

CHARACTERIZATION OF CERAMIC COATING FOR SCRATCH RESISTANCE ON ROBOT GRIPPER SURFACE

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Mechanical Engineering

By

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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A++" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of S. GUGAN (Reg. No. 40150720) and P. MANISH REDDY (Reg. No. 40150050) who carried out the project entitled "CHARACTERIZATION OF CERAMIC COATING FOR SCRATCH RESISTANCE ON ROBOT GRIPPER SURFACE" under our supervision from December 2023 to April 2024.

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We P. MANISH REDDY (Reg. No. 40150050) and S. GUGAN (Reg. No. 40150720) hereby declare that the Project Report entitled "**CHARACTERIZATION OF CERAMIC COATING FOR SCRATCH RESISTANCE ON ROBOT GRIPPER SURFACE**" done by us under the guidance of **Dr. R.B. DURAIRAJ., M.Tech., Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

1. 

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DATE: 06-04-2024

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ABSTRACT

Robot gripper surfaces play a critical role in ensuring effective and reliable manipulation of objects in various industrial and research applications. However, these surfaces are susceptible to wear and damage during frequent use, leading to reduced performance and service life. To address this issue, we present a comprehensive study on the characterization of ceramic coatings applied to robot gripper surfaces to enhance scratch resistance. Our findings reveal that specific ceramic coatings exhibit superior scratch resistance compared to conventional materials. The study provides valuable insights into the potential of ceramic coatings to enhance the durability and performance of robot gripper surfaces. This research contributes to the advancement of robotics and automation technologies, offering promising avenues for the development of more robust and long-lasting robot gripper systems.

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	v
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
1	INTRODUCTION	1
	1.1 Role of Ceramic Coatings	3
	1.2 Significance of Scratch Resistance	3
	1.3 Research Gap and Objectives	3
	1.4 Methodological Approach	4
	1.5 Potential Implications and Contributions	4
	1.6 Thermal Spraying Technology	4
	1.7 Direct Current (D.C.) Plasma Spraying	6
	1.8 Thermal Spray Coatings for Wear Resistance	7
2	LITERATURE SURVEY	8
3	AIM AND SCOPE	11
	3.1 Objective	11
	3.2 Scope of The Present Investigation	12
4	EXPERIMENTAL WORK	14
	4.1 Methodology	14
	4.2 Chemical composition	16
	4.2.1 Aluminum plate	16
	4.2.2 Ceramic coating material	17
	4.3 Plasma spraying method	19
	4.4 Advantages	23

CHAPTER NO.	TITLE	PAGE NO.
5	RESULTS AND DISCUSSION	25
	5.1 Results	25
	5.1.1 Micro Hardness Test	26
	5.1.2 Friction Test	29
	5.1.3 Sem Test	30
6	CONCLUSION	33
	REFERENCE	35

LIST OF TABLES

TABLE NO	TITLE	PAGE NO.
4.1	Chemical composition of AL6061	16
4.2	Chemical composition of Ceramic coating material	18
4.3	Specifications of plasma arc spray machine	20
4.4	Coating thickness	21
4.5	Distance Specification of plasma arc spray machine	21
4.6	Power requirements of plasma arc spray machine	22
5.1	Micro Hardness	27
5.2	Friction test parameters	29
5.3	Different elements weight and atomic %	32

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
4.1	Photography Of Raw Material (Aluminum Plate)	17
4.2	Photography Of Plasma Arc Spray Machine	19
4.3	Photography Of the CeramicCoated Al Alloy	22
5.1	Micro Hardness Graph	28
5.2	Micro Hardness Tested Sample	28
5.3	Friction Test Sample	29
5.4	Microscopy Figures of Coated Material	30
5.5	EDS Layered Figures of Coated Material	31
5.6	Graph Of Compositions of Different Elements	32

CHAPTER 1

INTRODUCTION

Soft grippers are revolutionizing the landscape of industrial automation, offering a dynamic and adaptable approach to handling objects of various shapes, sizes, and compliances. In contrast to their traditional rigid counterparts, soft grippers leverage flexible materials and innovative actuation mechanisms to provide enhanced versatility, efficiency, and safety in industrial applications.

Traditional grippers, predominantly composed of stiff components, are designed for specific tasks, resulting in costly, heavy, and bulky systems that struggle to accommodate the increasing diversity of parts encountered in modern industrial settings. These grippers often necessitate frequent tool changes and additional hardware, leading to increased operational cycle times and reduced workspace efficiency. Moreover, the rigid limits of traditional grippers limit their adaptability to objects with different geometries and compliances, requiring multiple grippers to be deployed for various tasks.

Soft grippers address these limitations by employing pliable structures that enable direct handling of objects with diverse characteristics. These grippers can adjust their shape and contact area to securely grasp objects through pinching, wrapping around, or using pincergrrips, facilitating efficient manipulation of objects with varying shapes, sizes, and compliances. This adaptability is crucial in industries where handling a wide range of parts is essential, such as manufacturing, logistics, and assembly.

The modular and lightweight design of soft grippers further enhances their utility, allowing for easy installation and integration with robotic manipulators. Unlike traditional grippers, which may be cumbersome and difficult to install, soft grippers are typically lightweight and modular, facilitating rapid deployment and customization for specific tasks or environments. This modularity enables users to adapt the gripper to different applications quickly, improving overall system flexibility and scalability.

Safety is another critical aspect where soft grippers excel compared to traditional grippers, particularly those relying on high-pressure pneumatic actuators. Traditional grippers operating at high pressures pose safety risks in the event of a failure, potentially causing injury to operators or damage to equipment. Soft grippers, on the other hand, often utilize safer actuation mechanisms, such as negative-pressure systems or granular jamming, which reduce the risk of injury and equipment damage.

Furthermore, soft grippers offer high dexterity and manipulation capabilities, making them suitable for a wide range of industrial tasks. Whether it's picking and placing objects on an assembly line, sorting items in a warehouse, or handling delicate materials in a laboratory setting, soft grippers offer the precision and control required for complex manipulation tasks. This high level of dexterity is achieved through innovative actuation mechanisms, such as pneumatic networks, granular jamming, or cable-driven systems, which enable precise control of the gripper's movements.

Despite these advantages, the state of the art in soft grippers still faces challenges and limitations that researchers are actively addressing. One limitation is the scalability of payload capacity, particularly for grippers relying on positive-pressure actuators. While soft grippers excel at handling small to moderately sized objects, they may struggle with larger or heavier payloads due to limitations in the actuation mechanism or structural design. Additionally, soft grippers may require smooth surfaces for optimal gripping performance, limiting their applicability in environments where objects have irregular or textured surfaces.

Another challenge is the trade-off between speed and payload capacity. Soft grippers that prioritize speed may sacrifice payload capacity, while those designed for heavier payloads may sacrifice speed. Achieving a balance between speed and payload capacity remains a key area of research and development in soft gripper technology.

Ongoing research efforts are focused on addressing these challenges and further advancing the capabilities of soft grippers. Innovations in materials science, actuation mechanisms, and control algorithms are driving improvements in gripper performance, efficiency, and reliability. Additionally, advancements in additive manufacturing

technologies are enabling the rapid prototyping and production of custom soft grippers tailored to specific applications.

1.1 ROLE OF CERAMIC COATINGS

Ceramic coatings have emerged as a promising solution to address the challenges faced by robot gripper surfaces. Ceramic materials are renowned for their exceptional hardness, making them highly resistant to scratches and abrasion. By applying ceramic coatings to gripper surfaces, it is possible to significantly extend their lifespan and enhance their resistance to wear, impacts, and other forms of mechanical stress.

1.2 SIGNIFICANCE OF SCRATCH RESISTANCE

Scratch resistance is a critical attribute for robot gripper surfaces, as it directly influences their durability and performance. Ceramic coatings offer superior scratch resistance compared to traditional surface treatments, thereby improving the overall effectiveness and longevity of robot grippers in industrial applications.

1.3 RESEARCH GAP AND OBJECTIVES

Despite the growing interest in ceramic coatings for robot grippers, there exists a notable research gap in terms of comprehensive characterization. This study aims to address this gap by conducting empirical research on how ceramic coatings perform in real-world applications and assess their effectiveness in enhancing scratch resistance on robot gripper surfaces.

The objectives of this research include:

- Employ recognized industry-standard methodologies to appraise the scratch resistance of ceramic coatings on robot gripper surfaces.
- Utilize advanced imaging techniques to scrutinize the microstructure and morphology of coated surfaces.
- Investigate the chemical composition of ceramic coatings and assess any alterations resulting from wear.
- Conduct practical experiments to evaluate the performance of ceramic-coated grippers in terms of grip strength, precision, and object manipulation.

- Subject ceramic-coated grippers to accelerated wear tests to predict the durability of the coatings.
- Examine the effects of environmental conditions, such as temperature fluctuations, humidity levels, and chemical exposure, on the scratch resistance of ceramic coatings.

1.4 METHODOLOGICAL APPROACH

Characterizing ceramic coatings for scratch resistance on robot gripper surfaces requires a multifaceted approach. The methodology employed in this study will incorporate recognized industry-standard techniques, such as Rockwell or Vickers hardness tests, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS). Additionally, practical experiments will be conducted to evaluate the performance of ceramic-coated grippers under various conditions.

1.5 POTENTIAL IMPLICATIONS AND CONTRIBUTIONS

The findings of this research are expected to have significant implications for the field of robotics and automation. Enhanced scratch resistance provided by ceramic coatings can contribute to the extension of the operational lifespan of robot grippers, thereby reducing maintenance and downtime and ultimately elevating the efficiency of automated systems. Furthermore, the characterization data generated from this study can aid in selecting the most suitable ceramic coatings, enhancing the reliability and robustness of robot grippers across diverse industrial sectors.

1.6 THERMAL SPRAYING TECHNOLOGY

The role of surface engineering is becoming increasingly crucial in the modern manufacturing industry as higher requirements are being set to achieve surface modification through material deposition. In many engineering applications, coating technologies can engender a performance that may not be achievable only with the base material. For example, a coated surface works outperforms a bare surface at higher temperature exposure, under corrosive, abrasive and/or erosive wear

conditions as well as ensures biocompatibility. Those are just a few examples of the motivation for coating implementation.

Various methods exist to generate such base material enhancements, and the deposited layer's thickness can set an initial demarcation. For example, thin film deposition, such as physical vapor deposition (PVD) or chemical vapour deposition (CVD), provides less than

20 μm layers. Even if this approach has multiple benefits (exceptional hardness and corrosion resistance), they have notable limitations. The requirement of a reduced-pressure environment raises the costs of the PVD and CVD processes while limiting the sizes of the object to be coated. On the other hand, thick film deposition methods, distinguished by a coating thickness of more than 30 μm , do not present such constraints. These processes include weld overlays, brazing, chemical or electrochemical plating and thermal spraying. This last deposition method can be of particular interest, due to the vast and emerging applications of the coating it can produce. In fact, the layer deposited with thermal spraying various techniques can be adapted to various industrial needs. Examples range from thermal barrier coating on aircraft turbine engine parts to wear-resistant depositions on textile bobbins.

Another advantage of thermal spraying processes relies on the possibility of depositing different materials, which can grant benefits depending on different implementations. While the most common feedstock materials for thermal spray are metals, ceramics and cermet composites, thermally sprayed polymer coatings are now considered for potential applications. The thermal spraying process involves coating formation by depositing layers of either metallic or non-metallic particles in a molten or semi-molten condition. However, several thermal spraying processes do not entirely adhere to the presented definition, yet they are still classified as thermal spray techniques. The cold spray variant, in fact, does not rely on molten or semi-molten particles to form layers, but nevertheless, it is included as a thermal spray process. For the above reasons, the proceeding paragraphs will further elucidate the concept of thermal spraying.

1.7 DIRECT CURRENT (D.C.) PLASMA SPRAYING

The process of creating a jet plasma stream to deposit surface coating has been well-established in the industry since its development in the 1960s. From its concept, there have been introduced several methods to generate a plasma state in the thermal processes; however, one of the most common due to process versatility and cost comparison remains the Direct Current (D.C.) Plasma Spray. Its central concept relies on generating an arc between a cathode, usually in the form of a rod, and the nozzle itself, which functions as the interactive anode. The function of the produced arc is to heat the plasma gas injected at the cathode base, resulting in a high temperature and velocity jet at the exit of the nozzle, used to impart the appropriate thermal/kinetic energy to the feedstock particles. Depending on multiple parameters, such as torch configuration or which plasma gases are involved, the peak temperature and velocities of the jet stream to be achieved can be considered quite variable. However, a range between 12.000 to 15.000K for peak temperature and 500 to 2.500 m/s for peak stream velocity can be considered a reasonable generalization.

Furthermore, particle injection into the heated stream can present different configurations depending on the spraying torch. One of the most common implementations is the radial injection system, whose concept is to introduce the feedstock powders perpendicularly to the plasma stream. Two ulterior sub models can be explored, one relying on the injection inside the spraying nozzle, at the arc base, the other injecting directly outside the nozzle, with a possible inclination angle relative to the stream. However, radial injection systems present a challenging limitation. They are relatively sensitive to feedstock powder size distribution. In fact, the high velocity of the plasma jet will create size segregation when the powder is injected. As a result, only the particles with a conforming size will manage to enter the middle of the stream and consequently be deposited, resulting in a significant waste of powdered material and an increase in the process cost. Another element to acknowledge is the momentum at which the particle needs to be injected into the jet flow, with a possible “bouncing” effect resulting in particles with slow velocity and low mass or completely passing through the stream for higher velocity and higher mass particles. The

alternative to overcome radial injection limitations is to adopt axial spraying, introducing the feedstock particles axially to the flow. This process can be achieved by implementing different torch configurations. An example can be shown by the Mettech Axial III torch, which benefits from three cathodes and anodes by converging the plasma jets into a single output high-velocity stream. Furthermore, the powder is fed through the convergence just before the nozzle. With the presented solution, the properties of the deposited coating will not be affected by feedstock varying powder size as severely as with the radial mode.

1.8 RESISTANCE THERMAL SPRAY COATINGS FOR WEAR

Thermal spraying exists to enhance the surface engineering performance of a base material exposed to different conditions, from high temperature to bio-environment, corrosive and wear-prone conditions. Many industrial applications require protection against sliding and abrasive wear. For example, in the mining industry alone, 210,000 million Euros constitute the annual estimated economic losses. Resistance against wear remains a crucial consideration in the design of numerous devices, including parts of gas turbines used in aerospace and power generation, compressors, pumps, and rollers used in paper manufacture, wire drawing, and other industrial components. Thermally sprayed coatings became an ideal option for providing surface protection in environments with high levels of wear due to the wide variety of material compositions it can process. As the general terminology of “wear” refers to a physical material removal from the surface of a material, to fully situate the protective role of thermal sprayed coatings, the following subsections are dedicated to coatings for three wear conditions. In conclusion, soft grippers represent a promising solution for overcoming the limitations of traditional grippers in industrial automation. With their flexible structures, versatile grasping modes, and innovative actuation mechanisms, soft grippers offer enhanced functionality, efficiency, and safety in a wide range of industrial applications. While challenges and limitations remain, ongoing research and development efforts are driving advancements in soft gripper technology, paving the way for more efficient and adaptable automation systems.

CHAPTER-2

LITERATURE SURVEY

Bruna Aparecida Rezende et al In order to obtain better cutting tool performance, coatings appear as an alternative in the machining process. The goal of the coating is to improve tribological conditions in the chip-tool and tool-workpiece interfaces. On the other hand, the use of coated tools decreases the wear of the tools. This study discusses the ceramic coatings characterization deposited in WC tools. The Al_2O_3 and TiO_2 films present properties such as thermal stability, chemical inertia, high hardness, and good mechanical properties. These coatings were prepared by sol-gel technology. The results indicated that the multilayer coating presents better adhesion on the substrate. Moreover, lower coefficients of friction were found for the coated tools. The analysis of variance (ANOVA) was used to evaluate the influence of the cutting parameters and tool coating on the cutting force. The lower cutting force was obtained using the multilayer-coated tool. Thus, the sol-gel method appears as a novel technique to deposit coating in the WC tools to improve their performance.

Ronny M. Gouveia et al. The difficulties in the machining of duplex stainless steel are well known. However, research on this matter is rather limited. Suppliers offer quite different cutting tools for the same raw material, with end mills of two, three or even four knives and a huge number of distinct coatings, some of them under commercial brands, making it difficult to assess the advantages they offer. Furthermore, there is a remarkable difference among the several types of duplex stainless steel available nowadays on the market. The present work intends to assess the machining performance of different tools, analyzing the behavior and wear mechanisms with two different cutting lengths, keeping constant the machining trajectory. Some other parameters were also kept constant, such as cutting speed, depth of cut and cutting width, as well as feed per tooth. The machining process was carried out under lubricated conditions, using an emulsion of 5% oil in water. Tools provided with a different number of teeth and surface coatings were tested, analyzing

the wear behavior of each cutting length using scanning electron microscopy, trying to identify wear performance and how each coating contributes to increased tool life. The surfaces produced were also analyzed by means of profilometry measurements, correlating toolwear and part surface roughness. This comparative study allows determining the advantages of different tools relative to others, based on coatings and tool geometry.

Sirisak Tooptong et al A series of turning experiments is conducted on Flake Graphite Iron (FGI), Compacted Graphite Iron (CGI), and Nodular Graphite Iron (NGI) under dry condition. With uncoated carbide inserts, the adhesion layer, covering the entire tool-work interfaces, is formed when cutting CGI and NGI, which reduced flank wear compared to FGI. By contrast, the flank wear on the multilayer-coated inserts, obviously significantly reduced compared to the uncoated inserts, is significantly higher for CGI and NGI compared to FGI. Finite Element Analysis (FEA) is used to estimate the average flank temperature under various cutting conditions, which indicates the elevated cutting temperature with CGI and NGI. With the cutting temperatures from FEA simulations, the observed flank wear for FGI, CGI, and NGI conforms to the two-body abrasive wear model, indicating a common abrasive wear mechanism. Therefore, the main reason for the poor machineabilities of CGI and NGI is the higher cutting temperatures on the cutting tools when cutting CGI and NGI.

Natália Fernanda Santos Pereira et al The present study proposes a novel coating applied on high-speed steel (HSS) drills, thinner and less expensive than the commercial ones. This new coating consists of a silicon dioxide (SiO_2) deposited by sol-gel process, and its performance was studied by means of drilling tests in nodular cast iron. For comparison purposes, two other cutting tools were also evaluated: uncoated and Tin-coated by physical vapor deposition process. Four outputs were investigated: thrust force, hole average surface roughness, hole average diameter (DA), and tool wear (VBBmax). Analysis of variance (ANOVA) was applied to determine the influences of the coatings and drilling parameters on the cutting

performances. The results indicated that the SiO₂ coating achieved performances significantly superior to the uncoated tools. They also behaved close to the commercial Tin coating in some respects. Scanning electron microscopy (SEM) analysis showed predominant flank wear in all the uncoated and coated tools. The “number of holes/maximum flank wear (VBB_{max})” ratios were calculated, indicating a performance 315% better for the SiO₂-coated tool when compared to the uncoated one. Therefore, the deposition of SiO₂ by sol-gel method is a promising technique to coat rapidly and efficiently cutting tools, including for tools of complex geometries such as drills.

Wen Deng et al. The cavitation erosion damage of the materials in seawater is more severe than in freshwater due to the coupling effect of mechanical impact, instantaneous high temperature and seawater corrosion. This study reported that the ceramic/organic coating fabricated by the vacuum pressure impregnation epoxy resin into as-sprayed ceramic coating is introduced. The corrosion inhibition mechanism of the ceramic-based coatings in seawater after introducing the epoxy resin was further clarified. The influence of epoxy resin on the microstructure and mechanical properties of the ceramic coatings were systematically evaluated based on SEM, Vicker hardness and scratch results. The corrosion behaviors of the ceramic-based coatings with/without sealing treatment were evaluated by electrochemical corrosion tester. Their cavitation erosion performance in seawater was comparatively studied using the ultrasonic vibration cavitation testing machine. It was demonstrated by the experimental results that the hardness, compactness, and cohesive strength of the ceramic/organic coatings were greatly improved compared with those of the as-sprayed ceramic coatings. The epoxy resin filled the defects of the ceramic coatings and effectively prevented the invasion of seawater. Accordingly, the anti-cavitation erosion of the ceramic/organic coatings was significantly improved.

CHAPTER-3

AIM AND SCOPE

3.1 AIM OF THE PROJECT

The objective of the tests was to assess the effectiveness of coating formation on aluminum alloys using the Plasma Arc Spraying method. Micro hardness analysis was conducted to verify the presence of a substrate-bonded coating, with thickness comparable to standard anodized coatings. The results of micro hardness measurements indicated that the black ceramic coatings exhibited significantly higher hardness compared to the aluminum alloy itself.

In response to evolving market demands, there's a growing need for higher quality casting surfaces. Alongside advancements in casting technology design, there's an increasing requirement to develop surface protection techniques for castings. The desired coatings are expected to offer enhanced corrosion resistance, as well as resistance against abrasion, scratches, and impacts, all while maintaining aesthetics and decorative appeal.

The Plasma Arc Spraying method was employed to deposit coatings onto aluminum alloys, aiming to improve their surface properties. Micro hardness analysis confirmed the formation of a substrate-bonded coating, which exhibited hardness levels like standard anodized coatings. Furthermore, the black ceramic coatings demonstrated notably higher hardness compared to the aluminum alloy itself, indicating their potential to enhance surface durability and performance.

The evolving landscape of market demands necessitates continuous advancements in surface protection techniques for castings. As such, the development of coatings that provide increased corrosion resistance, as well as resistance against abrasion, scratches, and impacts, while preserving aesthetics, becomes paramount. The findings from the tests underscore the potential of the Plasma Arc Spraying method in meeting these evolving requirements and improving the overall quality of casting surfaces.

3.2 SCOPE OF THE PRESENT INVESTIGATION

Thermal sprayed HEA coatings have shown immense potential of being next-generation coatings within their relatively brief time span under development. TS-HEAs have demonstrated promise, especially for applications in extreme engineering environments. There is further scope to study their properties in situ by methods such as higher temperature Nano indentation.

The advantage of TS manufacturing revolves around their ability to have rapid buildup of an engineered surface in comparison with vacuum-based film technology such as physical vapor deposition (PVD). The costlier alternatives of vacuum or low-pressure plasma spray are currently adopted for spraying oxygen-sensitive alloys, a detailed overview of the scope:

- Scratch Resistance Assessment:

Evaluate and characterize the scratch resistance properties of different ceramic coatings when applied to robot gripper surfaces. This includes assessing the coatings' ability to withstand scratches, wear, and abrasion under different conditions.

- Surface Analysis:

Conduct a comprehensive analysis of the coated gripper surfaces. This involves examining the microstructure, morphology, and composition of the ceramic-coated surfaces to identify any defects, cracks, or changes in the surface structure that may affect scratch resistance.

- Durability and Longevity Assessment:

Assess the long-term durability and wear resistance of the ceramic-coated gripper surfaces. This evaluation should consider factors such as the number of cycles, environmental conditions, and the effects of repeated use.

- Methodology and Testing:

Develop and employ testing methodologies to evaluate the scratch resistance of ceramic coatings, including industry-standard scratch tests, microstructural analysis.

- Cost-Benefit Analysis:

Evaluate the economic impact of using ceramic coatings on robot grippers. This includes estimating potential cost savings through reduced maintenance and replacement costs, as well as increased operational efficiency.

- Real-World Applications:

Explore how the findings from this investigation can be applied to a range of industries, including manufacturing, assembly, logistics, and any other sectors that rely on robotic systems. Understand the practical implications of enhancing the durability and scratch resistance of gripper surfaces.

- Innovation and Advancements:

Consider the potential for innovation in the development of new ceramic coating materials and processes. Investigate how ongoing research can lead to further advancements in this field.

- Practical Implementation:

Provide recommendations and insights into how the outcomes of this research can be practically implemented in industrial settings. This could involve guidance on coating selection, maintenance procedures, and best practices for achieving optimal gripper performance.

The investigation into the characterization of ceramic coatings for scratch resistance on robot gripper surfaces aims to contribute valuable knowledge and insights to the field of robotics and automation. The scope encompasses rigorous testing, analysis, and real-world application of ceramic coatings, with a focus on enhancing the durability and performance of robot grippers across various industries. The results of this investigation have the potential to revolutionize the way robot grippers are used, leading to increased efficiency.

CHAPTER 4

EXPERIMENTAL WORK

4.1 METHODOLOGY

The analysis procedure:

Choosing and analyzing ceramic coatings for scratch resistance on robot gripper surfaces involves a systematic methodology to ensure optimal performance and durability. Here's a step-by-step approach to guide you through the process:

Define Your Requirements: Identify the specific needs of your robot gripper surface, including the types of materials it will handle, environmental conditions, and expected wear and tear.

- **Material Selection:** Research and select ceramic materials suitable for your application, considering factors like hardness, thermal stability, and chemical resistance.
- **Surface Preparation:** Ensure that the robot gripper surface is properly cleaned and prepared before applying the ceramic coating. Surface preparation may include cleaning, sanding, and degreasing.
- **Coating Application:** Choose an appropriate method for applying the ceramic coating, such as spraying, dipping, or brushing. The choice will depend on the gripper's design and your resources.
- **Coating Thickness:** Control the thickness of the ceramic coating to achieve the desired scratch resistance. Measure and monitor the thickness using appropriate techniques, such as coating thickness gauges.
- **Curing and Drying:** Follow the manufacturer's recommendations for curing and drying the ceramic coating. This step is crucial to ensure the coating's durability and performance.
- **Adhesion Testing:** Perform adhesion tests to check the bond between the ceramic coating and the gripper surface. ASTM D3359 is a commonly used standard for this purpose.
- **Scratch Resistance Testing:** Evaluate the scratch resistance of the ceramic

coated gripper surface using standardized testing methods like ASTM D7027 or custom tests tailored to your specific needs.

- **Chemical Resistance Testing:** If chemical exposure is a concern, conduct chemical resistance tests to ensure the ceramic coating can withstand exposure to relevant chemicals in your application.
- **Abrasion Testing:** Test the ceramic coated gripper for abrasion resistance, as this can affect long term scratch resistance. ASTM D4060 or Taber Abrasion tests are often used for this purpose.
- **Performance Assessment:** After testing, assess the overall performance of the ceramic coated gripper surface, considering factors like scratch resistance, wear resistance, and adhesion.
- **Cost Analysis:** Evaluate the cost effectiveness of the chosen ceramic coating in comparison to alternative solutions. Consider factors like material cost, application costs, and expected maintenance.
- **Long Term Durability:** Monitor the ceramic coated gripper's performance over time to ensure it maintains its scratch resistance under real world conditions. Conduct periodic inspections and tests.
- **Maintenance and Repairs:** Develop a maintenance plan for the ceramic coated gripper surface. Determine how to repair or recoat the surface if necessary.
- **Documentation and Records:** Maintain detailed records of the entire process, including coating specifications, test results, maintenance schedules, and any issues encountered.
- **Continuous Improvement:** Continuously seek opportunities to improve the scratch resistance of the gripper surface by exploring new ceramic coatings or alternative solutions.
- **Safety Considerations:** Always prioritize safety when handling and applying ceramic coatings. Follow safety guidelines and use appropriate personal protective equipment (PPE).
- **Regulatory Compliance:** Ensure that your ceramic coating choice and

application process comply with any relevant regulations or industry standards.

- Robotic grippers find applications in various industries due to their ability to manipulate and handle objects effectively. Their adaptability, precision, and reliability make them essential components of robotic systems in a wide range of applications.

4.2 CHEMICAL COMPOSITIONS

4.2.1 Aluminum Plate AL6061(Base Material)

Aluminum Plate AL 6061 refers to a type of aluminum alloy that is commonly used in various industrial and structural applications. The designation "6061" denotes the specific alloy composition, which typically includes aluminum, magnesium, and silicon as primary elements. AL 6061 offers good mechanical properties, including high strength, good weldability, and excellent corrosion resistance. It is widely utilized in the aerospace, automotive, marine, and construction industries for components such as aircraft parts, bicycle frames, automotive parts, and structural frames. AL 6061 is available in various forms, including plates, sheets, bars, and extrusions, making it versatile for different manufacturing processes and applications.

Table.4.1 Chemical Composition of Aluminum Plate AL 6061

Element	Composition percentage (wt.%)
Aluminum	95.85-98.56
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron	0.0-0.7
Copper	0.15-0.40
Chromium	0.04-0.35
Zinc	0.0-0.25
Titanium	0.0-0.25
Manganese	0.0-0.15
Others	0.0-0.05



Fig:4.1 Photography of Raw Material (Aluminum Plate AL 6061)

4.2.2 Ceramic Coating Material

Ceramic coating materials are a type of protective coating applied to various surfaces to provide enhanced durability, resistance to corrosion, wear, and high temperatures. These coatings are composed of inorganic materials and offer several advantages over traditional organic coatings, such as paints and polymers. Some common ceramic coating materials include:

Silicon Carbide (SiC): Silicon carbide coatings provide excellent thermal stability, chemical resistance, and hardness. They are often used in high-temperature applications such as aerospace components, turbine blades, and industrial machinery.

Alumina (Al₂O₃): Alumina coatings offer high hardness, wear resistance, and thermal insulation properties. They are used in applications such as automotive exhaust systems, cutting tools, and semiconductor manufacturing.

Titanium Dioxide (TiO₂): Titanium dioxide coatings provide UV resistance and self-cleaning properties, making them suitable for outdoor applications like architectural surfaces and automotive paints.

Zirconia (ZrO₂): Zirconia coatings offer exceptional thermal barrier properties and resistance to thermal shock, making them ideal for applications in gas turbines, automotive engines, and industrial furnaces.

Ceramic Nanocomposites: These coatings combine ceramic nanoparticles with other materials to enhance specific properties such as toughness, adhesion, and corrosion resistance. They are used in various industries, including electronics, aerospace, and biomedical.

Silicon Nitride (Si₃N₄): Silicon nitride coatings provide excellent thermal shock resistance, high temperature stability, and wear resistance. They find applications in cutting tools, bearings, and turbine components.

Table.4.2. Chemical Composition of Ceramic Coating Material

Constituents	% by mass
Silicon Dioxide	66.57
Aluminum Oxide	21.60
Iron Oxide	1.41
Calcium Oxide	2.41
Sodium Oxide	1.41
Potassium Oxide	2.79
Zirconium Oxide	1.49

4.3 PLASMA SPRAYING METHOD

The ceramic material is prepared, usually in powder form. This substance may be a ceramic of any kind, including alumina, zirconia, or tungsten carbide.

Spraying: A high-temperature plasma stream is produced using an electric arc or RF plasma torch. Introduced into this stream, the ceramic powder quickly melts and is ejected onto the substrate surface.

"Coating Build-up": As the molten ceramic particles contact the substrate, they quickly solidify and layer by layer erect the ceramic coating. To reach the desired thickness, repeat this procedure.

Various factors, such as gas flow, powder feed rate, and torch power, are under control.

Benefits of plasma spraying include its ability to cover complex structures and durability to high temperatures as well as superior wear and corrosion resistance. It is frequently utilized for applications where strong ceramic coatings are required in the aerospace, automotive, and energy sectors.



Fig:4.2 Photography of Plasma Arc Spray Machine

Table.4.3. Specification Of Plasma Arc Spary Machine

Specification	Details
Input Voltage	220V/380V/440V (Dependent on model)
Power Consumption	Variable based on model (e.g., 10-100 kW)
Plasma Gas	Argon, Helium, Nitrogen (Dependent on application)
Gas Flow Rate	Adjustable (e.g., 10-50 l/min)
Cooling System	Water-cooled
Spray Gun	Handheld or Robotic (Dependent on model)
Spray Capacity	Up to several kilograms per hour
Spray Material	Various metals and alloys (e.g., Aluminum, Steel)
Material Feed System	Powder or Wire (Dependent on application)
Spraying Distance	Adjustable (e.g., 50-200 mm)
Control Interface	Digital control panel with touchscreen
Operating Environment	Indoor or Outdoor (Dependent on setup)
Safety Features	Overcurrent protection, Emergency stop button, etc.

Table 4.4 Coating Thickness

Coating Thickness									
Sl. No	Description	Spec	Unit	Before Coating	After Coating			Average Value	Coating Thickness Value
1	Coating	40-50	Micron	5.65	6.31	6.29	6.27	6.29	0.64
2	Thickness			5.70	6.02	6.29	6.30	6.20	0.50
3	(A Side)			5.88	6.30	6.41	6.31	6.34	0.46
4				5.75	6.34	6.30	6.33	6.32	0.57
5	Coating			5.87	6.40	6.35	6.32	6.36	0.49
6	Thickness			5.72	6.33	6.34	6.30	6.32	0.50
7	(B Side)			5.88	6.50	6.45	6.35	6.43	0.55
8				5.72	6.43	6.30	6.31	6.35	0.63

Table4.5. Distance Specification of Plasma Arc Spary Machine

Specification	Details
Maximum Spray Distance	Up to 300 mm (Dependent on model and application)
Minimum Spray Distance	Typically, around 50 mm (Dependent on setup)
Spray Distance Control	Adjustable via control panel or software interface
Accuracy of Distance Control	Typically, within a few millimeters
Spray Pattern Adjustment	Yes, typically adjustable for different spray patterns
Workpiece Size Limitations	Dependent on the size of the spray booth and accessibility

Table 4.6. Power Requirements of Plasma Arc Spary Machine

Specification	Details
Power Source	Electric (AC/DC)
Input Voltage	220V/380V/440V (Dependent on model)
Power Consumption	Variable based on model (e.g., 10-100kW)
Cooling System	Water-cooled

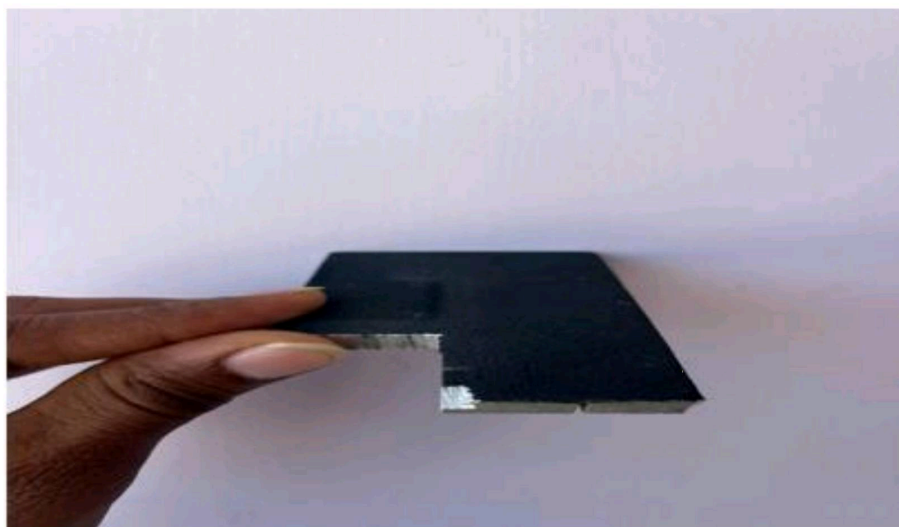


Fig: 4.3. Photography of the Ceramic coated al alloy

4.4

ADVANTAGES

1. **Enhanced Scratch Resistance:** Ceramic coatings provide a robust protective layer that significantly improves the scratch resistance of gripper surfaces. This is vital in applications where grippers regularly come into contact with objects of varying materials and shapes.
2. **Increased Durability:** The application of ceramic coatings extends the lifespan of gripper surfaces by reducing wear and tear. This results in lower maintenance and replacement costs, making robotic systems more cost-effective over time.
3. **Improved Grip Precision:** By maintaining the integrity of gripper surfaces, ceramic coatings ensure consistent and reliable grip precision. This is essential for tasks that require accuracy in handling objects.
4. **Resistance to Wear and Abrasion:** Ceramic coatings excel in wear resistance, making them ideal for applications involving constant friction and abrasion. This is particularly valuable in industries where robotic systems operate in challenging environments.
5. **Protection Against Corrosion:** Many ceramic coatings offer excellent corrosion resistance, safeguarding gripper surfaces from chemical exposure and environmental factors that can cause corrosion and degradation.
6. **High Hardness:** Ceramic coatings are known for their high hardness, which not only makes them scratch-resistant but also ensures they can withstand the physical demands of industrial applications.
7. **Versatility:** Ceramic coatings can be tailored to meet the specific requirements of different industries and applications. They can be customized for diverse substrates and environmental conditions.

8. **Temperature Tolerance:** Ceramic coatings can withstand high temperatures, which is essential in applications where grippers may encounter extreme heat, such as in metalworking or foundry environments.
9. **Chemical Compatibility:** These coatings exhibit resistance to various chemicals, ensuring the gripper surfaces.
10. **Reduced Downtime:** With improved scratch resistance and durability, the need for maintenance and replacement of gripper surfaces is significantly reduced. This results in less downtime and higher overall operational efficiency.
11. **Energy Efficiency:** Robotic systems with ceramic-coated grippers can perform tasks with greater energy efficiency since they maintain their grip precision and reliability over extended periods.
12. **Cost Savings:** The longevity and reduced maintenance requirements of ceramic-coated gripper surfaces translate into substantial cost savings over time. This is especially important in industries with high equipment maintenance costs.
13. **Environmental Benefits:** In applications where wear and tear lead to the release of particulate matter or contaminants, ceramic coatings can mitigate these environmental impacts by reducing surface degradation.
14. **Innovative Applications:** Ceramic coatings enable the adoption of robotic systems in emerging fields like soft robotics, where grippers require advanced surface protection to handle delicate materials and objects.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 RESULTS

The investigation into the plasma arc process for ceramic coating on Al7075 alloy yielded significant findings, shedding light on the morphology, composition, and mechanical properties of the resulting coatings.

1. Surface Morphology and Porosity:

Scratch testing revealed a porous surface morphology, initially characterized by random sub-micron and micron-sized pores. However, as the current frequency of the process was increased, a notable transition occurred, leading to a more uniform distribution of micron-sized pores. This evolution in porosity suggests a direct correlation with the process parameters, indicating the potential for tailored surface characteristics.

2. Coating Thickness and Oxide Layers:

The fabricated ceramic coatings exhibited an average thickness of approximately 25 μm . Furthermore, microscopic analysis identified the presence of two distinct oxide layers within the coating. Through scratch and micro hardness measurements, the external layer was identified as $\alpha\text{-Al}_2\text{O}_3$, while the internal layer was determined to be $\gamma\text{-Al}_2\text{O}_3$. This characterization provides valuable insights into the structure and composition of the coatings, crucial for understanding their functional properties.

3. Micro Hardness and Crystallinity:

Micro hardness measurements revealed values exceeding 776 HV, indicating the crystalline nature of the coatings. This observation underscores the potential for enhanced mechanical strength and wear resistance in applications where such properties are crucial. Additionally, the saturation value of micro hardness achieved after N = 10 grams turns for the Al-6061 MMC demonstrated reasonable agreement

with the hardness variation recorded, ranging from 28HV to 35HV. This correlation suggests a direct influence of reinforcement content on the mechanical properties of the alloy.

4. Optimization Strategies:

In light of the findings, optimization of current and voltage parameters of the plasma arc sprayer emerges as a key strategy for achieving desired ceramic coatings on Al alloys. Fine-tuning these parameters holds the potential to enhance coating thickness and strength, thereby maximizing the functional capabilities of the coated components. Such optimization efforts are essential for ensuring the efficacy and reliability of plasma arc processes in industrial applications.

Overall, the comprehensive characterization and analysis presented in this study provide valuable insights into the plasma arc process for ceramic coating fabrication on Al alloys. These findings not only contribute to the fundamental understanding of coating formation mechanisms but also offer practical guidance for optimizing process parameters to meet specific performance requirements in various engineering applications.

5.1.1 Micro Hardness Test

The micro hardness test is a technique used to measure the hardness of materials on a microscale. Hardness refers to a material's resistance to indentation or scratching, and it is an essential property in various industries such as engineering, manufacturing, and materials science. The micro hardness test provides detailed information about the material's mechanical properties, including its strength, wear resistance, and durability.

There are several methods for conducting micro hardness tests, but two of the most common ones are the Vickers and Knoop tests:

Vickers Hardness Test: In this method, a pyramidal diamond-shaped indenter with a square base is pressed into the material's surface with a known force. The indentation size is measured, and the Vickers hardness value is calculated based on the area of the indentation.

Knoop Hardness Test: Similar to the Vickers test, the Knoop test uses a different indenter shape, which is elongated and has a rhombic-based pyramid geometry. The steps involved in conducting a micro hardness test typically include:

Sample Preparation: The material sample needs to be properly prepared, which may involve grinding, polishing, and cleaning to ensure a smooth and flat surface.

Indentation: The sample is placed under a microscope, and the indenter is pressed into the material's surface with a controlled force for a specified duration.

Measurement: The size of the indentation is measured using the microscope's reticle or an automated image analysis system.

Hardness Calculation: The Vickers or Knoop hardness value is calculated based on the dimensions of the indentation and the applied force.

Data Analysis: The hardness values obtained from multiple indentations are often averaged to provide a more representative measurement of the material's hardness.

Micro hardness testing is widely used for quality control, material characterization, and research purposes in industries such as metallurgy, ceramics, and semiconductor manufacturing. It provides valuable information about the material's mechanical properties, which can help in material selection, process optimization, and product development.

Table 5.1 Micro Hardness

Al alloy 6061	Ceramic coated al alloy
35 HV	776 HV
SCRATCH	No bare metal scratch noticed.

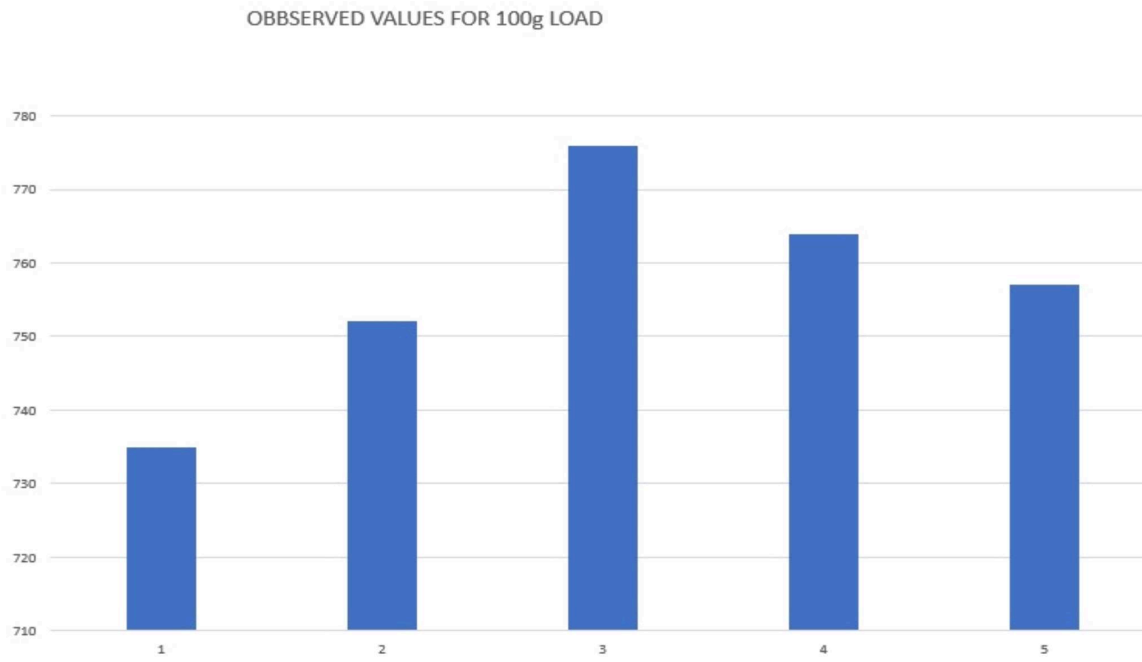


Fig.5.1 Micro hardness graph

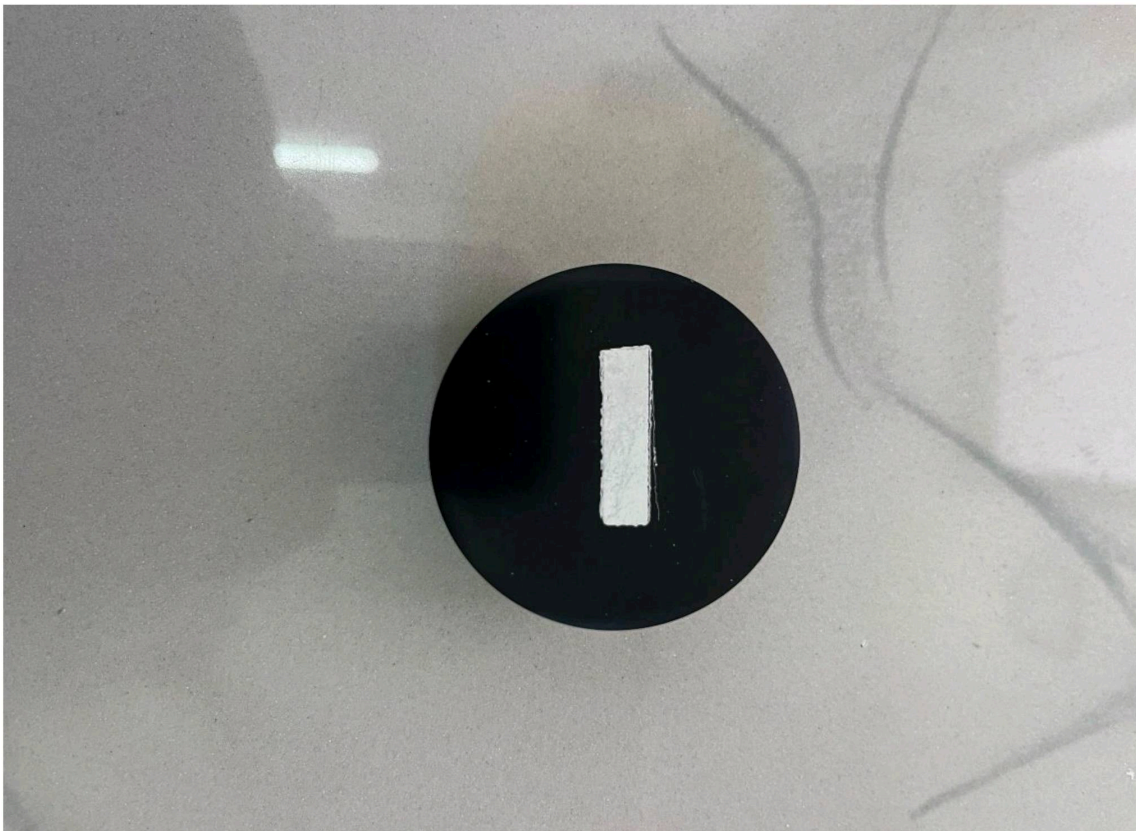


Fig.5.2 Micro hardness tested sample.

5.1.2 Friction (Wear) Test:

A friction (wear) test is a method used to assess the frictional properties and wear resistance of materials under controlled conditions. These tests are crucial for evaluating the performance and durability of materials in various applications where friction and wear are significant factors, such as automotive components, industrial machinery, and consumer products. Friction tests provide valuable insights into the material's response to sliding, rolling, or rubbing contact, helping engineers and researchers make informed decisions regarding material selection, lubrication, and surface treatments

Test Parameters:

Table 5.2 Friction Test Parameters

Diameter	6mm
Load	10N
Frequency	4HZ
Stroke	10mm
Temperature	50
Time	5400s
Ball Radius	6.00

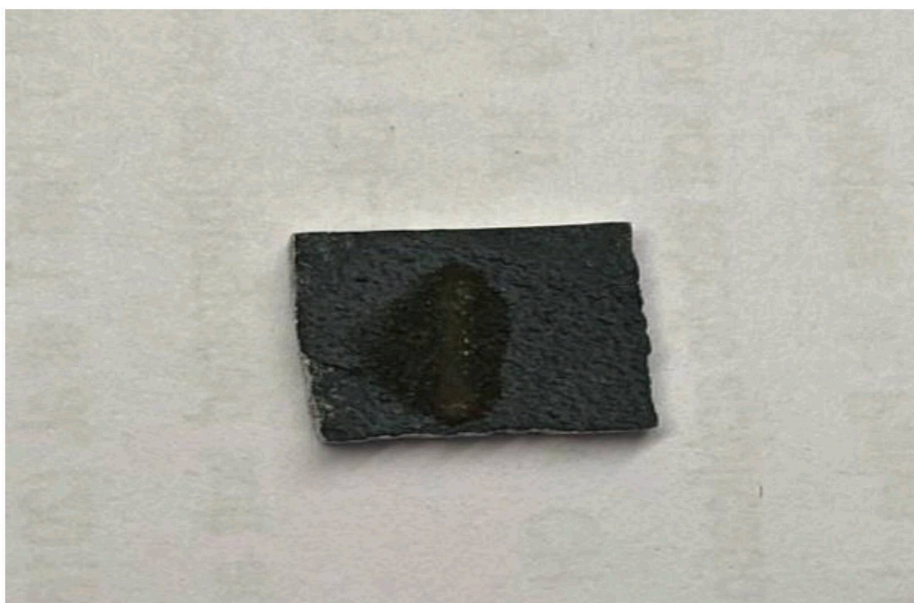


Fig.5.3 Friction (Wear) Tested Sample

5.1.3 SEM TEST (Scanning Electron Microscope)

In an SEM test, a sample is first prepared by coating it with a thin conductive layer (typically gold or carbon) to improve its conductivity and reduce charging effects during imaging. The sample is then placed in the vacuum chamber of the SEM instrument.

During imaging, a focused beam of electrons is scanned across the sample's surface. When the electrons interact with the atoms in the sample, various signals are generated, including secondary electrons (SE), backscattered electrons (BSE), and characteristic X-rays. These signals provide information about the sample's topography, composition, and crystallographic structure.

The SEM instrument detects and collects these signals using specialized detectors, allowing for the generation of high-resolution images with exceptional detail.

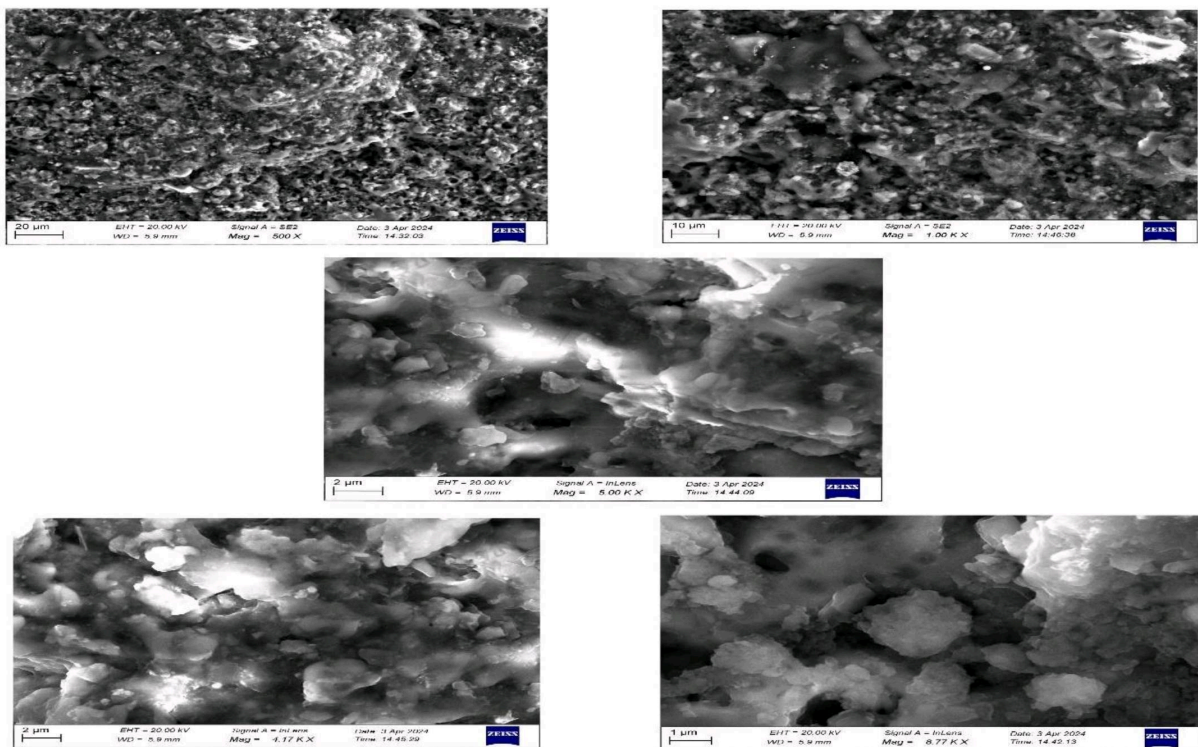


Fig.5.4 Microscopy Figures of Coated Material

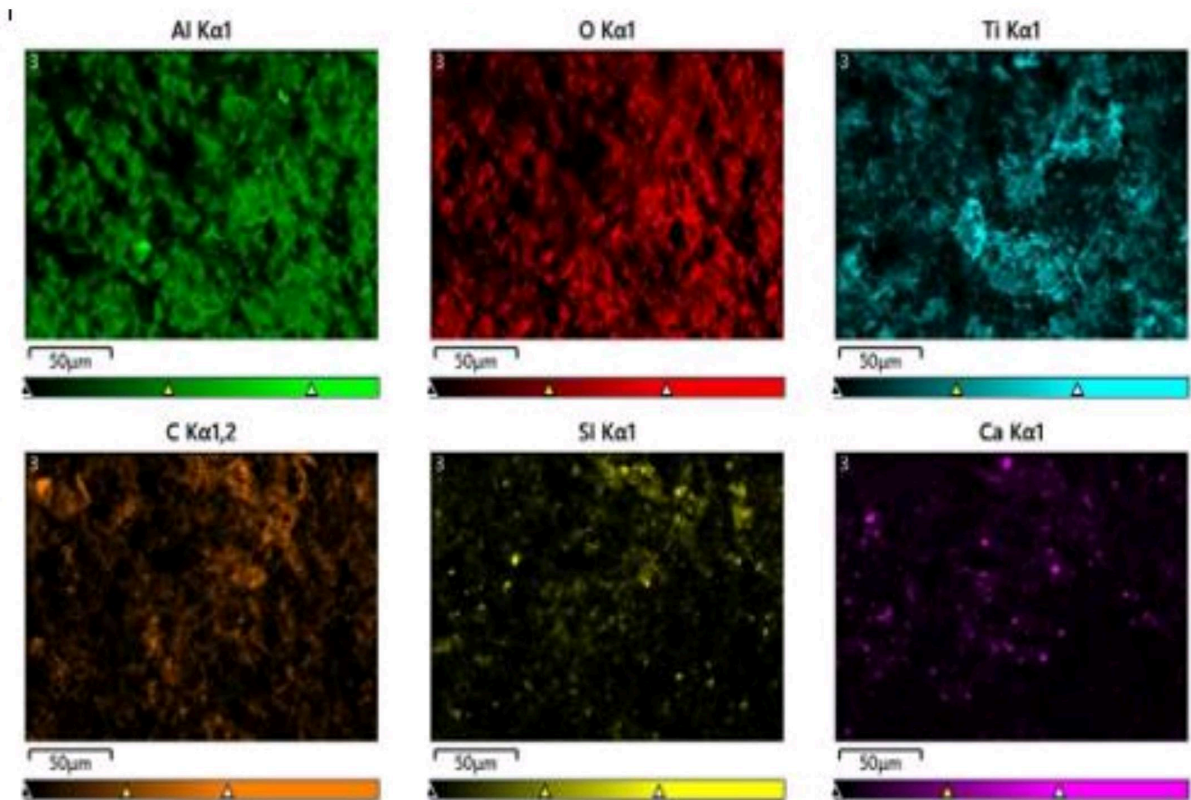
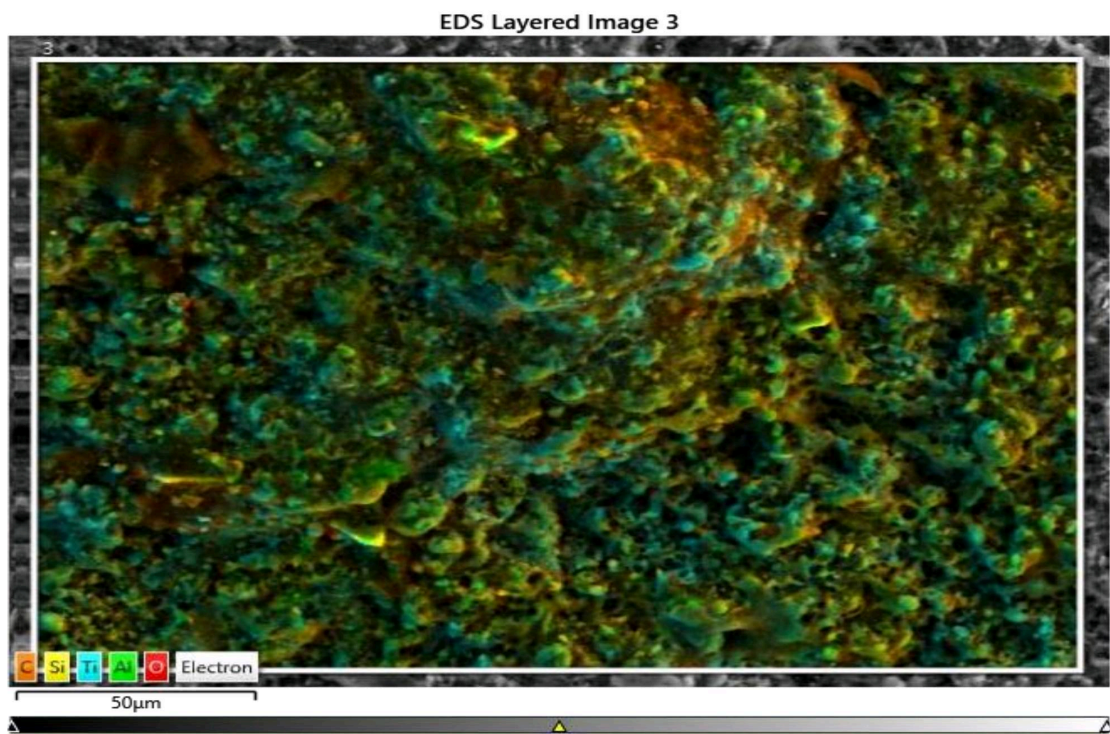


Fig.5.5 EDS Layered figures of coated material

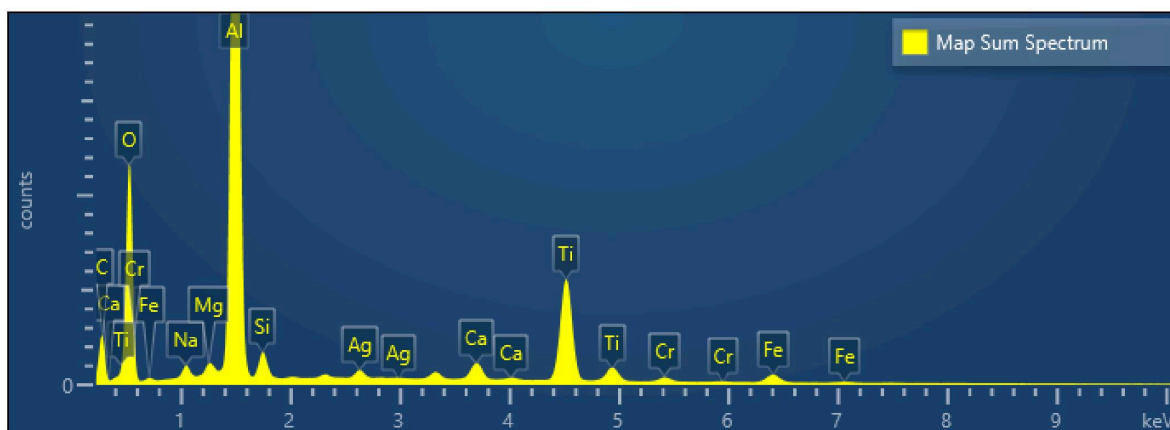


Fig:5.6 Graph shows of composition of different elements in coated material

Table.5.3 Shows different elements and their weight % and atomic% of coated material

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	24.06	0.12	35.66
O	K series	38.40	0.08	42.74
Na	K series	0.67	0.01	0.52
Mg	K series	0.42	0.01	0.31
Al	K series	24.15	0.05	15.94
Si	K series	1.11	0.01	0.71
Ca	K series	0.91	0.01	0.41
Ti	K series	8.54	0.02	3.17
Cr	K series	0.48	0.01	0.16
Fe	K series	1.23	0.01	0.39
Ag	L series	0.02	0.01	0.00
Total		100.00		100.00

CHAPTER-6

SUMMARY AND CONCLUSION

The focus of this study lies in exploring the effectiveness of the plasma arc process for creating ceramic coatings on Al7075 alloy, followed by a detailed characterization of these coatings. The process involves subjecting the alloy to plasma arc, resulting in the formation of a ceramic layer. Scratch testing was employed to analyze the surface morphology, revealing a porous structure initially dominated by random sub-micron and micron-sized pores. Interestingly, as the current frequency of the process increased, a notable shift towards a more uniform distribution of micron-sized pores was observed. This suggests a direct correlation between process parameters and surface morphology, with implications for coating performance.

The thickness of the coatings, averaging at 25 μm , was determined through meticulous examination. Additionally, microscopic analysis unveiled the presence of two distinct oxide layers within the coating. Scratch and micro hardness measurements provided valuable insights into the composition of these layers, with the external layer identified as $\alpha\text{-Al}_2\text{O}_3$ and the internal layer as $\gamma\text{-Al}_2\text{O}_3$. Such detailed characterization is crucial for understanding the structure-property relationships of the coatings, essential for their practical applications.

Values exceeding 776 HV in micro hardness measurements suggest the crystalline nature of the coatings. This observation highlights the potential for enhanced mechanical strength and wear resistance, vital for applications demanding robust surface properties. Moreover, the saturation value of micro hardness achieved after $N = 10$ grams turns for the Al-6061 MMC demonstrated reasonable agreement with the hardness variation recorded, ranging from 28HV to 35HV. This correlation underscores the influence of reinforcement content on the mechanical properties of the alloy, emphasizing the importance of material composition in determining performance characteristics.

Furthermore, the discussion touches upon the production of aluminum alloy in sheet form. This highlights the versatility of aluminum alloy manufacturing processes,

offering various forms to suit diverse industrial needs. In the context of further testing, the optimization of current and voltage parameters of the plasma arc sprayer emerges as a promising strategy to enhance ceramic coatings on Al alloys in terms of thickness and strength. Fine-tuning these parameters holds the potential to improve coating quality and performance, thereby maximizing the functional capabilities of coated components.

In conclusion, the comprehensive investigation presented in this study provides valuable insights into the plasma arc process for ceramic coating fabrication on Al alloys. The findings contribute to a deeper understanding of coating formation mechanisms and structure-property relationships, essential for optimizing process parameters and enhancing coating performance. Moreover, the correlation between micro hardness saturation values and reinforcement content underscores the significance of material composition in determining mechanical behaviour. Moving forward, further research and development efforts can build upon these insights to advance the utilization of ceramic coatings in various industrial applications, leveraging the unique properties offered by the plasma arc process.

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