **118**: p. 156-161.
36. Buckle, J., D. MacDougall, and R.J.C.S.o.F.S.J. Grant, *PDQ—paint data queries: the history and technology behind the development of the Royal Canadian Mounted Police Forensic Laboratory Services Automotive Paint Database.* 1997. **30**(4): p. 199-212.
37. Domnick, J., et al., *Investigations of the drying process of a water based paint film for automotive applications.* 2011. **50**(5-6): p. 495-502.
38. Jalili, M.M. and S.J.P.i.O.C. Moradian, *Deterministic performance parameters for an automotive polyurethane clearcoat loaded with hydrophilic or hydrophobic nano-silica.* 2009. **66**(4): p. 359-366.
39. Tahmassebi, N., et al., *Effect of addition of hydrophobic nano silica on viscoelastic properties and scratch resistance of an acrylic/melamine automotive clearcoat.* 2010. **43**(3): p. 685-693.
40. Yari, H., et al., *The weathering performance of acrylic melamine automotive clearcoats containing hydrophobic nanosilica.* 2014. **11**: p. 351-360.
41. Sung, L.-P., et al., *Scratch behavior of nano-alumina/polyurethane coatings.* 2008. **5**: p. 419-430.
42. Kardar, P., M. Ebrahimi, and S.J.P.i.O.C. Bastani, *Study the effect of nano-alumina particles on physical–mechanical properties of UV cured epoxy acrylate via nano-indentation.* 2008. **62**(3): p. 321-325.

43. Al-Haik, M., et al., *Synthesis and characterisation of nano alumina dental filler.* 2008. **1**(4): p. 411-428.
44. Xie, Y., et al., *The effect of novel synthetic methods and parameters control on morphology of nano-alumina particles.* 2016. **11**: p. 1-11.
45. Shojaie-Bahaabad, M. and E.J.M.L. Taheri-Nassaj, *Economical synthesis of nano alumina powder using an aqueous sol–gel method.* 2008. **62**(19): p. 3364-3366.
46. Li, M., et al., *Water-based acrylate copolymer/silica hybrids for facile preparation of robust and durable superhydrophobic coatings.* 2018. **447**: p. 489-499.
47. Shen, Y., et al., *Multi-type nanoparticles in superhydrophobic PU-based coatings towards self-cleaning, self-healing and mechanochemical durability.* 2021. **159**: p. 106451.
48. Zhang, X.-F., et al., *Robust superhydrophobic coatings prepared by cathodic electrophoresis of hydrophobic silica nanoparticles with the cationic resin as the adhesive for corrosion protection.* 2020. **173**: p. 108797.
49. Farag, H.K. and F.J.J.o.M.C. Endres, *Studies on the synthesis of nano-alumina in air and water stable ionic liquids.* 2008. **18**(4): p. 442-449.
50. Kaur, A., et al., *A review on template assisted synthesis of multi-functional metal oxide nanostructures: Status and prospects.* 2022. **286**: p. 116005.
51. Park, J.-Y., et al., *Alumina-supported iron oxide nanoparticles as Fischer–Tropsch catalysts: Effect of particle size of iron oxide.* 2010. **323**(1-2): p. 84-90.
52. Akia, M., et al., *Optimizing the sol–gel parameters on the synthesis of mesostructure nanocrystalline γ-Al2O3.* 2009. **122**(1-3): p. 72-78.
53. Zhang, R., et al., *Effect of nano alumina on the properties of fluorinated polyurethane.* 2019. **12**(24): p. 4120.
54. Carreño, F., et al., *Synthesis and characterization of superhydrophobic surfaces prepared from silica and alumina nanoparticles on a polyurethane polymer matrix.* 2019. **135**: p. 205-212.
55. Tok, A., F. Boey, and X.J.J.o.M.P.T. Zhao, *Novel synthesis of Al2O3 nano-particles by flame spray pyrolysis.* 2006. **178**(1-3): p. 270-273.
56. Yilbas, B., et al., *Laser texturing of alumina surface for improved hydrophobicity.* 2013. **286**: p. 161-170.

57. Penna, M.O., et al., *Organophilic nano-alumina for superhydrophobic epoxy coatings.* 2020. **255**: p. 123543.
58. Boomadevi Janaki, G. and J.R.J.J.o.M.S. Xavier, Part A, *Effect of indole functionalized nano-alumina on the corrosion protection performance of epoxy coatings in marine environment.* 2020. **57**(10): p. 691-702.
59. Ammar, S.H., H.J. Khadim, and A.J.N.f.E.E. Al-Farraji, *Synthesis of Ni@ γ-Al 2 O 3@ PID\SiW recyclable nanocatalyst and its catalytic reduction and antibacterial activities.* 2020. **5**: p. 1-11.
60. AA, E., M. Mousa, and W. Ali, *Effect Of Aluminum Oxide Nanofibers On The Abrasive Wear Of Polyvinyl Chloride Coating.*
61. Jiao, L., et al., *Thermal degradation characteristics of rigid polyurethane foam and the volatile products analysis with TG-FTIR-MS.* 2013. **98**(12): p. 2687-2696.
62. Gregori Valdes, B.S., et al., *Synthesis and characterization of isosorbide-based polyurethanes exhibiting low cytotoxicity towards HaCaT human skin cells.* 2018. **10**(10): p. 1170.
63. Trovati, G., et al., *Characterization of polyurethane resins by FTIR, TGA, and XRD.* 2010. **115**(1): p. 263-268.
64. Jiang, Z., et al., *Study of FTIR spectra and thermal analysis of polyurethane.* 2006. **26**(4): p. 624-628.
65. Bhatnagar, A., E. Kumar, and M.J.C.E.J. Sillanpää, *Nitrate removal from water by nano-alumina: Characterization and sorption studies.* 2010. **163**(3): p. 317-323.
66. Krishnaveni, C. and S.S.J.M.T.P. Selvan, *Study on nano-alumina in concrete.* 2021. **46**: p. 3648-3652.
67. Farahmandjou, M. and N.J.J.o.C.P.R. Golabiyan, *New pore structure of nano-alumina (Al2O3) prepared by sol gel method.* 2015. **16**(2): p. 1-4.
68. Chen, X., et al., *Large-scale fabrication of superhydrophobic polyurethane/nano-Al2O3 coatings by suspension flame spraying for anti-corrosion applications.* 2014. **311**: p. 864-869.
69. Adapala, P., et al., *Development and evaluation of nano-silica dispersed polyurethane based coatings for improved anti-graffiti and scratch resistance.* 2015. **5**(12): p. 808.

70. Bahramnia, H., et al., *Epoxy/polyurethane nanocomposite coatings for anti-erosion/wear applications: A review.* 2020. **54**(22): p. 3189-3203.
71. Mohanty, D., *Improvement of scratch and abrasion resistance properties of automobile paint*. 2023.
72. Bai, Y., et al., *Recent progresses of superhydrophobic coatings in different application fields: An overview.* 2021. **11**(2): p. 116.
73. Kodgire, V.V., *Organic inorganic hybrids: preparation, characterization and applications in adhesives and coatings.* 2012.