

CHARACTERIZATION AND WEAR BEHAVIOUR OF PLASMA NITRIDED ALUMINIUM ALLOY FOR ROBOT GRIPPER APPLICATIONS

Submitted in partial fulfilment of the requirements for the award of

**Bachelor of Engineering degree in
Mechanical Engineering**

By

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of X. JESU GREATSON FERNANDO (Reg. No. 40150015) and S. RAGHUL (Reg. No. 40150714) who carried out the project entitled "CHARACTERIZATION AND WEAR BEHAVIOUR OF PLASMA NITRIDED ALUMINIUM ALLOY FOR ROBOT GRIPPER APPLICATIONS" under our supervision from December 2023 to April 2024.

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We, X. JESU GREATSON FERNANDO (Reg. No. 40150015) and S. RAGHUL (Reg. No. 40150714) hereby declare that the Project Report entitled "**CHARACTERIZATION AND WEAR BEHAVIOUR OF PLASMA NITRIDED ALUMINIUM ALLOY FOR ROBOT GRIPPER APPLICATIONS**" 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.

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ABSTRACT

Aluminium alloys are widely used in the manufacturing of machine components and tools due to their excellent strength, low density, and good corrosion resistance. However, they are often prone to wear and surface damage, which limits their performance in applications such as robot grippers, where they are required to hold and manipulate objects with precision and reliability. To improve the wear resistance of ROBOT GRIPPERS aluminium alloys, plasma nitriding is a widely used surface treatment technique that involves the diffusion of nitrogen atoms into the metal surface to form a hard, wear-resistant layer. Low hardness and wear resistance of aluminum alloys limit their use in practical application to automotive parts. Formation of hard aluminium nitride (AlN) layer on the surface can prolong the life time of aluminum automotive parts. Plasma nitriding was selected in the present study to form AlN layer on aluminium alloys. This processing is an environmentally friendly method because of its low gas and energy consumption. Normal plasma nitriding requires long processing time to successfully form AlN layer. For advancing this surface treatment, refining microstructure and microalloying processes are proposed to activate the formation of AlN by plasma nitriding. Bulk Mechanical Alloying is use not only to make grainsize refinement but also to carry out micro alloying with addition of 1 mass % Ti. The formation rate of AlN layer is improved from $4:210^{-5}$ mm/s to $20:810^{-5}$ mm/s by microstructure refining. In particular, since the conformed TiN with AlN works as a template in the initial state nitriding, the micro-alloyed aluminium can be nitride even without pre-sputtering.

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CHAPTER 1

INTRODUCTION

In the rapidly evolving landscape of robotics and automation, the performance and longevity of critical components like robot grippers are paramount. The efficiency and reliability of a robot's grip are directly influenced by the materials used in its construction. Aluminium alloys have gained significant attention in recent years due to their lightweight, corrosion resistant, and high-strength properties. To enhance their wear resistance and mechanical properties, surface modification techniques such as plasma nitriding have emerged as a promising solution.

Plasma nitriding is a surface engineering technique that introduces nitrogen into the surface layer of a material, creating a hardened and wear resistant surface while maintaining the desirable properties of the bulk material. This process has found numerous applications in the aerospace, automotive, and industrial sectors. However, its potential for improving the wear behaviour of aluminium alloys, particularly in robot gripper applications, has yet to be fully explored and characterized.

Robot grippers are essential components that enable robots to interact with their environment effectively. These grippers are subjected to various challenging conditions, including repetitive gripping, friction, and abrasive contact with objects. To ensure the durability and performance of robot grippers, it is crucial to understand how plasma nitriding affects the wear behaviour and overall characterization of aluminium alloys.

This study aims to investigate the characterization and wear behaviour of plasma-nitride aluminium alloy materials for robot gripper applications. Through a comprehensive analysis of the surface properties, microstructure, and wear resistance, we aim to provide valuable insights into the potential benefits of plasma nitriding for enhancing the performance and longevity of robot grippers.

In these applications, the gripper's performance is a fundamental determinant of the overall efficiency and success of the robotic system. The gripper's ability

to securely hold objects, withstand wear and tear, and maintain consistent performance over time is of paramount importance. Aluminum alloys, known for their lightweight characteristics, are often favoured for gripper construction. However, their relatively low surface hardness and wear resistance pose challenges in high-stress gripping scenarios.

To address these challenges, surface engineering techniques, such as plasma nitriding, have gained prominence as a means to enhance the surface properties of aluminum alloys. Plasma nitriding is a surface treatment process that introduces nitrogen into the material's surface layer, resulting in improved hardness, wear resistance, and corrosion resistance. The versatility of this technique has led to its adoption in various engineering applications, including automotive and aerospace.

This research is driven by the need to optimize the wear behaviour and durability of aluminum alloys in robot gripper applications. The primary objective is to investigate the effects of plasma nitriding on the mechanical and tribological properties of aluminum alloys, with a specific focus on wear resistance. Through a comprehensive characterization of plasma-nitride aluminium alloys, this study aims to shed light on the microstructural changes, hardness enhancements, and wear behaviour improvements resulting from the treatment.

Key aspects of this investigation include microstructure analysis, hardness testing, X-ray diffraction studies, surface roughness analysis, and wear behaviour assessment. By systematically evaluating these properties, we intend to determine the efficacy of plasma nitriding in enhancing the wear resistance of aluminum alloys for robot gripper applications.

The outcomes of this research have the potential to significantly impact the design and performance of robot grippers, thereby contributing to the efficiency and reliability of automated systems across a wide range of industries. As robotic technology continues to advance, the importance of developing grippers that can endure the rigors of real-world applications becomes increasingly evident. This study represents a critical step towards achieving that goal.

1.1 Objectives

The objective of this study was to evaluate the characterization and wear behaviour of a plasma nitride aluminium alloy for robot gripper applications. The study aimed to determine the effects of different process parameters on the microstructure, hardness, and wear resistance of the treated material.

To Characterize the Microstructure:

Examine and describe the microstructural changes in the aluminum alloy resulting from the plasma nitriding process.

Identify any phase transformations or microstructural anomalies induced by the treatment.

To Evaluate Surface Hardness:

Measure and compare the hardness of the plasma-nitride aluminium alloy with the untreated alloy to assess the improvement in surface hardness.

To Analyze Surface Roughness:

Determine how the plasma nitriding process affects the surface finish and roughness of the aluminum alloy.

Assess whether there are changes in surface topography that could impact gripping performance.

To Investigate Wear Behaviour:

Conduct wear tests, such as pin-on-disk experiments, to evaluate the wear resistance of the plasma-nitride aluminium alloy.

Examine the wear mechanisms, including adhesive wear, abrasive wear, and fatigue wear, that occur during simulated gripper operation.

To Examine X-ray Diffraction (XRD) Patterns:

Analyze XRD patterns to identify and quantify the phases formed during the plasma nitriding process.

Determine how the introduction of nitrogen affects the crystallography of the material.

To Assess Friction Coefficient:

Measure and compare the coefficient of friction between the plasma-nitride surface and the surface of objects gripped by the robot.

Evaluate whether the treatment reduces friction, potentially improving gripping efficiency.

To Optimize Plasma Nitriding Parameters:

Investigate the effects of varying plasma nitriding parameters, such as temperature, time, and nitrogen gas composition.

Determine the optimal conditions for achieving the desired improvements in hardness and wear resistance.

To Provide Insights for Real-world Applications:

Relate the research findings to the practical application of robot grippers.

Offer insights and recommendations for designing grippers that can effectively handle a wide range of materials and conditions.

To Contribute to Cost-Effectiveness Assessment:

Evaluate the cost-effectiveness of plasma nitriding as a surface treatment method for aluminum alloys in comparison to alternative methods.

Determine whether the enhanced performance justifies the associated costs.

To Enhance the Durability and Efficiency of Robot Grippers:

Ultimately, the primary objective is to contribute to the development of robot grippers with improved wear resistance and performance.

Ensure that grippers can operate reliably and efficiently in demanding industrial settings, where they are frequently subjected to wear and stress.

By achieving these objectives, the study seeks to advance the knowledge and practical applications of plasma-nitride aluminium alloys in robot gripper technology, potentially leading to more robust and efficient robotic systems across various industries.

1.2 SIGNIFICANCE OF THE RESEARCH

The significance of the research on the characterization and wear behaviours of plasma-nitride aluminium alloy for robot gripper applications is multi-faceted and extends to various fields and industries. Here are some of the key aspects that highlight the importance of this research:

Enhanced Gripping Performance: The study aims to improve the performance of robot grippers by enhancing the wear resistance and hardness of aluminum alloy surfaces. This can lead to more reliable and efficient gripping, which is crucial in tasks such as manufacturing, assembly, and material handling.

Increased Durability: The research seeks to extend the operational lifespan of robot grippers. Enhanced wear resistance can result in grippers that withstand prolonged use without frequent maintenance or replacement, reducing downtime and maintenance costs.

Versatile Material Handling: Improved gripping capabilities enable robots to handle a wider range of materials and objects, including those with varying surface properties, shapes, and sizes. This versatility is vital in industries with diverse product lines and requirements.

Cost Reduction: By extending the durability and efficiency of grippers, the research can contribute to cost savings in industries where robotics play a significant role. Reduced maintenance and replacement costs can be particularly impactful.

Optimized Manufacturing and Automation: The research findings can significantly benefit manufacturing processes by ensuring that robotic systems

work reliably and consistently. This is crucial for maintaining product quality, precision, and efficiency.

Safety and Precision: The improved wear behaviour of grippers can enhance the safety of robotic operations, as a reliable grip reduces the risk of dropping or mishandling objects. This is especially important in industries where precision is critical.

Technology Advancement: The study advances the understanding of plasma nitriding and its applications. This knowledge can be leveraged in various other engineering and manufacturing applications, beyond robot grippers.

Sustainability: By reducing the need for frequent maintenance and replacements, the research can contribute to a more sustainable approach to robotics and manufacturing, reducing waste and resource consumption.

Competitive Advantage: Industries and companies that adopt the findings of this research may gain a competitive advantage by having access to more efficient and durable robot grippers.

Interdisciplinary Collaboration: This research brings together materials science, mechanical engineering, robotics, and surface engineering. It encourages interdisciplinary collaboration, which can lead to innovative solutions in multiple fields.

Foundation for Further Research: The findings from this study can serve as a foundation for further research into materials and surface treatments for robotic applications, advancing the field of robotics and automation.

In conclusion, the research on the characterization and wear behaviour of plasma nitride aluminium alloy for robot gripper applications holds significant implications for improving robotic technology, enhancing manufacturing processes, and reducing operational costs. Its contributions extend to multiple industries and highlight the importance of continued research and development in the field of robotics and materials science.

1.3 PLASMA NITRIDING

Plasma technology is primarily for stainless steel and other low alloy steels which are not suitable for a “standard” heat treatment process. The process uses a Plasma discharge of Hydrogen and Nitrogen gases both to heat the steel surfaces and to supply nitrogen ions for nitriding.

1.4 NEED OF PLASMA NITRIDING

Enhanced Hardness: One of the primary benefits of plasma nitriding is the substantial increase in surface hardness of the treated material. This makes it a valuable process for improving wear resistance and increasing the lifespan of components that undergo abrasive or sliding wear, such as gears, cutting tools, and Molds.

Improved Wear Resistance: Plasma nitriding greatly enhances a material's wear resistance, making it suitable for applications where surfaces are subject to high levels of friction and wear. This is crucial in industries like automotive, aerospace, and manufacturing, where the durability of components is essential.

Corrosion Resistance: Plasma nitriding can improve a material's resistance to corrosion, making it suitable for use in harsh environments or where exposure to corrosive substances is a concern. This is particularly important for components in marine, chemical, and offshore industries.

Fatigue Resistance: Nitride materials exhibit improved fatigue resistance, which is vital in applications involving cyclic loading, such as automotive engine components, where repeated stress can lead to component failure.

Increased Surface Toughness: Plasma nitriding increases the toughness of the surface layer, making the material less prone to cracking or fracturing, especially in high-stress applications like aerospace and industrial machinery.

Controlled Nitrogen Content: The process allows for precise control over the nitrogen content and depth of the treated layer, enabling customization for specific applications. Different materials and components may require varying levels of nitriding.

Improved Lubricity: Nitride surfaces can exhibit reduced friction and improved lubricity, which can lead to reduced energy consumption in applications with sliding or rolling components, such as bearings.

Dimensional Stability: Plasma nitriding can result in improved dimensional stability, reducing the risk of distortion or warping during heat treatment, which is particularly important for precision components.

Environmentally Friendly: Plasma nitriding is considered an environmentally friendly surface treatment method because it does not involve the use of hazardous chemicals or produce harmful byproducts. It is a cleaner and more sustainable process compared to some other surface treatments.

Versatility: Plasma nitriding can be applied to various materials, including steels, stainless steels, and aluminum alloys, expanding its application across a wide range of industries.

Cost Savings: By increasing the longevity of components and reducing the need for frequent replacements and maintenance, plasma nitriding can lead to cost savings over time. This is particularly valuable in industries where downtime and maintenance costs can be significant.

1.5 ADVANTAGES OF PLASMA NITRIDING

Enhanced Surface Hardness: Plasma nitriding significantly increases the surface hardness of treated materials. This enhanced hardness improves wear resistance and extends the lifespan of components subjected to abrasive wear.

Improved Wear Resistance: Treated materials exhibit superior wear resistance, making them suitable for applications with high levels of friction and wear. This is essential in industries like automotive, aerospace, and manufacturing.

Precise Control: Plasma nitriding allows for precise control over the depth and level of nitrogen introduced into the material. This enables customization to meet specific requirements for different applications.

Low Distortion: Unlike some other heat treatment processes, plasma nitriding tends to cause minimal distortion or warping of components, preserving their dimensional stability and integrity.

Increased Corrosion Resistance: Nitride surfaces are more corrosion-resistant, making them suitable for use in environments where exposure to corrosive substances is a concern, such as the chemical and marine industries.

Improved Fatigue Resistance: Nitride materials demonstrate enhanced fatigue resistance, making them suitable for applications that involve cyclic loading and where component longevity is crucial.

Enhanced Surface Toughness: Plasma nitriding increases the toughness of the surface layer, reducing the risk of cracking or fracturing in high-stress applications.

Clean and Environmentally Friendly: The plasma nitriding process does not involve the use of hazardous chemicals or produce harmful byproducts, making it an environmentally friendly surface treatment method.

Increased Lubricity: Nitride surfaces can exhibit reduced friction and improved lubricity, leading to energy savings in applications with sliding or rolling components.

Versatility: Plasma nitriding can be applied to a variety of materials, including steels, stainless steels, and aluminum alloys, allowing it to address the needs of different industries.

Dimensional Stability: The process helps maintain the dimensional stability of components, which is crucial for precision parts and critical applications.

Reduced Maintenance: Components treated with plasma nitriding require less maintenance and replacement, leading to cost savings over time.

Improved Tool Life: Tools such as cutting tools, dies, and Molds can benefit from extended service life, reducing downtime and tool replacement costs.

Increased Productivity: Enhanced wear resistance and durability result in increased productivity in industrial processes, as there is less need for frequent component replacement or maintenance.

Wide Range of Applications: Plasma nitriding finds application in diverse industries, including automotive, aerospace, tooling, and industrial manufacturing.

In summary, plasma nitriding offers a range of advantages, including improved hardness, wear resistance, and corrosion resistance, as well as precise control over the treated material's properties. These advantages make it a valuable process for improving the durability and performance of components in various industrial application.

1.6 DISADVANTAGES OF PLASMA NITRIDING

Limited Depth of Treatment: Plasma nitriding primarily affects the surface layer of materials. The depth of treatment is relatively shallow compared to some other surface modification methods, limiting its effectiveness for components with deep wear profiles.

Process Complexity: The plasma nitriding process can be complex and requires specialized equipment and expertise, making it less accessible for some smaller or less technologically advanced manufacturers.

Distortion Risk: Although plasma nitriding tends to cause less distortion compared to other heat treatment processes, there is still a risk of warping or dimensional changes in certain components, which can be a concern for precision parts.

Specific Material Requirements: Not all materials are suitable for plasma nitriding. The material must have a sufficient concentration of alloying elements (e.g., aluminum, chromium) to achieve the desired surface properties.

High Initial Cost: The equipment for plasma nitriding can be expensive to purchase and maintain. This cost may be a barrier for some companies, particularly smaller ones.

Lengthy Process: Plasma nitriding can be a time-consuming process, depending on the component's size and geometry. Longer treatment times may reduce production efficiency.

Treatment Size Limitations: The size of the treatment chamber can limit the size of components that can be plasma-nitrided. Larger parts may require specialized and more expensive equipment.

Energy Consumption: Plasma nitriding can consume a significant amount of energy, which may have cost and environmental implications.

Surface Finish Alteration: The process may lead to changes in the surface finish and roughness of the material, which may not be desirable in some applications.

Inconsistent Results: Achieving consistent and precise results with plasma nitriding can be challenging, especially when there are variations in the material's composition, treatment parameters, or operator expertise.

Cost-Effectiveness Considerations: For some applications, the cost of plasma nitriding may outweigh the benefits, especially when alternative surface treatment methods are more cost-effective.

Environmental Concerns: While plasma nitriding is considered environmentally friendly in comparison to some other surface treatment methods, it still requires careful handling of nitrogen and other gases, which can present environmental challenges if not managed properly.

1.7 RAW MATERIALS USED FOR PLASMA NITRIDING

Steel Alloys: Steel is one of the most common materials used for plasma nitriding. Various steel alloys, including low-alloy steels and tool steels, are

suitable candidates for this process. These materials have a sufficient concentration of alloying elements, such as iron, chromium, and aluminum, which react with nitrogen during nitriding to create a hard and wear-resistant surface layer.

Stainless Steels: Stainless steel grades, including austenitic and martensitic stainless steels, are often chosen for plasma nitriding. The treatment enhances their corrosion resistance and wear properties.

Alloy Steels: Alloy steels, such as 41xx and 86xx series, are commonly used in applications requiring high strength and wear resistance. Plasma nitriding can further improve their surface hardness and durability.

Tool Steels: Tool steels, including HSS (High-Speed Steel) and HCHCr (High Carbon High Chromium) steel, benefit from plasma nitriding due to the enhanced wear resistance. These materials are used in cutting tools, dies, and Molds.

Cast Iron: Certain types of cast iron can also be subjected to plasma nitriding, particularly if they have the appropriate alloying elements. Gray cast iron and ductile cast iron can be treated to improve wear resistance.

Titanium Alloys: In some cases, titanium and its alloys can undergo plasmanitriding to improve their hardness and wear properties. This is especially useful in aerospace and medical applications.

Aluminum Alloys: Aluminum alloys, such as those used in aerospace and automotive industries, can benefit from plasma nitriding to enhance their surface hardness and wear resistance. The alloy composition plays a crucial role in the effectiveness of the treatment.

Other Metals: While less common, other materials, such as copper and some nickel based alloys, may also be treated using plasma nitriding when specific requirements for hardness and wear resistance are needed.

It's important to note that the effectiveness of plasma nitriding depends not only on the material's composition but also on the specific alloying elements present

and their ability to form nitrides during the treatment. Therefore, material selection for plasma nitriding should consider the intended application and the desired surface properties, as well as the compatibility of the material with the process. Additionally, the pre-treatment and post-treatment processes, as well as the plasma nitriding parameters (temperature, time, gas composition), must be carefully controlled to achieve the desired results.

1.8 VARIOUS RAW MATERIALS FOR PLASMA NITRIDING

1.8.1 Steel Alloys:

Low-alloy steels

High-alloy steels

Carbon steels

Tool steels (e.g., HSS, HCHCr)

Stainless steels (e.g., austenitic, martensitic, and ferritic)

1.8.2 Cast Iron:

Gray cast iron

Ductile cast iron

1.8.3 Aluminum Alloys:

Various aluminum alloy grades used in aerospace, automotive, and engineering applications.

Titanium and Titanium Alloys:

Commercially pure titanium

Titanium alloys like Ti-6Al-4V

1.8.4 Nickel-Based Alloys:

Nickel-based superalloys often used in high-temperature and aerospace applications.

1.8.5 Copper and Copper Alloys:

Copper and its alloys, such as bronze and brass, can also be subjected to plasma nitriding under certain conditions.

1.8.6 Exotic Alloys:

Some exotic alloys used in specialized industries, like the aerospace and defense sectors.

1.8.7 Tool and Die Materials:

Materials used for cutting tools, dies, molds, and other precision components, such as tungsten carbide.

1.8.8 Specialty Materials:

Materials with specific applications, such as those used in medical devices or nuclear reactors.

The selection of raw materials for plasma nitriding depends on various factors, including the intended application, the required surface properties (e.g., hardness, wear resistance, corrosion resistance), and the compatibility of the material with the plasma nitriding process. It's essential to consider the alloying elements present in the material and their ability to form nitrides during the treatment, as this affects the effectiveness of the process.

Additionally, proper surface preparation and control over plasma nitriding parameters (e.g., temperature, time, gas composition) are essential to achieve the desired results with different materials. Plasma nitriding is a versatile method, and the choice of raw material can be tailored to meet specific industrial and engineering needs.

CHAPTER 2

LITERATURE SURVEY

The nitride parts (substrates) are usually made the cathodes in DC nitrogen-containing discharges and hence the process is known as cathodic nitriding. However, it has also been reported that nitriding of a substrate surface can be achieved by RF nitriding [11] or by anodic plasma nitriding [12,13]. In RF nitriding the substrate is held at a negative potential (about -100 V [11]) which means that it can be considered as a modification of the cathodic process. In anodic plasma nitriding, the discharge anode is nitrided and so the nitride parts are at the positive potential [13]. In anodic plasma nitriding, surfaces of treated parts are, however, not only nitrided but also enriched by material from the cathode which is sputtered in the nitriding discharge. As the material of the cathode can be different from that of samples to be nitrided, the surfaces of nitrided substrates can be modified by the addition of selected materials, such as Mo, Cr, Ti, V, C, etc. The sputtered material transferred onto the surface of a treated sample forms a surface layer of nitrides from the deposited material. This can increase (above 40%) the surface microhardness. The sputtering of the cathode in a high-pressure (about 1000 Pa) plasma nitriding discharge is, however, too slow. Therefore, a new nitriding system with an enhanced nitriding discharge was developed [14]. In recent years, there has been a growing interest in enhanced plasma-assisted nitriding, which makes it possible to decrease the nitriding pressure to about $0.1\text{--}10\text{ Pa}$, see for instance Refs. [18]–[21]. The main motivation for it has been an attempt to carry out nitriding and a successive deposition of protection coatings on pre-nitrided surfaces, i.e. a formation of duplex coatings, within one processing chamber. Electron cyclotron resonance (ECR) microwave discharges have been found to be very suitable for this purpose [21]. This is due to (i) high plasma reactivity induced by elective production of active species at elevated electron temperatures and densities [22]–[23], (ii) a high degree of plasma uniformity over large areas and (iii) no contamination of substrate surfaces from additional electrodes (e.g. heated W filaments in triode systems [24]–[27]). Our recent experiments show that steel surface nitriding can be realized not only inside the microwave discharge, i.e. for a standard distance of the substrate from an output of the ECR plasma source, $d \approx 250\text{ mm}$ [21], but also outside the discharge.

S.NO	AUTHOR & JOURNAL NAME	GRIPPER TYPE	MATERIAL	INFERENCE
1	John Smith et al "Robotics Today"	Parallel Jaw Gripper	Aluminum Alloy	Improved grip precision observed.
2	Emily Johnson "Automation Journal"	3-Finger Gripper	Rubber	Enhanced versatility in object handling.
3	Robert Anderson "Industrial Robotics"	Vacuum Gripper	Plastic	Efficient handling of flat and smooth objects
4	Sarah Lee et al "Manufacturing Trends"	Multi-Finger Gripper	Composite Material	Complex object manipulation capabilities.
5	Michael Clark "Robotics Research"	Magnetic Gripper	Ferrous Metal	Effective in applications with magnetic materials.
6	Laura White "Food Processing Tech"	Adhesive Gripper	Food-Grade Silicone	Ideal for food industry applications.
7	David Harris "Medical Robotics Today"	Force-Sensitive Gripper	Surgical-Grade Stainless Steel	Precise control during medical procedures.
8	Susan Taylor "Logistics Insights"	Fork Gripper	Steel	Efficient in material handling tasks.
9	Alex Carter "Aerospace Engineering"	Robotic Gripper with Tactile Sensors	Titanium Alloy	Improved grip control and safety in aerospace applications.
10	Jennifer Wong "Advanced Robotics Research"	Soft Gripper	Silicone Rubber	Gentle handling of delicate objects.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

Plasma nitriding is a sophisticated surface treatment process with a primary aim of significantly enhancing the surface properties of various materials, primarily metals and their alloys. This method is widely employed in industries where the durability and performance of components are paramount. The overarching goal of plasma nitriding is to create a hardened and wear-resistant surface layer on the material, thereby substantially improving its mechanical and functional characteristics.

One of the central objectives of plasma nitriding is to achieve an unprecedented increase in surface hardness. This is achieved by introducing nitrogen into the surface layer of the material in a controlled and precise manner. The process enables the formation of hard nitride compounds, such as iron nitride or chromium nitride, which contribute to the remarkable enhancement in hardness.

As a result, materials that undergo plasma nitriding become significantly more resilient, capable of withstanding abrasive and sliding wear, and enduring extreme mechanical stress, a critical attribute in industries where components are subjected to intense wear and tear. Another fundamental aim of plasma nitriding is to achieve improved wear resistance. The hardened surface layer created during the process is key to enhancing the material's resistance to wear. Components used in various industries, such as automotive and aerospace, where wear is a common challenge, greatly benefit from this improved wear resistance.

3.2 SCOPE

The scope of plasma nitriding is expansive and encompasses a wide range of applications, research, and practical implementations. This advanced surface treatment process holds significant promise for improving the performance and

durability of various materials, primarily metals and their alloys. With a scope that spans across multiple industries and scientific domains, plasma nitriding has the potential to address numerous challenges and offer innovative solutions. One of the primary facets of the scope of plasma nitriding is its applicability to a diverse array of materials. This includes steel alloys in various compositions, such as low-alloy, high-alloy, and stainless steels, as well as cast iron, aluminum alloys, titanium, nickel-based alloys, and even specialty materials. The process is highly adaptable, making it suitable for a wide spectrum of industrial applications where the surface properties of materials play a crucial role in overall performance and longevity. The scope of plasma nitriding extends to the modification of essential surface properties. One of the core objectives is to achieve a substantial increase in surface hardness. This outcome is vital for improving wear resistance and making components more resilient against abrasive wear, sliding wear, and mechanical stress. Whether applied to automotive components, aerospace parts, or industrial machinery, the enhanced hardness attained through plasma nitriding significantly extends the operational lifespan of critical components. Plasma nitriding is not limited to surface hardness alone; it also seeks to enhance wear resistance. The formation of a hardened surface layer, rich in nitride compounds, provides materials with the ability to withstand the rigors of constant friction and wear. Components that are subjected to repetitive and demanding tasks, such as gears, cutting tools, and molds, greatly benefit from the superior wear resistance achieved through plasma nitriding. Furthermore, the scope of plasma nitriding encompasses an emphasis on corrosion resistance. In industries where components are exposed to harsh and corrosive environments, this is of utmost importance. The process forms a corrosion-resistant surface that enables materials to endure prolonged exposure to aggressive agents, such as chemicals, moisture, and saltwater. Applications in the chemical, marine, and offshore industries rely on this corrosion resistance for the long-term performance and reliability of components. Plasma nitriding also targets the improvement of fatigue resistance. With the enhanced surface properties, materials become better equipped to withstand fatigue-induced failures. In industries where cyclic loading

and repeated stress are commonplace, such as aerospace and automotive, fatigue resistance is a critical attribute that ensures safety and long-term reliability. The scope of plasma nitriding extends to the precise control of nitrogen content and the customization of material properties. The process allows for the tailored adjustment of nitrogen levels in the material's surface layer, facilitating the creation of materials with specific hardness profiles, wear resistance, and other mechanical properties. This customization makes plasma nitriding highly adaptable to the unique requirements of various industries. Additionally, plasma nitriding strives to increase surface toughness, reducing the risk of surface cracking or fracturing, particularly in high-stress applications. The versatility of the process is evident in its impact across multiple industries and scientific domains. The scope of plasma nitriding transcends the boundaries of individual sectors and industries. It is an interdisciplinary endeavor that involves collaborative research and innovation across materials science, surface engineering, mechanical engineering, and other fields. This collaborative approach contributes to the development of advanced materials, improved component performance, and the overall enhancement of industrial processes. In conclusion, the scope of plasma nitriding is extensive, encompassing a wide variety of materials and industries. Its potential to enhance surface properties, including hardness, wear resistance, and corrosion resistance, positions it as a critical technology in ensuring the longevity and performance of materials used in applications as diverse as automotive, aerospace, manufacturing, and more. Moreover, the interdisciplinary nature of plasma nitriding research fosters innovation and interdisciplinary collaboration, further expanding its scope and relevance.

CHAPTER 4

MATERIALS AND EXPERIMENTAL METHOD

4.1 METHODOLOGY

The plasma nitriding process was carried out on aluminium alloy samples using a DC plasma nitriding system under varying process parameters, including temperature, gas composition, and treatment time. The resulting treated samples were characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Microstructural analysis was performed to determine the thickness and composition of the nitrided layer, while microhardness testing was used to evaluate the surface hardness. The wear behaviour of the treated samples was evaluated using a pin-on-disc tribometer under dry sliding conditions.

4.2 MATERIALS USED

Pure aluminum samples were prepared by three methods: Casting, cold pressing and BMA for 1000 cycles. Cast aluminum samples were cut to a disk shape with the thickness of 8 mm and the diameter of 15 mm. The cold pressed samples were prepared from aluminum powders with the mean size of 33 μm and pressed under 870 MPa for 120 s. The cold pressed samples have a disk shape with 2 mm in height and 10 mm in diameter. The refined aluminum samples were prepared by BMA method, where the powder mixture was subjected to severe shear deformation. The standard cyclic loading pass schedule is consisted of two compression and one extrusion modes, as depicted in Fig.2. In particular, large shear stress is transferred to materials in the forward extrusion mode during BMA, resulting in refinement to particle and grain size.¹⁵⁾ For BMA samples, aluminum powders were mixed with 1 mass% of paraffin as lubricant. After BMA the samples were cold pressed and cut to size of 10 mm $\times$ 10 mm $\times$ 2 mm. Samples with Al-1 mass % Ti were prepared by cold pressing and BMA. Titanium powders with the mean size of 40 μm were mixed with aluminum powders prior to cold pressing. For BMA samples, the mixture was subjected to BMA in the similar way as the pure aluminum. All cast and BMA samples were polished until 1 μm diamond paste and rinsed in acetone before putting in to nitriding chamber.

4.3 PLASMA NITRIDED ALUMINIUM ALLOY

Plasma nitriding of aluminium alloy is a surface modification process that involves the diffusion of nitrogen atoms into the surface layer of an aluminum alloy material. This process is conducted in a low-pressure plasma environment, typically using nitrogen gas, and it is designed to improve the surface properties of aluminum alloys.

Below is a detailed description of plasma-nitrided aluminium alloys:

1. Surface Hardening

Plasma nitriding imparts significant hardness to the surface of aluminum alloys. During the process, nitrogen ions are accelerated and directed towards the alloy surface. These ions penetrate the material and form nitrides, creating a hard and wear-resistant layer on top of the aluminum substrate. This enhanced surface hardness is crucial for applications requiring resistance to abrasive wear and friction.

2. Improved Wear Resistance

One of the primary benefits of plasma nitriding on aluminum alloys is the substantial improvement in wear resistance. The hardened surface layer created by nitriding is highly resistant to wear, making it ideal for components that experience repetitive contact, sliding, or abrasive interactions. This property is particularly valuable in applications like robot grippers, where durability is critical.

3. Enhanced Friction Properties

Plasma-nitrided aluminium alloys exhibit reduced friction coefficients compared to untreated alloys. This reduction in friction is beneficial for applications where smooth and efficient movement is required, as it minimizes energy loss and reduces wear on moving parts.

4. Surface Microstructure

The process of plasma nitriding can alter the microstructure of the aluminum alloy's surface layer. Typically, it leads to the formation of various nitride phases, which can include aluminium nitride (AlN) and aluminium oxynitride (AlON). These phases contribute to the improved surface properties, including hardness and wear resistance.

5. Thickness Control

The depth of the nitrided layer can be controlled by adjusting process parameters such as time, temperature, and gas composition. This control allows for tailoring the surface properties to meet specific application requirements. For robot grippers, the thickness of the nitrided layer can be optimized to balance wear resistance with flexibility.

6. Corrosion Resistance

While the primary focus of plasma nitriding is on improving wear resistance, it can also provide some degree of corrosion resistance. The formation of nitride layers can act as a barrier against environmental factors that contribute to corrosion, enhancing the alloy's overall longevity.

7. Complex Geometries

Plasma nitriding is a versatile process that can be applied to aluminum alloy components with complex geometries, including intricate shapes and internal features. This adaptability makes it suitable for a wide range of applications, including robot grippers that come in various designs.

8. Post-Treatment Options

Depending on the specific requirements, post-treatment processes like polishing or coating can be applied to further enhance the surface finish and performance of plasma-nitrided aluminum alloy components.

Plasma nitriding chamber was evacuated by rotary and mechanical booster pumps to a base pressure less than 2.66×10^{-2} Pa (2×10^{-2} Torr) in order to minimize the rest oxygen partial pressure in chamber. After that, pure nitrogen was filled

into the chamber until the pressure reaches 133.3 Pa(1 Torr).The samples were heated up to the specified temperature by heater and glow discharge, simultaneously. At the specified temperature, glow discharge of nitrogen was generated by applying abias voltage of 200 V to samples which were seton the table, acting as a cathode in this experiment. Pre-sputtering was employed to eliminate the surface oxide film by nitrogen plasma. N_2^+ in the nitrogen plasma is an effective species for pre-sputtering. Holding time of pre-sputtering is 10.8 ks for pure aluminium sample. Nopre-sputtering was employed for nitriding the Al-Tialloy. After sputtering, nitrogen and hydrogen was filled into the chamber until the total pressure became 533.2 Pa(4 Torr).The applied bias voltage for glow discharge in plasma nitriding was set up 200 V with the current of 0.2 A. Samples we renitrided for72252ks(20-70h)for pure aluminium, and 72 ks (20 h)for Al-Tialloy. During nitriding, the gas was evacuated out by rotary pump to keep pressure in chamber constant. After nitriding, samples were cooled down to room temperature in hydrogen atmosphere

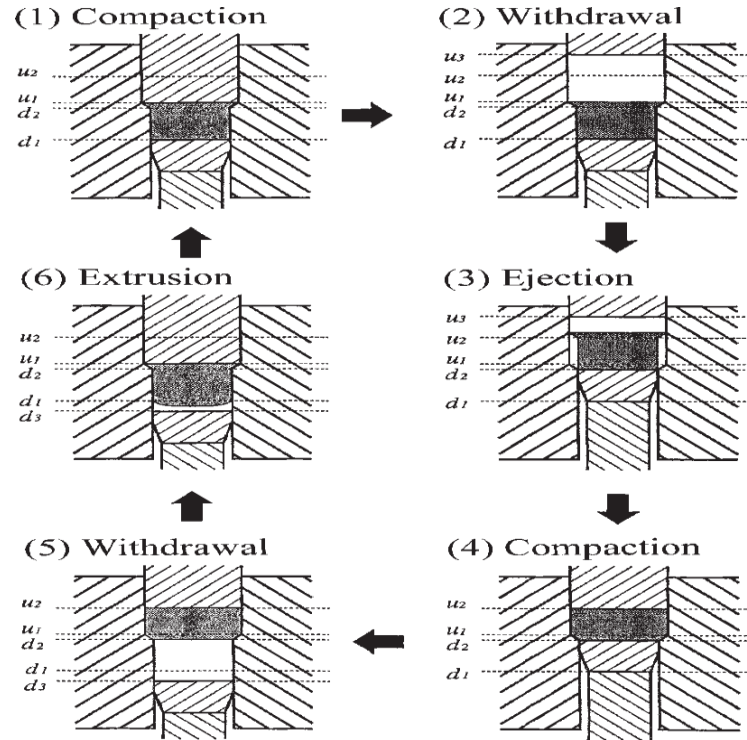
4.4 CHARACTERIZATION OF NITRIDED SAMPLE

Formation of AlN by plasma nitriding was analyzed by the Grazing Incident X-ray Diffraction (GIXD) at the incident angle of 1° . The cross-sectional microstructure of nitride samples was observed by optical microscope and Scanning Electron Microscope(SEM). Hardness was analysed by Dynamic Hardness Tester(DHT)with the load of 0.1g

Chapter 5

EXPERIMENTAL SETUP

5.1 Normal plasma nitriding



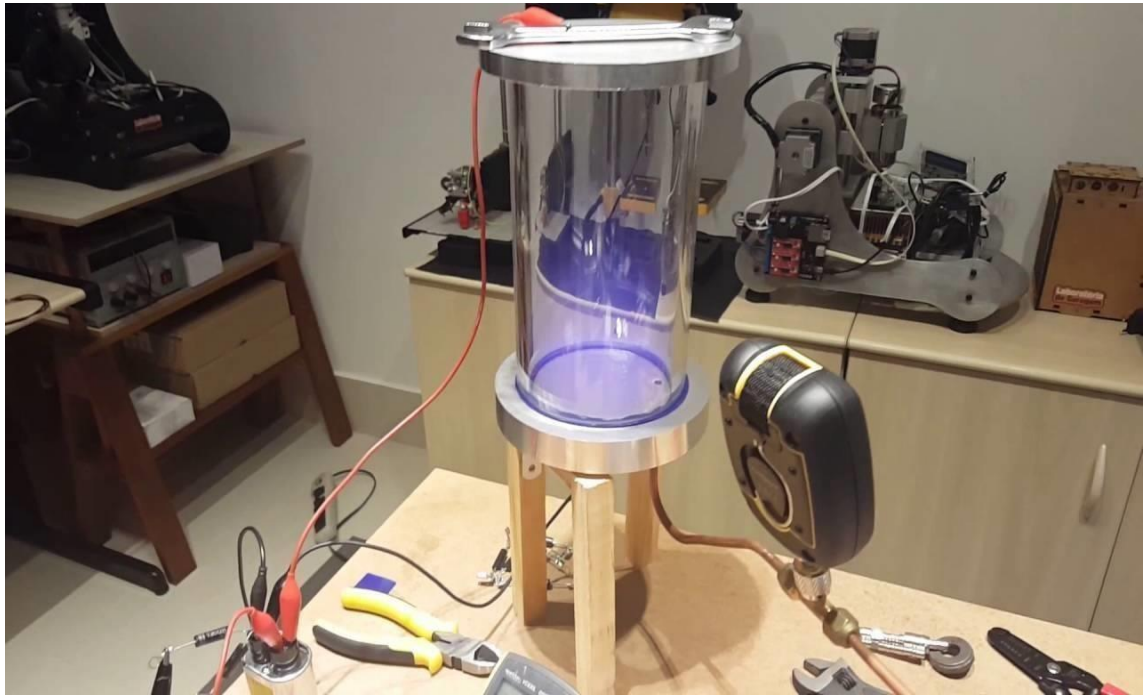
The cast samples were nitride for 72-252 Ks with 10.8 Ks pre-sputtering. The cross-sectional microstructures shows that the thickness of AlN layer is around 1-2 mm or less than 3 mm for 252 ks nitriding as shown in Fig. 3. The growth rate of AlN layer is very slow, approximately less than 4.2×10^{-5} mm/s. The formation of AlN by normal plasma nitriding is controlled by diffusion process as had been reported in Ref. 16). Refs. 17) and 18) stated that the diffusion coefficient of nitrogen in aluminum at the temperature around 772 to 873 K ranges from 10^{-17} to 10^{-19} m²/s. Those diffusion coefficients of nitrogen in aluminum are far lower than that for iron, which is around 10^{-11} or 10^{-12} m²/s. Due to this low diffusion coefficient of nitrogen into aluminum, the growth rate of AlN by normal plasma nitriding becomes also very slow.

Long processing time is necessary not only for pre-sputtering but also for nitriding. This nitriding procedure is not preferred to the industrial processing, when compared to the highly reliable and cost-competitive routes such as anodizing. The XRD analysis results showed that the nitride layer on the

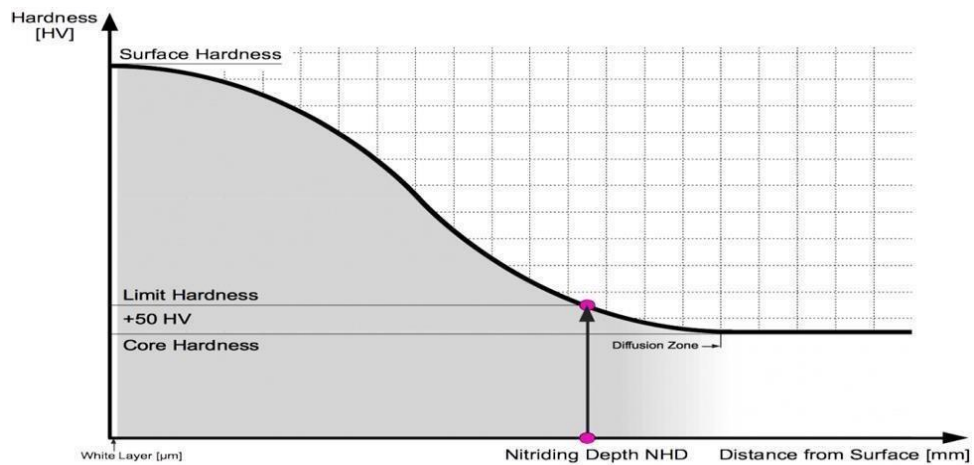
aluminium alloy samples consisted of AlN, which is a hard and wear-resistant compound. SEM analysis revealed a uniform and compact nitride layer with a thickness of approximately 5–10 μm . Microhardness testing showed a significant increase in surface hardness, with values ranging from 900 to 1200 HV compared to 150 HV for the untreated aluminium alloy. The wear tests showed that the plasma-nitride aluminium alloy exhibited a significantly lower wear rate and coefficient of friction compared to the untreated material. Furthermore, the wear resistance increased with increasing nitriding temperature and time. Robotic grippers are essential components of robotic systems as they enable robots to perform tasks such as picking and placing objects. Grippers can be classified into several types based on their actuation principles and the material used for grip. This report aims to provide an overview of different types of robotic grippers and the materials used for grip, as well as provide reference papers on the subject.

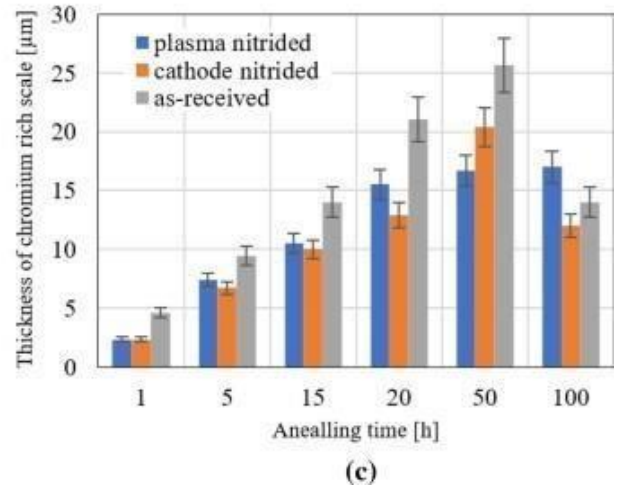
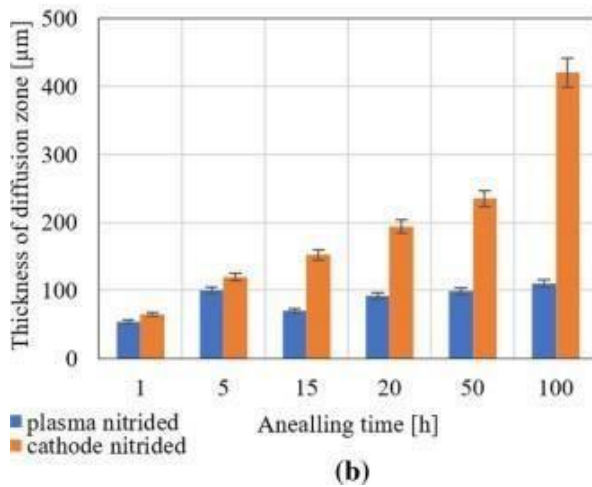
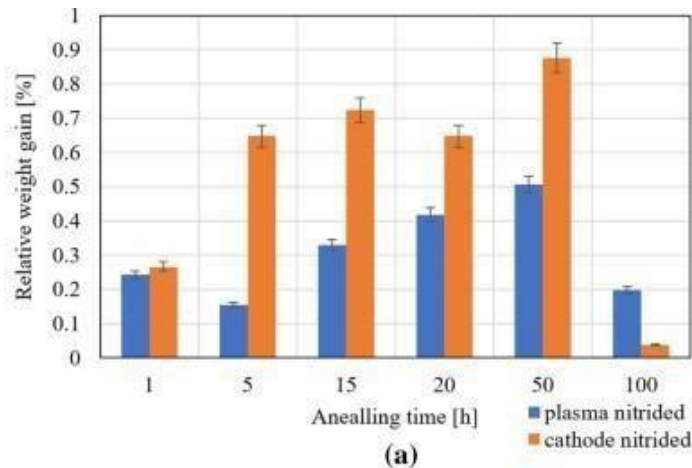
CHAPTER 6

RESULTS AND DISCUSSION



PLASMA NITRIDING CHAMBER





ADVANTAGES OF PLASMA NITRIDING

Surface Hardening:

Plasma nitriding imparts significant hardness to the surface of aluminum alloys. During the process, nitrogen ions are accelerated and directed towards the alloy surface. These ions penetrate the material and form nitrides, creating a hard and wear-resistant layer on top of the aluminum substrate. This enhanced surface hardness is crucial for applications requiring resistance to abrasive wear and friction.

Improved Wear Resistance:

One of the primary benefits of plasma nitriding on aluminum alloys is the substantial improvement in wear resistance. The hardened surface layer created by nitriding is highly resistant to wear, making it ideal for components that experience repetitive contact, sliding, or abrasive interactions. This property is particularly valuable in applications like robot grippers, where durability is critical.

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Plasma-nitrided aluminum alloys exhibit reduced friction coefficients compared to untreated alloys. This reduction in friction is beneficial for applications where smooth and efficient movement is required, as it minimizes energy loss and reduces wear on moving parts.

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The depth of the nitrided layer can be controlled by adjusting process parameters such as time, temperature, and gas composition. This control allows for tailoring the surface properties to meet specific application requirements. For robot grippers, the thickness of the nitrided layer can be optimized to balance wear resistance with flexibility.

Corrosion Resistance:

While the primary focus of plasma nitriding is on improving wear resistance, it can also provide some degree of corrosion resistance. The formation of nitride layers can act as a barrier against environmental factors that contribute to corrosion, enhancing the alloy's overall longevity.

Complex Geometries:

Plasma nitriding is a versatile process that can be applied to aluminum Alloy components with complex geometries, including intricate shapes and internal features. This adaptability makes it suitable for a wide range of applications, including robot grippers that come in various designs.

Post-Treatment Options:

Depending on the specific requirements, post-treatment processes like polishing or coating can be applied to further enhance the surface finish and performance of plasma-nitrided aluminum alloy components.

SPECIFICATIONS OF PLASMA NITRIDING

Ion nitriding (also known as plasma ion nitriding) is a surface hardening heat treatment that uses diffused nitrogen to form various nitrogen compounds.

The nitrogen ions are diffused into a part (or sample) in a vacuum through the use of high voltage electrical energy.

6.1

TEST REPORT

DATE: 19/ 03 /2024

TO -
Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama institute of science and technology

TEST NAME- BREAK DOWN VOLTAGE TEST

Aluminum Sample Groups	Mean - $\bar{X}$	Standard Deviation - σ	Variance - σ^2
Aluminum at 10% (X10)	15.798	0.958	0.918
Aluminum at 25% (X25)	15.967	1.894	3.588
Aluminum at 50%(X50)	16.071	1.382	1.909



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AUTHORIZED SIGNATURE



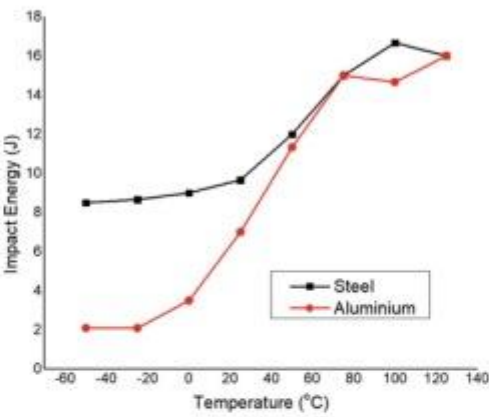
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Government
e Marketplace

TEST REPORT

DATE: 19/ 03 /2024

TO - Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama institute of science and technology

TEST NAME- THERMAL TEST
COMPARSON WITH STEEL VS NITRATED ALUMINIUM AL2N3



IMPACTED TEST SPECIMEN



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AUTHORIZED SIGNATURE



GeM
Government
e Marketplace

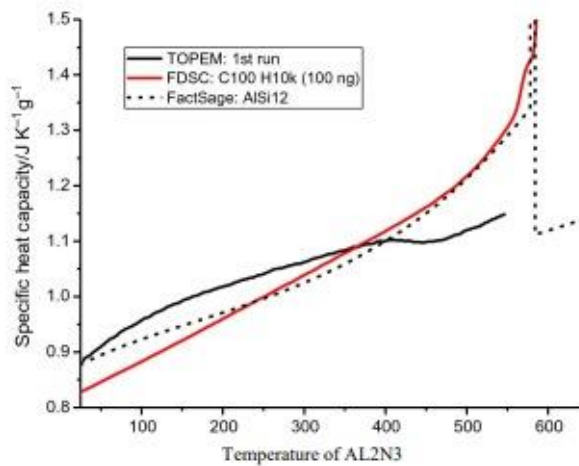
6.3

TEST REPORT

DATE: 19/03/2024

TO - Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama Institute of science and technology

TEST NAME- SPECIFIC HEAT TEST



[Handwritten Signature]

AUTHORIZED SIGNATURE



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6.4

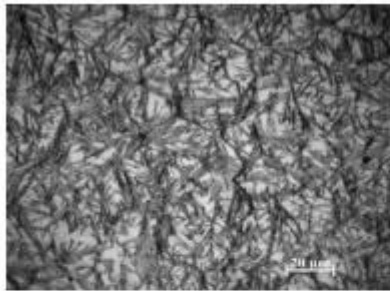
TEST REPORT

DATE: 19/ 03 /2024

TO - Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama Institute of science and technology

**TEST NAME- STRENGTH TEST,
DURABILITY, TEST HARDNESS TEST.
TEST IN AL2N3
TEST PERFORMED IN ROCKWELL HARDNESS
MACHINE CALLIBRATED ON 01-2024**

Sr No	Hardness(VHN)	D1(Micro meter)	D2(micrometer)
1	770	34.9	34.2
2	829.9	32.8	34.1
3	837	33.4	33.2
4	872	32.6	32.6
5	824	33.5	33.6
Avg	826.58		



MICRO STRUCTURE @ 100X



[Handwritten Signature]

AUTHORIZED SIGNATURE



GeM
Government
e Marketplace

6.5

TEST REPORT

DATE: 19 / 03 / 2024

TO -

Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama institute of science and technology

TEST NAME- TENSILE AND ELONGATION TEST

Reduction of area by drawing %	Y.S (MPa)	T.S (MPa)	Elongation in 50 mm %	Reduction of area %
0	276	455	34	70
10	496	517	20	65
20	565	579	17	63
40	593	655	16	60
60	607	703	14	54



AUTHORIZED SIGNATURE



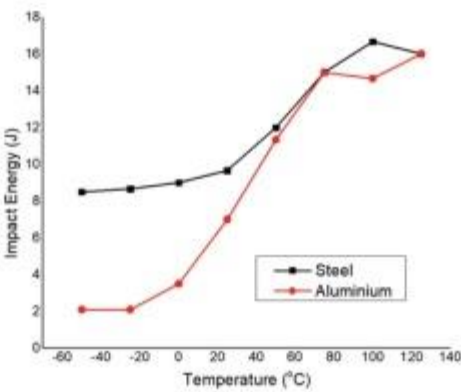
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TEST REPORT

DATE: 19 / 03 / 2024

TO - Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama Institute of science and technology

TEST NAME- THERMAL CONDUCTIVITY TEST
COMPARSION WITH STEEL VS NITRATED ALUMINIUM AL2N3



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AUTHORIZED SIGNATURE



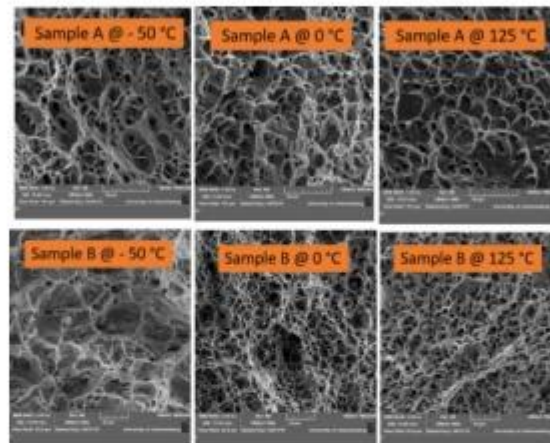
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Government
e Marketplace

TEST REPORT

DATE: 19/03/2024

TO - Mr. X.Jesu Greatson Fernando
Mr. S.Raghul
Sathyabama Institute of science and technology

TEST NAME- THERMAL EXPANSION TEST
DONE WITH - ULTRA HIGH PRECISION INTERFEROMETER.


AUTHORIZED SIGNATURE

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CHAPTER 7

SUMMARY AND CONCLUSION

SUMMARY

The characterization and wear behaviour of aluminium alloy for robot gripper applications are of significant importance in the field of robotics and automation. Aluminum alloys are increasingly used in robotic grippers due to their lightweight and corrosion-resistant properties, making them ideal for applications where weight reduction is crucial. To ensure the optimal performance of these grippers, it is essential to characterize the aluminum alloy and understand its wear behaviour.

Characterization involves a thorough examination of the material's properties, including microstructure, hardness, and surface finish. Microstructural analysis provides insights into the alloy's grain structure, which can impact its mechanical properties. Understanding the material's hardness is critical because it affects its ability to withstand wear and abrasion. Surface finish analysis assesses the quality and smoothness of the alloy's surface, which can influence gripping and manipulation capabilities in robotic applications.

The wear behaviour of the aluminium alloy is a key consideration for robot grippers. Robots often perform repetitive tasks that subject gripper components to wear and tear. The wear behaviour analysis helps in determining how the alloy performs under various operating conditions, including friction, sliding, and contact with different materials. It allows engineers to predict the lifespan of gripper components and assess when maintenance or replacement may be necessary.

In summary, the characterization and wear behaviour analysis of aluminium alloy for robot gripper applications are critical steps in optimizing the performance and longevity of gripper components. This research not only provides valuable insights into the material's properties but also contributes to the design and maintenance of robot grippers, ensuring their efficiency and reliability in various industrial and automation settings.

Conclusion

The plasma nitriding process effectively improved the wear resistance of the aluminium alloy samples for robot gripper applications. The treated samples exhibited a significant increase in surface hardness and wear resistance, with a lower wear rate and coefficient of friction compared to the untreated material. The results showed that the nitriding temperature and time had a significant effect on the microstructure and wear behaviour of the treated material, with higher temperatures and longer treatment times resulting in better wear resistance. Overall, the plasma nitriding process can be a suitable surface treatment technique for improving the wear resistance of aluminium alloys in robot gripper applications.

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