Study the corrosion behaviour of AA 6063 at different retrogression and re-ageing temperatures

A thesis submitted in partial fulfillment of the requirements for the award of a degree of

Master of Engineering in Industrial Metallurgy

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By

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of his **“STUDY THE CORROSION BEHAVIOUR OF AA 6063 AT DIFFERENT RETROGRESSION AND RE-AGING TEMPERATURE**” studies**.** All information in this document has been obtained and presented under academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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This is to certify that the entitled **"Study the corrosion behaviour of AA 6063 at different retrogression and re-ageing temperatures**" has been carried out by **Mr Sagar Chakraborty (Exam Roll: M4MET24005, Registration No: 163724 of 2022 - 2023)** under my guidance and supervision and accepted in partial fulfillment for the degree of Master of Engineering in Industrial Metallurgy from Jadavpur University. To the best of our knowledge, the contents of this thesis or any part thereof have not been previously submitted for the award of any degree or diploma.

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List of table:

List of abbreviations:

Sl	Abbreviations	Description
1	WE	Working electrode
2	CE	Counter electrode
3	RE	Reference electrode
4	RRA210-10	Retrogression And Re-ageing at 210^0c for 10 min
5	RRA210-15	Retrogression And Re-ageing at 210^0c for 15 min
6	RRA280-10	Retrogression And Re-ageing at 280^0c for 10 min
7	RRA280-15	Retrogression And Re-ageing at 280^0c for 15 min
8	RRA400-10	Retrogression And Re-ageing at 400^0c for 10 min
9	RRA400-15	Retrogression And Re-ageing at 400^0c for 15 min
10	SEM	Scanning electron microscopy
11	XRD	X-Ray Diffraction
12	EDS	Energy dispersive spectroscopy
13	SCE	Saturated Calomel Electrode

List of figures:

ABSTRACT:

This term paper presents a comprehensive study of the corrosion behaviour and electrochemical impedance of AA6063 at different temperature aging conditions. The investigation aims to understand the effect of temperature aging on the material's electrochemical characteristics and corrosion resistance. The study involves sample preparation, electrochemical measurements using impedance spectroscopy, and data analysis. The findings contribute to a deeper understanding of the aging behaviour of AA6063 and provide valuable insights for optimizing its performance in different environments.

Keywords- AA6063, microstructure study, XRD analysis, EDAX analysis, SEM analysis, retrogression and re-aging, corrosion behaviour, Microhardness

CHAPTER-1
Introduction

1. INTRODUCTION:

Aluminum alloy 6063 is a versatile and popular alloy commonly referred to as an architectural alloy. It is a medium-strength alloy with magnesium and silicon as the primary alloying elements. Its good extrudability, corrosion resistance, and ability to be formed into complex shapes make it ideal for a wide variety of applications, particularly in the building and construction industries.[26]

Overview of the properties of al alloy 6063:

The basic composition of aa6063 is primarily aluminum with magnesium and silicon as alloying elements. It has medium strength. It has high Corrosion resistance property. It has excellent formability:, can be extruded into complex shapes. Weldability is Good also Good machinability. It Can be anodized for a variety of colors and improved corrosion resistance.[27]

Due to its combination of properties, 6063 aluminum is commonly used in the following applications:

1. Window and door frames 2. facades 3.Cladding panels 4. Sunshades and louvers 5.Curtain walls 6.Irrigation tubing 7.Electrical enclosures 7.Marine applications (such as boat railings and hatches) 7.Furniture 8.Storage tanks[28]

When choosing an aluminum alloy for a specific application, it is important to consider the required strength, corrosion resistance, formability, and other factors. While 6063 is a good all-around alloy, other alloys may be better suited for applications requiring higher strength, such as 6061 or 6082.[29]

Like many aluminum alloys, 6063 comes in various temper designations indicating its heat treatment and mechanical properties. The most common tempers for 6063 are:

T4: Offers good formability, making it suitable for bending and shaping after extrusion. Often used in applications like railings with formed elbows.[30]

T6: The most widely available temper, providing a good balance between strength and machinability. Commonly used in architectural extrusions like window frames and cladding panels.[31]

While 6063 offers good strength for many architectural applications, it's considered a medium-strength alloy. If your project requires higher structural strength, alloys like 6061 or 6082 might be better choices.[33]

There are some specific reason for taking AA6063:

Ensures product longevity and safety: Aluminum 6063 is widely used in building and construction, transportation, and marine applications. Understanding how it reacts in different environments helps predict its lifespan and prevent failures that could compromise safety or lead to expensive repairs.[32]

Optimizes material selection and design: By knowing how 6063 behaves in various conditions (e.g., exposure to salt water, acidic rain, high temperatures), engineers can select alternative alloys or implement protective measures (like coatings or anodizing) to improve its corrosion resistance in specific applications.[34]

Minimizes maintenance costs: Corrosion can necessitate frequent maintenance or replacements. Studying corrosion behavior allows for the development of preventative strategies, reducing long-term maintenance costs associated with 6063 products.[35]

Promotes sustainable practices: Premature corrosion necessitates material replacement, increasing waste. Understanding how to optimize the use of 6063 through corrosion prevention strategies promotes sustainability by extending the product's life cycle and reducing waste.[36]

By thoroughly investigating these aspects, researchers and engineers can develop new alloys or surface treatments that enhance the corrosion resistance of 6063, ultimately leading to more reliable, durable, and sustainable products.[37]

AA6063 is an aluminium alloy that belongs to the 6xxx series of aluminium alloys. The AA prefix stands for Aluminium Association, which is an organization that sets standards for aluminium alloys.[38]

AA6063 is primarily composed of aluminium, with magnesium and silicon as the main alloying elements. It is known for its good formability, high corrosion resistance, and excellent extrudability, which makes it suitable for various applications.[45]

One of the significant uses of AA6063 is in manufacturing extruded aluminium profiles. These profiles are commonly used in architectural applications, such as window frames, door frames, curtain walls, and other structural components. The alloy's combination of strength, durability, and aesthetic appeal makes it a popular choice for these purposes.[46][47]

AA6063 can also be found in the production of heat sinks, which are used to dissipate heat from electronic devices. Its thermal conductivity and ease of extrusion make it suitable for this application.[51]

Furthermore, AA6063 is weldable and can be subjected to various surface treatments, including anodizing, painting, and powder coating, to enhance its appearance and provide additional protection against corrosion.[48]

The retrogression is a short-duration, high-temperature heat treatment followed by a rapid cooling. During the retrogression, it is thought that the strengthening microstructural precipitates within the aluminium matrix partially dissolve, or retrogress, back into solution.[49]

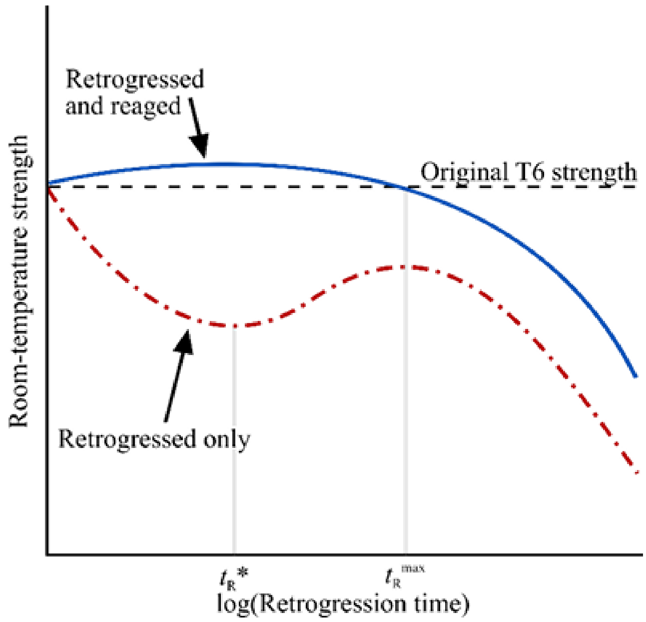

Fig.1: Original vs retrogression vs retrogression reaging graph with respect to strength

It's worth noting that while AA6063 is a widely used aluminium alloy, there are other alloys within the 6xxx series, such as AA6061, that have similar properties but with slight variations in composition and performance characteristics [39].

This project relates the corrosion rate at different retrogression and reaging temperatures.

CHAPTER-2

BACKGROUND

2. **BACKGROUND**:

6063 aluminium alloy is part of the 6xxx series of aluminium alloys known for their excellent extrudability, formability, and corrosion resistance.[40]

2.1. **Mechanical Properties**:

The mechanical properties of 6063 depend on its different temper (heat treatment) condition. Here the basics of heat-treated aa6063[41]

6063-0(Un-heat-treated):

It has a maximum tensile strength which is to 130 MPa (19,000 psi) and Elongation in plastic deformation is (stretch before ultimate failure)18%[43]

6063-T1 (T1 temper):

It has an ultimate tensile strength of at least 120 MPa (17,000 psi) for thicknesses up to 12.7 mm (0.5 in) and a Yield strength of at least 62 MPa (9,000 psi) for thicknesses up to 13 mm (0.5 in).[45]

6063-T4 and 6063-T5 (T5 temper):

The Ultimate tensile strength of this AA6063 is at least 140 MPa (20,000 psi) for thicknesses up to 13 mm (0.5 in) and yield strength is at least 97 MPa (14,000 psi) for thicknesses up to 13 mm (0.5 in)[45]

6063-T6 (T6 temper):

It has at least 190 MPa (28,000 psi) ultimate tensile strength and Yield strength of at least 160 MPa (23,000 psi).

In this project, AA6063 t6 has been taken for its good corrosion property. Good Tensile behaviour and various types of uses in modern industries

Some basic applications are 6063 is widely used for **aluminium extrusion** due to its ability to form complex shapes with smooth surfaces suitable for anodizing.[47]

Common applications of this alloy is Window frames ,Door frames ,Roofs ,Sign frames ,Visible architectural components.[50]

Comparison with 6061 Alloy:[52]

6063 has a slightly different composition compared to the popular 6061 aluminium alloy.While 6061 contains more alloying elements (0.7% Mg, 0.4% Si, and 98.9% Al), 6063 is more basic (0.7% Mg, 0.4% Si, and 98.9% Al). These numbers can vary based on manufacturing preferences or natural impurities within tolerances[2].

CHAPTER-3

OBJECTIVE & PLAN OF WORK

3. OBJECTIVE:

This project aims to study the corrosion behaviour and electrochemical impedance of AA 6063 at different temperature ageing. AA6063 has been heat treated in different retrogression and re-aging conditions & also studied how the ageing temperature affects the corrosion resistance property of the Al alloy. And to study the relationship between temperature ageing and microstructural changes(grain boundary, precipitation, grain size) in the alloy. Also to find out the corrosion behaviour in acidic and salt mediums, so that to find out the best use of retrogression and reageing heat treatment for AA6063. This information can be used to optimize the ageing process to achieve the best possible corrosion resistance for a particular application.

The corrosion resistance of aluminium alloys is affected by a number of factors, including the composition of the alloy, the surface finish, and the environment in which the alloy is exposed. The ageing temperature is also an important factor, as it affects the microstructure of the alloy and the properties of the oxide film that forms on the surface of the alloy.

The results of this study will provide valuable information on how to improve the corrosion resistance of AA 6063. This information can be used to develop new aluminium alloys that are more corrosion-resistant in a wider range of environments.

4. PLAN OF WORK:

The plan has been designed as follows:

- Preparing the AA6063 sample with metallographic process
- Temperature Aging Procedures for AA6063

Temp. 210°c for 10 m +175°c for 4 hours

Temp. 210°c for 15 m +175°c for 4 hours.

Temp. 280°c for 10 m +175°c for 4 hours

Temp. 280°c for 15 m +175°c for 4 hours

Temp. 400°c for 10 m +175°c for 4 hours

Temp. 400°c for 15 m +175°c for 4 hours

- Microstructure observation of base metal and aged metal
  - With an **optical microscope** and **scanning electron microscope** (SEM) to examine the polished or etched samples.
  - Optical microscopy allows to observe the **overall microstructure and grain boundaries.**
  - SEM provides higher magnification and allows for **detailed observations of microstructural features, including precipitates, grain boundaries, and dislocations.**
- Corrosion Behaviour Study of base metal and aged metal by 3.5 wt% of NaCl sol. & N/10 H_2SO_4
- Perform the microhardness of base metal and aged metal With Vickers to compare its hardness between base sample and aged sample.
- EDAX analysis for elemental composition analysis

CHAPTER-4

LITERATURE REVIEW & PREVIOUS RESEARCH

4. LITERATURE REVIEW:

Regarding mechanical deformation of aluminum alloy it should be underlined that the deformation takes place in the range of elastic or plastic deformations. Elastic deformation of metals takes place by moving atoms over distances not greater than lattice distances, thus there is no fundamental change in the arrangement of atoms in the lattice. Compared to elastic deformation, plastic deformation remains after the stress is removed. In the case of the tested aluminum alloys, a slip mechanism is responsible for the deformation of such materials. The slip in the EN AW-6063 alloy is realized in many different grains at the same time. It is worth to mention, that the grains are single crystals differently oriented in space, which limit each other, thus the deformation of one grain must be accompanied by a simultaneous deformation of the adjacent grains. For this reason, slips in one grain in a specific slip system are accompanied by slips in adjacent grains, in the same or a different system. Changes in the metallic-based alloy structure caused by deformations affect the corrosion resistance of the material [17,18]. Coating protections of aluminum alloys, depending on the degree of deformation of the alloy, may deteriorate or retain their anti-corrosion properties. Surprisingly, current laboratory experimental procedures aimed to determine the durability of architectural aluminum construc tion elements do not take into account mechanical nor the physical loads acting on such elements after implementation in real-life working conditions. This motivated us to set the scope of the study presented in this manuscript. We designed a novel experi mental approach, in which both mechanical and physical loads were taken into account regarding assessment of the durability of anodized aluminum EN AW-6063 (T6 temper) alloy.[52]

Aluminum alloy 6063, often referred to as an architectural alloy, is a notable member of the 6000 series of aluminum alloys. This series is known for its versatility, offering a blend of good mechanical properties and excellent corrosion resistance. The specific characteristics of 6063 make it ideal for applications requiring intricate extrusions, high-quality surface finishes, and durability against environmental factors.[53]

Making Aluminum alloy 6063 is an industrial process that requires specialized equipment and expertise. [55]

Raw materials: The process starts with high-purity Aluminum ingots and precise amounts of magnesium and silicon, following the AA 6063 standard composition.

Melting: The Aluminum ingots and alloying elements are melted together in a furnace at high temperatures (around 700°C or 1292°F).[58]

Fluxing: Special fluxing agents are added to remove impurities and improve the melt quality.[59]

Degassing: The molten metal undergoes degassing to remove any trapped gasses that can create imperfections in the final product.

Alloying: The molten metal is carefully mixed to ensure a uniform distribution of the alloying elements (magnesium and silicon) throughout.

Homogenization: The molten alloy might undergo homogenization treatment at specific temperatures to further ensure even distribution of elements and eliminate any segregation.

Casting or extrusion: Depending on the desired final form, the molten metal is either cast into sows for further processing or directly extruded into desired shapes. Extrusion is a common method for 6063 due to its excellent extrudability.

Heat treatment: The extruded or cast shapes might undergo heat treatment to achieve specific temper designations (like T4 or T6) influencing strength and formability.

Finishing: The final product may undergo various finishing processes like machining, anodizing, or painting depending on the application.

Safety and complexity: Remember, this process involves high temperatures, molten metal, and specialized equipment. Attempted at home, it can be dangerous and is not recommended.[8]

T6 means for 6063 aluminum:

Solution heat treated and artificially aged: The T6 temper involves two key heat treatment steps:

Solution heat treatment: The alloy is heated to a high temperature (around 530°C or 986°F) for a specific duration. This dissolves the magnesium and silicon alloying elements into the aluminum matrix, creating a uniform microstructure.

Artificial aging: The alloy is then quenched rapidly (usually by submerging it in water) and then artificially aged at a lower temperature (around 180°C or 356°F) for a controlled time. This allows the dissolved elements to precipitate in a fine, dispersed form, significantly strengthening the alloy.[60]

Properties of T6 temper: Compared to other tempers like T4, T6 temper offers:

Increament in strength: T6 is the strongest temper typically used for 6063, making it suitable for applications requiring good structural integrity.[62]

Good machinability: Despite the increased strength, T6 6063 remains machinable, allowing for shaping and drilling after extrusion.[61]

a. The alloy composition of 6063 is:[2]

Table. 1 Chemical composition of AA6063

Name of the elements	**Minimum percentage (wt%)**	**Maximum percentage (wt%)**
Aluminium	97.5%	99.35%
Magnesium (Mg)	0.45%	0.90%
Silicon (Si)	0.20%	0.60%
Iron (Fe)	0	0.35%
Chromium (Cr)	0	0.10%
Copper (Cu)	0	0.10%
Manganese (Mn)	0	0.10%
Titanium (Ti)	0	0.10%
Zinc (Zn)	0	0.10%
(others)	0	0.15%

Physical properties

- Density (ρ) - 2.69 g/cm3[1][2]

Mechanical properties

- Young's modulus (E) - 68.3 GPa (9,910 ksi)
- Tensile strength (σt) - 145–186 MPa (21.0–27.0 ksi)
- Elongation (ε) at break - 18–33%
- Poisson's ratio (ν) - 0.3

Thermal properties

- Melting temperature (Tm)- 615 °C (1,139 °F)
- Thermal conductivity (k)- 201–218 W/[m·K]
- Linear thermal expansion coefficient (α) - 2.34·10−5/K
- Specific heat capacity (c) - 900 J/kg·K

Electrical properties

- Volume resistivity (ρ) - 30–35 n Ohm·m

Some specific aspects of corrosion behaviour studied for 6063:

Effect of different environments: How exposure to salt water, acidic rain, or industrial pollutants affects the corrosion rate of 6063.[63]

Influence of temperature: The impact of temperature fluctuations on the corrosion process for 6063.

Role of surface treatments: How anodizing, painting, or other coatings influence the corrosion resistance of 6063.

Understanding the mechanisms: Studying the underlying electrochemical processes that drive corrosion in 6063 helps develop better mitigation strategies.

Microstructure of aa6063:

The microstructure of AA6063, an aluminum alloy, is influenced by its composition and the thermal processing it undergoes during manufacturing and heat treatment. AA6063 is a widely used alloy known for its excellent extrudability, good corrosion resistance, and moderate strength. Below is a general description of the typical microstructure of AA6063:

Primary Phase: The primary phase in AA6063 is aluminium, which forms the alloy's matrix. The aluminium matrix is a face-centered cubic (FCC) crystal structure.[65]

Alloying Elements: The key alloying elements in AA6063 are silicon (Si) and magnesium (Mg). Silicon is added to improve the alloy's extrudability and strength, while magnesium enhances its response to heat treatment.[49]

Precipitates: During the heat treatment process, the alloying elements, particularly magnesium and silicon, form precipitates within the aluminium matrix. The main precipitate phase is **Mg_2Si (magnesium silicide)**. These precipitates contribute to the strengthening of the material, as they hinder the movement of dislocations and improve the mechanical properties.[34]

Grain Structure: The grain structure in AA6063 can vary depending on the manufacturing process and heat treatment conditions. Typically, the alloy has a fine grain structure, which contributes to its good mechanical properties and formability.[68]

Dislocation Structure: The mechanical processing and thermal treatments introduce dislocations into the aluminum grains. These dislocations play a significant role in the material's strength and deformation behaviour.[29]

Secondary Phases (Impurities): AA6063 may contain minor secondary phases or impurities, such as iron (Fe) and copper (Cu). The presence of these elements is usually kept to a minimum to avoid adverse effects on the material's properties.[67]

The microstructure of AA6063 can be further modified through heat treatments, such as the T5 and T6 tempers. The T5 temper involves artificially aging the material at a relatively low temperature to achieve some precipitation hardening. In contrast, the T6 temper undergoes a solution heat treatment followed by artificial aging at a higher temperature to achieve maximum precipitation hardening. These heat treatments result in a more refined microstructure and improved mechanical properties.

It's essential to note that the specific microstructural details of AA6063 can vary depending on the exact processing conditions, alloy composition, and any subsequent heat treatments applied. To obtain detailed and up-to-date information about the microstructure of AA6063 in specific conditions, it is best to refer to research papers, technical literature, or consult with experts in the field.[68]

Corrosion behaviour of AA6063:

When aluminium surfaces are exposed to the atmosphere, a thin invisible oxide skin forms immediately, this protects the metal from further oxidation. This self-protecting characteristic gives aluminium its high resistance to corrosion. Unless exposed to some substance or condition that destroys this protective oxide film, the metal remains fully protected against corrosion [17]. But the oxide film is not homogeneous and contains weak points. Breakdown of the oxide film at weak points leads to the onset of localized corrosion. The oxide film becomes more nonhomogeneous with increasing alloying content, and on heat-treatable alloys as opposed to non-heat-treatable alloys [18]. Heat-treatable wrought aluminium-magnesium-silicon alloys can be susceptible to intergranular corrosion (IGC) which is a selective corrosion that takes place at grain boundaries or at closely adjacent regions without appreciable attack of the grains themselves [17]. IGC is the result of micro-galvanic cell action at the grain boundaries, due to formation of grain boundary precipitates, which are either more active or more noble than the surrounding solid solution aluminium matrix. As a result, preferential dissolution occurs at the sites where these precipitates, or the adjacent precipitate-free zone, undergo anodic reactions [18]. Therefore intergranular corrosion (IGC) depends upon grain boundary features such as grain boundary precipitates, alloying element segregation and alloying element depleted zones [16]

The mechanism of corrosion of aluminum and aluminum alloys in neutral solutions is based on the dissolution of aluminum atoms from the active sites or flawed regions of the naturally formed barrier film. It represents an irreversible coupled reaction, the anodic part of which is the metal dissolution and the cathodic counterpart is the reduction of water or oxygen to OH-, according to the cathodic reactions:

$H_2O(s) + e = H + OH$

And

$H + H_2O(s) + e- = H_2 + OH-$.

In oxygen-rich solutions (naturally aerated or oxygen-saturated), the cathodic part occurs through oxygen reduction:

$1/2\ O_2 + H2O(s) + e- = OH_{ads} + OH^-$

$OH_{ads} + e- = OH^-$.

Where (s) refers to the electrode surface. The anodic reactions are:

$Al(s) + OH=Al\ (OH)_{ads} + e-$,

$Al\ (OH)_{ads} + OH- = Al(OH)_{2ads} + e^-$

And

$Al(OH)_{2\ ads} + OH=Al(OH)_{3ads} + e^-$.

The formation of the adsorbed $Al(OH)_3$, which transforms into $Al_2O_3.3H_2O$ in neutral media, leads to the observed passivity.

The presence of Cl- ions in neutral solutions leads to reactions of the type:

$Al(s) + Cl^- = AlCl_{ads} + e-$,

$AlCl_{ads} + Cl= AlCl_2 + e$

And

$AlCl_2 + Cl^-=AlCl_{3soln} + e^-$.

And thus

$Al(s) + 3\ Cl^- =AlCl3 + e-$.

AlCl3 goes into the solution and hydrolyzes therein, leaving bare active sites available for attack. This explains the observed increase in the rate of corrosion in the presence of Cl-. In the case of Al-Cu, the presence of Cu on the material surface leads to an increase in the ratio of cathodic area and the formation of highly active galvanic couples which lead to an increase in the corrosion rate.[58]

Corrosion forms on Al alloy

When corrosion of aluminum and aluminum alloys occurs, it is usually of a localized nature and is most commonly caused by pitting or at points of contact with dissimilar metals in a conductive environment (seawater or road splash containing deicing salts).[64] Corrosion can also be combined with other processes. Examples include the following:

Mechanically assisted degradation, which includes forms of corrosion that contain a mechanical component (such as velocity, abrasion, and hydrodynamics) and results in erosion, cavitation, impingement, and fretting corrosion.[62]

Environmentally assisted cracking, which is produced by corrosion in the presence of static tension stress (stress-corrosion cracking) or cyclic stress (corrosion fatigue). [48]

Uniform or general corrosion of aluminum is rare, except in special, highly acidic or alkaline corrogents. However, if the surface oxide film is soluble in the environment, as in phosphoric acid or sodium hydroxide, aluminum dissolves uniformly at a steady rate. If heat is involved, as with dissolution in sodium hydroxide, the temperature of the solution and the rate of attack increase. Depending on the specific ions present, their concentration, and their temperature, the attack can range from superficial etching to rapid dissolution. Uniform attack can be assessed by measurement of weight loss or loss of thickness.[39]

Dissolution is most uniform in pure aluminum and then next most uniform in dilute alloys and the non-heat-treatable alloys. Highly alloyed heat-treatable alloys often show some surface roughness, especially when thick cross-sections are etched because variable dissolution rates through thickness result from variations in solid solution concentration of the alloying elements as well as variations in the distribution of constituent particles.[23],[25]

Localized Corrosion. In environments in which the surface film is insoluble, corrosion is localized at weak spots in the oxide film and takes one of the following forms:

• Pitting corrosion

• Crevice corrosion

• Filiform corrosion

• Galvanic corrosion, including deposition and stray- current corrosion. (It should be noted that while galvanic corrosion most often appears highly localized, uniform thinning can occur if the anodic area is large enough and a highly conductive electrolyte exists.) [41]

• Intergranular corrosion

• Exfoliation corrosion

• Biological corrosion, which often causes or accelerates pitting or crevice corrosion. [49]

Localized corrosion has an electrochemical mechanism and is caused by a difference in corrosion potential in a local cell formed by differences in or on the metal surface. The difference is usually in the surface layer because of the presence of cathodic microconstituents that can be insoluble intermetallic compounds or single elements. Most common are $CuAl_2$, $FeAl_3$, and silicon. However, the difference can be on the surface because of local differences in the environment. A common example of the latter is a differential aeration cell.[55]

General Corrosion Resistance: AA6063 demonstrates good resistance to general atmospheric corrosion, making it suitable for outdoor applications. It forms a protective oxide layer on the surface when exposed to air, which helps to prevent further corrosion.[44]

Pitting Corrosion: Pitting corrosion is localized corrosion that can occur in the presence of aggressive ions, such as chloride ions. AA6063 has moderate resistance to pitting corrosion, and its resistance can be further enhanced through appropriate surface treatments or protective coatings.[46]

Galvanic Corrosion: AA6063 can experience galvanic corrosion when it comes into contact with dissimilar metals in the presence of an electrolyte. The galvanic corrosion behaviour depends on the specific metal combination and the electrolyte conditions. Proper design and insulation can mitigate galvanic corrosion risks.[60]

Stress Corrosion Cracking (SCC): AA6063 is susceptible to stress corrosion cracking under certain conditions, particularly when exposed to corrosive environments in combination with tensile stresses. To minimize the risk of SCC, appropriate alloy design, surface treatments, and stress management techniques are employed.[51

Intergranular Corrosion: AA6063 is prone to intergranular corrosion in certain situations, especially when exposed to elevated temperatures for extended periods. This type of corrosion affects the grain boundaries of the alloy and can be mitigated through appropriate heat treatments and alloy modifications.[49]

To enhance the corrosion resistance of AA6063, various protective measures can be applied, including anodizing, painting, powder coating, and other surface treatments. These treatments provide an additional barrier against corrosion and improve the aesthetic appearance of the alloy.[39]

Mechanics of corrosion

Corrosion in Al and Al alloys:

Aluminium generally has excellent resistance to corrosion and gives years of maintenance-free service in natural atmospheres, fresh waters, seawater, many soils and chemicals, and most foods [5]. Aluminium, as indicated by its position in the electromotive force (emf) series, is a thermodynamically reactive metal; among structural metals, only beryllium and magnesium are more reactive. Aluminum owes its excellent corrosion resistance to the barrier oxide film that is bonded strongly to its surface. The conditions for thermodynamic stability of the oxide film are expressed by the Pourbaix (potential versus pH) diagram, aluminium is passive (is protected by its oxide film) in the pH range of about 4 to 8.5.[26]The limits of this range, however, vary somewhat with temperature, with the specific form of oxide film present, and with the presence of substances that can form soluble complexes or insoluble salts with aluminium. Beyond the limits of its passive range, aluminum corrodes in aqueous solutions because its oxides are soluble in many acids and bases, yielding A13+ ions in acids and AlO2(aluminate) ions in bases.[32] There are, however, instances when corrosion does not occur outside the passive range, for example, when the oxide film is insoluble or when the film is maintained by the oxidizing nature of the solution [4].

In a prior research study, Donik et al. (2008) explored the impact of artificial aging on the corrosion behavior of the aluminium alloy AA 6063 in solutions containing chloride. Their findings revealed that as the aging temperature increased, the corrosion rate also increased. Furthermore, they observed that the alloy at its peak-aged state exhibited the highest level of corrosion resistance [23].

In a study conducted by Okora in 2000, the corrosion resistance of the 6063 alloy was examined under under-aged, peak-aged, and over-aged conditions. The findings indicated that both weight loss and the rate of weight loss were influenced by the duration of exposure and the temperature used during heat treatment[21].

In 2014, Padmalatha and her colleagues investigated the corrosion behavior of the 6063 aluminum alloy in both acidic and alkaline environments. The results revealed that the corrosion rate was notably higher in alkaline media compared to acidic media[22].

In a study conducted by Kiourtsidis and Skolianos in 2007, they explored the electrochemical impedance of 6063 aluminium alloy under varying environmental conditions. Their findings revealed that the impedance spectra exhibited a semicircle in the high-frequency range, which was linked to the resistance of the oxide film.[9]

In 2012, Sivaprakash et al. investigated the corrosion behavior of AA 6063 under various retrogression and re-aging conditions using electrochemical impedance spectroscopy (EIS). Their research revealed that the impedance spectra exhibited a semicircle in the high-frequency range, which was linked to the resistance of the oxide film. Moreover, they observed a reduction in the resistance of the oxide film as the retrogression temperature increased.

In 2017, Gupta et al. examined the corrosion behavior of AA 6063 under various retrogression and re-aging conditions using potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS). Their findings indicated that the corrosion resistance of the alloy was enhanced following retrogression and re-aging processes. Notably, they identified that the optimal retrogression temperature for achieving this improved corrosion resistance was 50°C[1].

APPLICATION OF AA6063 ALLOY

AA6063 is an aluminium alloy that offers several advantageous properties, making it suitable for various applications. Some common uses of AA6063 include:

- **Architectural Applications**: AA6063 is widely used in the construction industry for window frames, doors, curtain walls, and other architectural elements due to its lightweight, corrosion resistance, and ease of fabrication.[62]
- **Extrusions**: The alloy's excellent extrudability makes it a preferred choice for manufacturing extruded shapes like rods, bars, and tubes for a range of industries.[68]
- **Automotive Components**: AA6063 is utilized in the automotive sector for manufacturing parts like trim components, heat exchangers, and structural elements due to its lightweight nature and good corrosion resistance.[50]

- **Electronics and Electrical Components**: The alloy's electrical conductivity and thermal properties make it suitable for heat sinks, electrical enclosures, and other electronic components.[44]
- **Furniture**: AA6063 is used to create lightweight and durable furniture frames, particularly for outdoor furniture, thanks to its corrosion resistance.[36]
- **Ladders and Scaffolding**: Its combination of strength and lightweight properties makes it a preferred material for ladders, scaffolding, and other access equipment.[37]
- **Sporting Goods**: AA6063 is employed in the production of sporting goods like bicycle frames, fishing rods, and various other outdoor equipment.
- **Piping and Tubing**: The alloy is used for manufacturing pipes and tubes for applications requiring corrosion resistance, such as irrigation systems and marine structures.[30]
- **Heat Sinks**: Its thermal conductivity makes it ideal for heat sinks in electronic devices, helping dissipate heat efficiently.[40]
- **Railings and Balustrades**: AA6063's combination of strength, corrosion resistance, and aesthetic appeal makes it popular for railings and balustrades in both indoor and outdoor settings.

These are just a few examples of the diverse applications of AA6063, showcasing its versatility and widespread use across various industries.[24]

CHAPTER – 5

MATERIALS AND METHODS

5.1. Material:

AA6063- AA6063 has taken at desired size(12mmX240mmX5mm) and then heat treated at desired temperature retrogression and reaging.

5.2.Experimental Method:

Conducting a comprehensive study on the corrosion behaviour and electrochemical impedance of AA6063 at different temperature aging conditions requires careful planning and execution.

5.2.1. Sample Preparation:

Sample preparation by the metallographic process before observation of the microstructure. When preparing samples for microscopy, it is crucial to ensure the sample accurately represents the entire specimen. Achieving this with a single sample may not always be feasible. Therefore, it is advisable to mount samples of the material under investigation in multiple orientations. The preparation method should account for variations in material properties; for instance, very soft or ductile materials can be challenging to polish mechanically.

5.2.2. Cutting of sample:

As the sample were cut in 12cmx1 cm in the prior it was hard to mount and taking the image from optical microscope

Fig.2: Test sample

5.2.3. Keller's reagent:

Keller's reagent is a mixture of nitric acid, hydrochloric acid, and hydrofluoric acid. It's used to etch aluminum alloys to reveal their microstructure, particularly grain boundaries and orientations. This helps metallurgists understand the properties of the material.

5.2.4. Emery paper:

A series of emery paper(180,400,800,1500,2000,2500) is used to polish the sample.

Metallographic process brief(grinding, paper,

5.3.Temperature Aging Procedures:

5.3.1. Retrogression:

The AA6063 T6 alloy is subjected to a retrogression treatment. In this project, the material is typically heated to a different temperature 210,280,400^{0}C (483k,553k,673K) for a specific period(10 min & 15 min)for each temperature. The purpose of retrogression is to promote the partial dissolution of the precipitates that formed during the solution heat treatment.

5.3.2. Reaging:

Following the retrogression step, the material is reaged by heating it to a higher temperature, 175°C (448K) for 4 hours. The re-aging treatment allows for the reformation and growth of fine and homogeneous precipitates, which contribute to increased strength and hardness.

Design a systematic temperature aging plan that covers a range of temperatures and aging times relevant to the material's applications and service conditions.

Set up an aging furnace to control the temperature accurately during the aging process.

Table :2. Heat treatment procedure of AA6063

Sample	Temperature	Heat treatment process
AA6063	T6	520°C/1 hr+water quench+175°C/8hr
	RRA 210-10	520°C/1 hr+water quench+175°C/8hr +210°C/10min+175°C/4hr
	RRA 210-15	520°C/1 hr+water quench+175°C/8hr +210°C/15min+175°C/4hr
	RRA 280-10	520°C/1 hr+water quench+175°C/8hr + 280°C/10min+175°C/4hr
	RRA 280-15	520°C/1 hr+water quench+175°C/8hr + 280°C/15min+175°C/4hr
	RRA 400-10	520°C/1 hr+water quench+175°C/8hr + 400°C/10min+175°C/4hr
	RRA 400-15	520°C/1 hr+water quench+175°C/8hr + 400°C/15min+175°C/4hr

5.4.<u>Microstructural Analysis</u>:

- Prepare the aged samples & base material for microstructural analysis using an optical microscope & scanning electron microscope (SEM).

5.4.1. **Optical microscopy**:

A metallurgical microscope equipped with image analysis accessories was employed for the optical microscopic examination of the AA6063 samples. Prior to microscopic observation, the specimens were metallographically polished and etched. Magnifications of 100x, 200x, 500x, and 1000x were utilized for all samples."

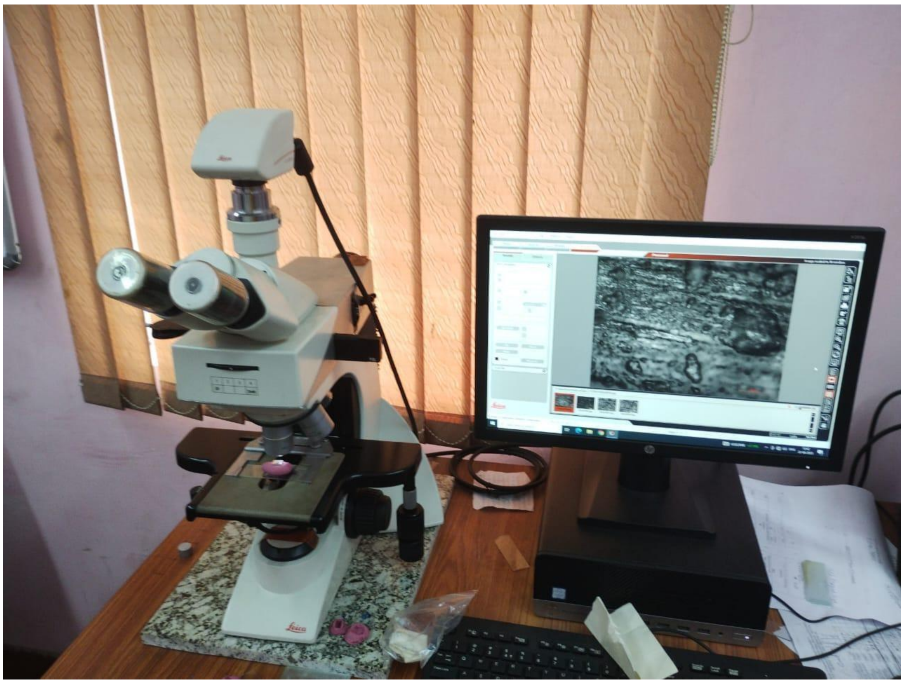

Fig.3: Leica DM2000 Ergonomic system microscope

5.4.2. **Scanning electron microscope**:

A metallurgical microscope with image analysis accessories was used for the rail steel samples' scanning electron microscopic (SEM) investigation. The SEM model used was HITACHI SU 3800, with an applied voltage of 20 kV. The specimens were metallographically polished and etched in a nital solution prior to microscopic examination. Ensure all materials needed for etching are prepared before performing the SEM analysis. Magnifications of 250x, 500x, 1000x, 1500x, and 2000x were used for all samples in the scanning electron microscope.

F*ig. 4: HITACHI scanning electron microscope*

Consider using etchants to reveal microstructural features, such as precipitates and grain boundaries.

5.5. XRD analysis:

Size Selection of Specimens:

Choose representative samples of the item you want to analyze with X-ray diffraction. Make sure the samples are 12 mm in height and 10 mm in width on the XRD instrument's sample holder or stage.

Sample Orientation:

If the sample displays a preferred crystallographic orientation, it might be necessary to align it with the X-ray beam in a particular way.

Fig.5 : Picture of XRD machine used for the XRD analysis

To determine the proper orientation for the material of interest, consult relevant literature or crystallographic databases.

To achieve the desired orientation, use the specialized goniometers or alignment stages that the XRD instrument provides.

Once the samples are ready, mount them onto the sample holder or stage of the XRD instrument, making sure they are properly aligned and oriented. Start the analysis after configuring the XRD instrument with the required measurement parameters, such as the copper beam used, whose wavelength was 1.5406 Å, scanning range of 20°-90° and the scanning rate of 3 degrees/min. The crystal structure, phase composition, and other pertinent details of the material can then be ascertained from the diffraction patterns obtained from the XRD instrument.

5.6.Hardness test:

Microhardness measurement of base material and aged samples by Vickers microhardness tester. For microhardness testing, select representative samples of the material is use. The samples are 5 mm in height and 12 mm in width to accommodate the indenter during testing. The Load of the test is selected at 200gf of 10sec.

After etching, carefully rinse the samples with distilled water to stop the etching process and remove any remaining etchant.

Fig.6: Conation Digital Vickers Micro Hardness Tester

5.7. Corrosion Behaviour Study:

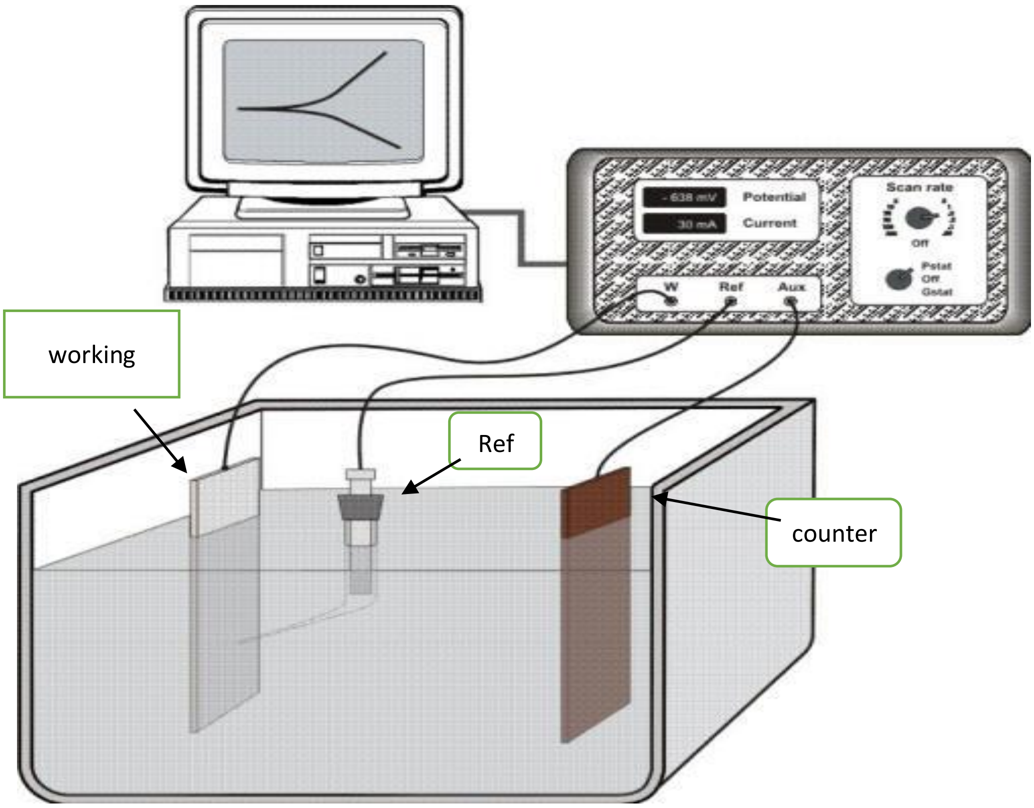

Fig.7: Schematic of corrosion circuit.

The **saturated calomel electrode (SCE)** is used as a reference electrode

Composition: The SCE consists of elemental mercury and mercury(I) chloride (Hg_2Cl_2). The aqueous phase in contact with the mercury and Hg_2Cl_2 is a saturated solution of potassium chloride (KCl) in water.

Function: It serves as a reference electrode in various applications, including pH measurement, cyclic voltammetry, and general aqueous electrochemistry.

Potential: At 20°C, the SCE has a potential of +0.248 V vs. the standard hydrogen electrode (SHE). This potential is slightly higher when the chloride solution is less than saturated

Graphite Electrode: Anode: The anode (negative electrode) made from graphite. Graphite serves as a host structure for intercalation, allowing reversible aluminium storage during charge and discharge cycles.

Corrosion testing is performed to evaluate a material's susceptibility to degradation in corrosive environments. The aim is to assess the material's corrosion resistance and determine its suitability for a specific application. The general procedure for conducting corrosion tests is outlined as follows.

Test Setup:

Set up the corrosion test apparatus or tools according to the selected test method. This may involve arranging an electrochemical cell for electrochemical testing, placing the samples in a test chamber, or immersing them in an acidic solution(N/10 H2SO4) and basic solution(3.5 wt% NaCl) of scan rate .001v/s of anodic range -1 to -5 with step .001

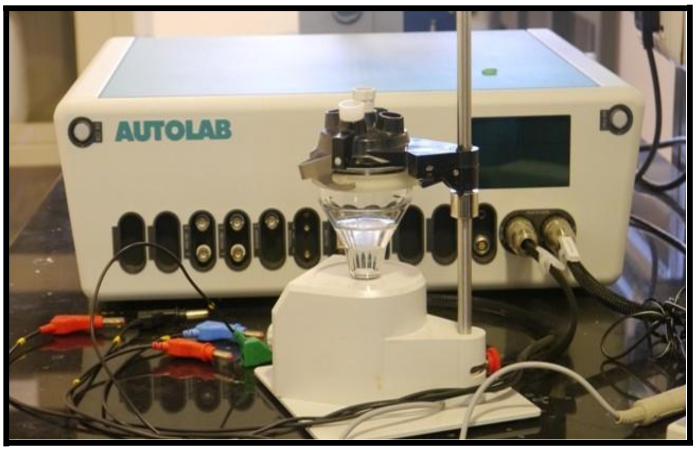

Fig. 8: AUTOLAB corrosion testing machine

The Process:

- **Electrode Setup:** A sample of the material (e.g., 6063 aluminum) is used as a working electrode in an electrochemical cell containing an electrolyte solution.
- **Potential Sweep:** An instrument called a potentiostat gradually increases or decreases the electrical potential (voltage) applied to the working electrode over time. This process is called a potential sweep.
- **Current Measurement:** Throughout the potential sweep, the current flowing between the working electrode and another electrode in the cell (counter electrode) is continuously monitored and recorded.

- **Corrosion Rate measurement:** By analyzing the resulting plot of current versus potential (polarization curve), researchers can gain valuable insights into the corrosion behavior of the material. The curve can indicate the:
  - **Corrosion potential (Ecorr):** The potential at which the corrosion rate is minimal.
  - **Anodic and cathodic branches:** The parts of the curve that correspond to oxidation (metal dissolving) and reduction (oxygen reduction or other reactions) processes, respectively.
  - **Corrosion current density:** The magnitude of current associated with corrosion processes.

to study the corrosion rate measurement we can find it by the equation:

.Corrosion parameters suchas corrosion potential (Ecorr), corrosion current density (icorr), anodic slope (ba) and cathodic slope (bc) are obtained from the Tafel polarization curves. Results are tabulated in Tables 2 and 3. The corrosion rate was calculated using Eq.(1).

$$\upsilon_{\mathrm{corr}}(\mathrm{mm\,y^{-1}}) = \frac{3270 \times M \times i_{\mathrm{corr}}}{\rho \times Z}, \quad (1)$$

CHAPTER – 6
RESULT & DISCUSSION

6.1. Microstructural analysis:

The microstructure of the base and the heat-treated sample are given in the figure

Figure:

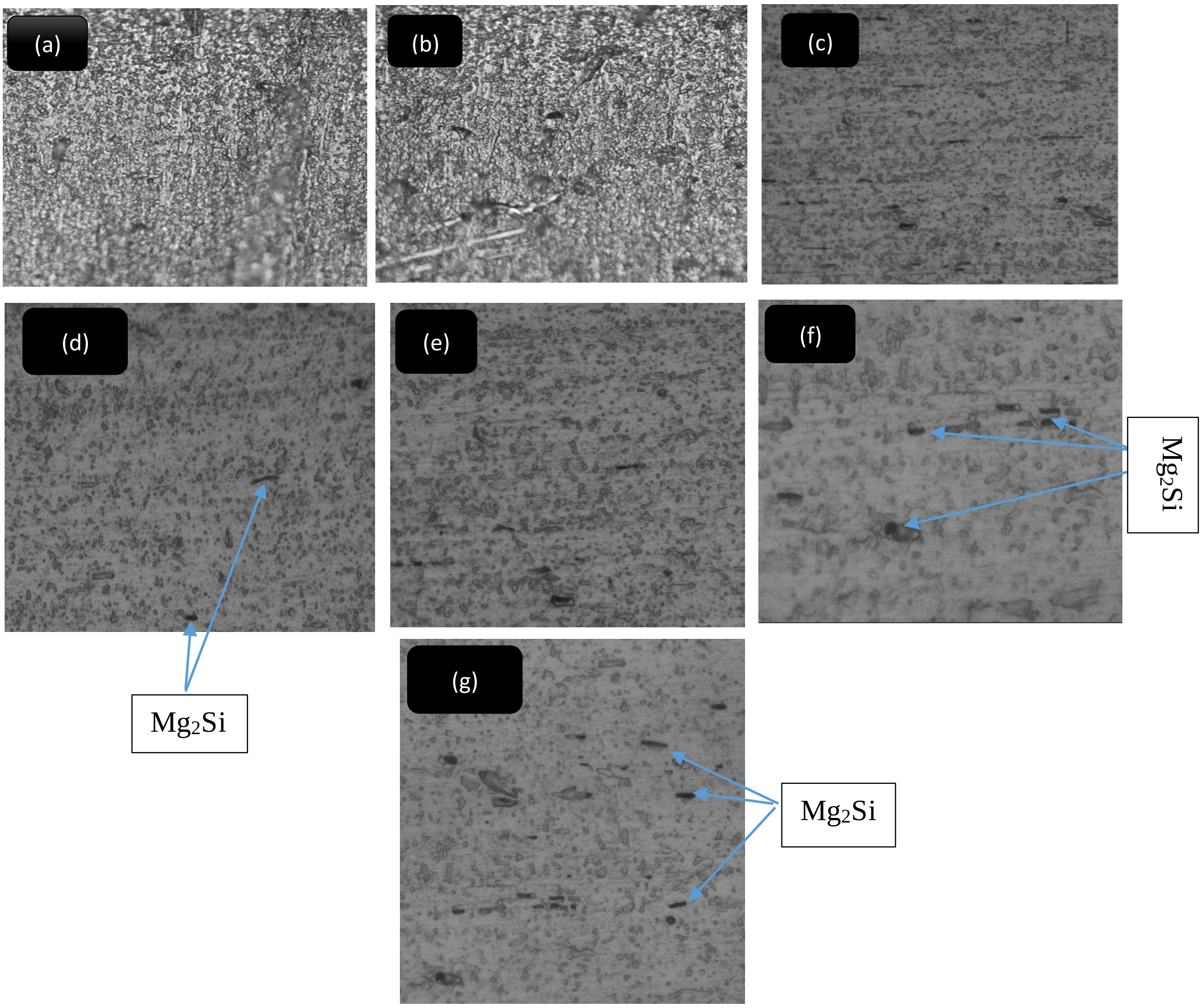

Fig: 9.(a) Microstructure of base material using optical microscopy (b) Microstructure of RRA210-10 (c) Microstructure of RRA210-15 (d) Microstructure of RRA280-10 (e) Microstructure of RRA280-15 (f) Microstructure of RRA400-10 (g) Microstructure of RRA400-15

Relation between heat treatment and microstructure

In the study of microstructure the precipitation(Mg_2Si) in Base Material, RRA210-10, RRA210-15, and RRA280-10 is highly dense and it is less in number but in RRA280-15, RRA400-10, RRA400-15 is low dense and high in number.

6.2. XRD Analysis:

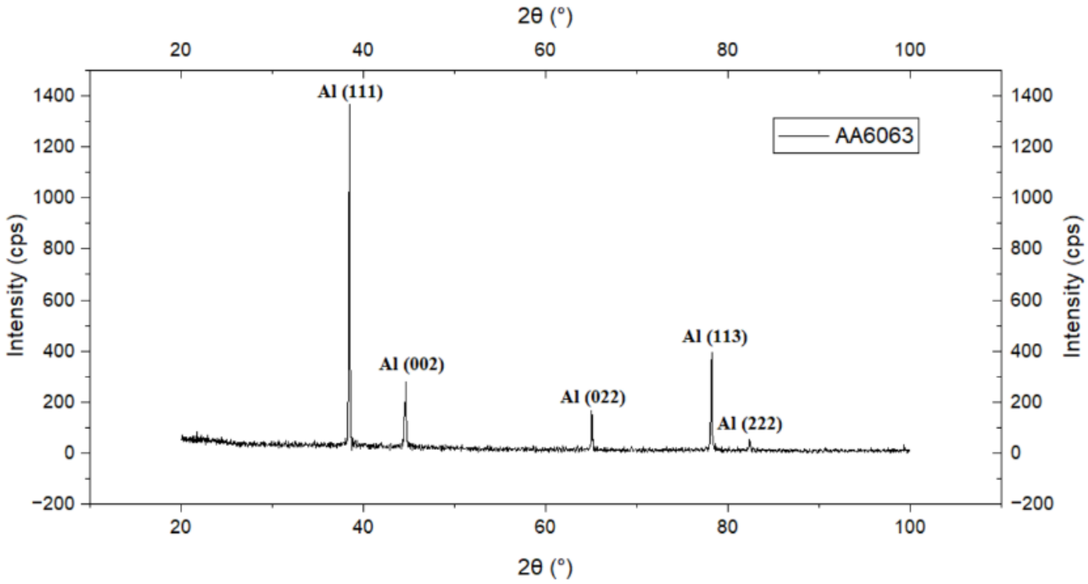

Fig.10: XRD Analysis of AA6063.

From fig. 9 Al can be found in following miller indices(111),(002),(022),(113),(222)

6.3. Tafel plot measurement:

Electrochemical corrosion behaviour of the heat-treated samples was characterized by potentiodynamic polarization tests. Electrochemical corrosion test samples were determined via IGC results and potentiodynamic polarization tests were applied to samples for T6, RRA 200-10, RRA 280-10, RRA 400-10 RRA 200-15, RRA 280-15, RRA 400-15. Electrochemical corrosion tests were carried out by using Autolab in 3.5wt.% NaCl solution and at room temperature with a scanning rate of 0.1mV/s. Samples were polished, cleaned with acetone, and dried with warm air. The corrosion test cell consisted of the reference electrode Saturated calomel electrode(SCE), a working electrode (test sample), and a Counter electrode (Graphite). The surface area of the working electrode was determined as $50mm^2$.

Both techniques were repeated at least three times. The average value of the best three agreeing values was reported.

The effect of H_2SO_4 and NaCl on the corrosion rate of aa6063 Sanple was studied using the tofel polarization technique. fig 1 represents the potentiodynamic polarization curves of 6063 aluminium alloy in N/10 H_2SO_4 and 3.5 wt% NaCl solution.

Acid Medium:

In an acid medium the aa6063 makes a good corrosion resistance. Shows a good performance in atmospheric degradation. Table -3 is the table of corrosion test analysis:

Table: 3 Ecorr, Icorr, Corrosion rate in acid Medium

Heat treatment	Ecorr(v)	Icorr	Corrosion test(mm/yr)
Base material	-0.69046	$2.0034X10^{-5}$	0.2998
RRA210.10	-0.56275	$2.9599X10^{-5}$	0.3207
RRA210.15	-0.6143	$2.6106X10^{-5}$	0.3033
RRA280.10	-0.58863	$1.7154X10^{-5}$	0.1933
RRA280.15	-0.55707	$1.6251X10^{-5}$	0.1888
RRA400.10	-0.64031	$1.0673X10^{-5}$	0.1240
RRA400.15	-0.62407	$1.8239X10^{-5}$	0.2119

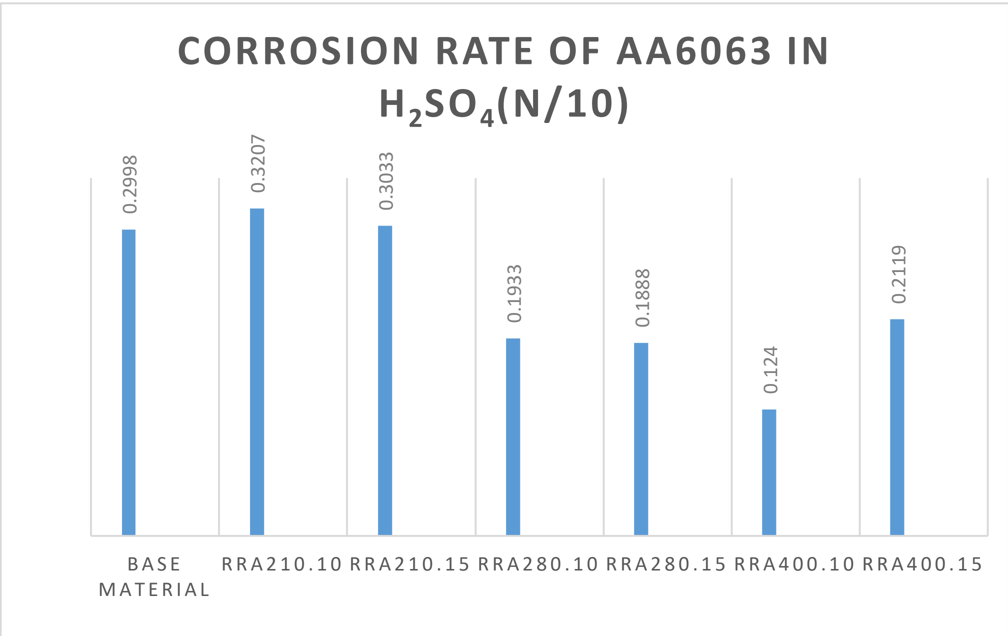

Fig.11. Corrosion Rate analysis in Acid medium.

Compare: If we compare the corrosion properties we can see that at the temperature 210-10 min heat treated aa6063 shows the high corrosion rate of 0.3207 mm/yr here are the corrosion graph of the aa6063, and good corrosion resistance in 400-10 i.e. 0.1240 mm/yr.

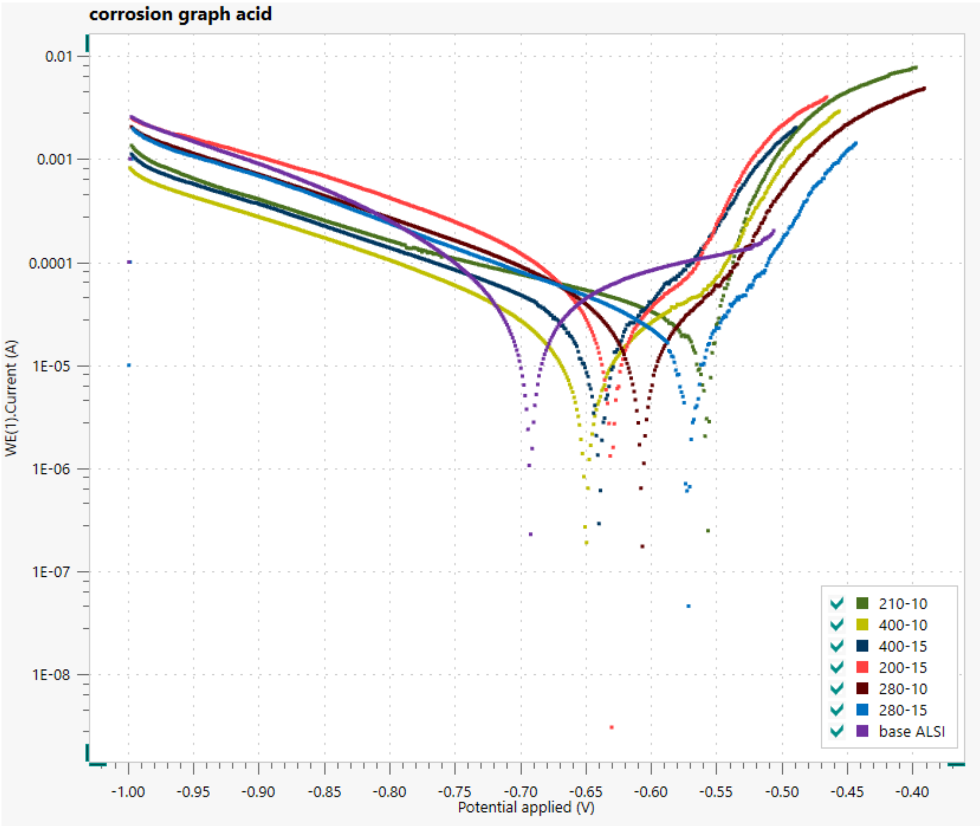

Fig.12:- Corrosion graph in acid medium of aa6063 I.WE(aa6063), II RE(SCE),III.CE(graphite).

Salt Medium:

In an salt medium, the aa6063 makes good corrosion resistance. Shows a good performance in atmospheric degradation. Table-3 is the table of corrosion test analysis:

Table: 4 Ecorr, Icorr, Corrsion rate in Salt medium.

Heat treatment	Ecorr(v)	Icorr(mA)	Corrosion rate:(mm/yr)
Base material	-0.643	$1.2745x10^{-6}$	0.01338
RRA210-10	-0.74357	$2.2745x10^{-6}$	0.02643
RRA210-15	-0.7399	$4.5121x10^{-6}$	0.05243
RRA280-10	-0.7411	$8.045x10^{-7}$	0.00934
RRA280-15	-0.7474	$1.5751x10^{-7}$	0.00183

RRA400-10	-0.8893	$1.4031x10^{-8}$	0.00016
RRA400-15	-0.7463	$2.475x10^{-7}$	0.00287

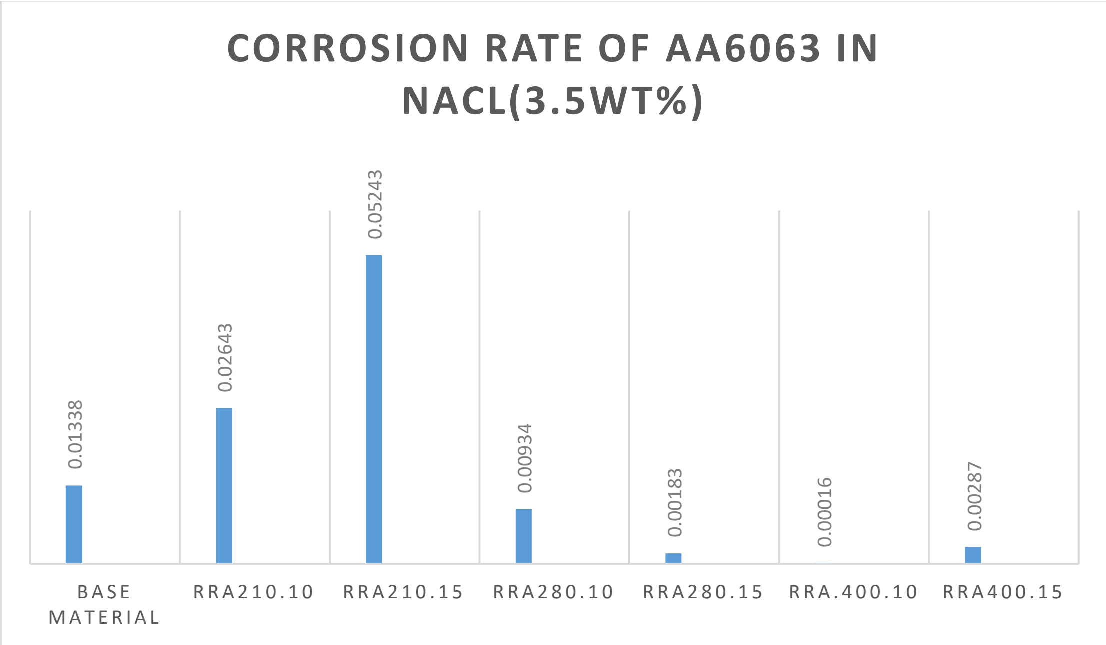

Fig.13: Corrosion Rate analysis in the Salt medium.

Compare: If we compare the corrosion properties we can see that at the temperature RRA400-10 shows a high corrosion rate of 0.00183 mm/yr here is the corrosion graph of the aa6063, and good corrosion resistance in RRA210-15 i.e. 0.05243mm/yr.

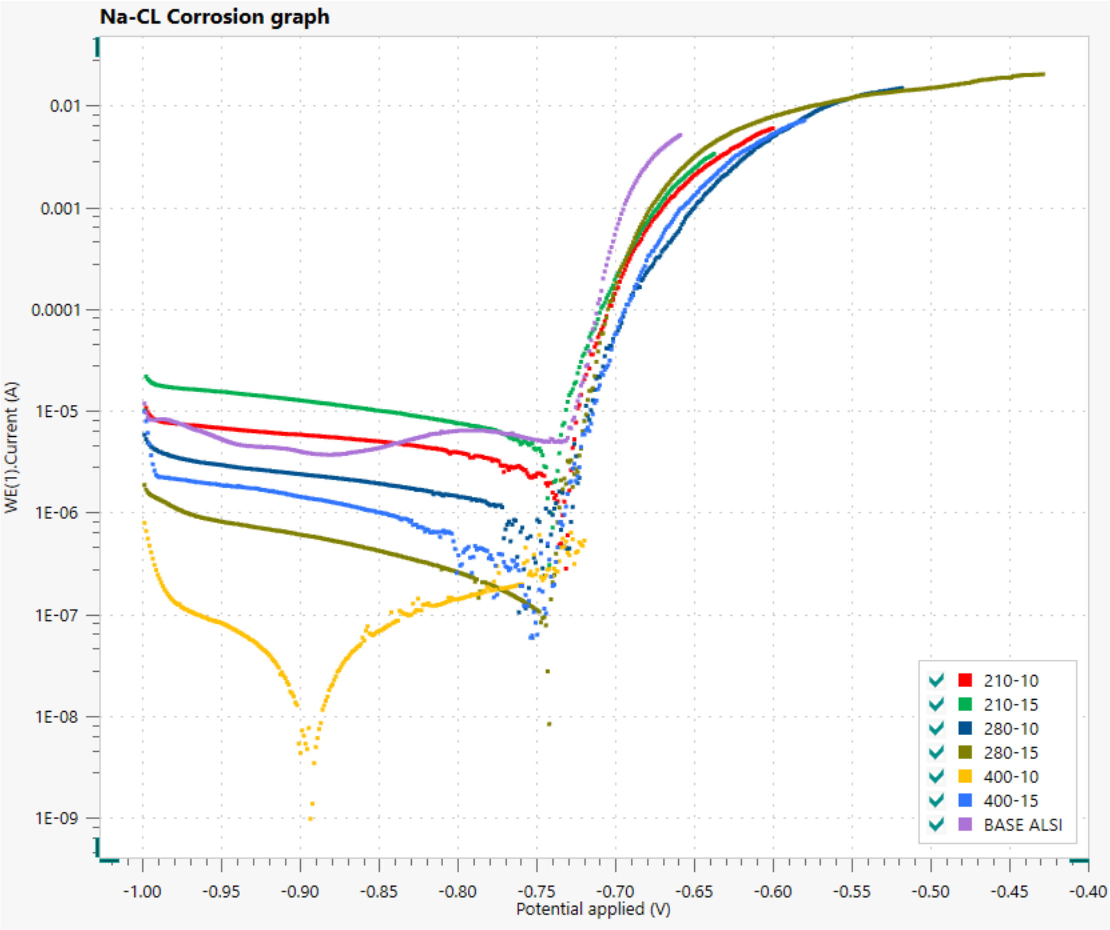

Fig.14: Corrosion graph in salt medium of aa6063 I.WE(aa6063), II RE(SCE),III.CE(graphite).

Relation between heat treatment and corrosion rate:

Relation between the heat-treated aa6063 and corrosion is found in both acidic and salt mediums. this medium is taken as 3.5 wt% of Nacl and N/10 of H_2SO_4In potentiodynamic polarization, it is found that at the temperature of 210 of retrogression temp and 10 mins and 175^o C re-aging temp and 4 hours gives the maximum corrosion.

Acid:

In acid medium RRA400-10min shows the minimum rate of corrosion and RRA210-10min shows the high corrosion in acid medium after that RRA210-15min shows an approximate high range. RRA280-10,RRA280/15,RRA400-15 show average corrosion rates.

Salt:

In the salt medium, RRA400-10 min shows the minimum rate of corrosion and RRA210-15 min shows the high corrosion in the acid medium after that RRA210-15 min & base material show an approximate high range. RRA280-10, and RRA280-15,400-15 shows average corrosion rates.

Relation Between Acidic & Basic Corrosion.

In Fig & Fig show that the corrosion between NaCl (Basic medium) is lesser than H_2SO_4 (acidic medium). The basic medium has a range of (0.00016 -0.05243)mm/year and in the acidic medium (0.1240-0.3207)mm/year. In Acidic corrosion Oxide formation is faster than base which is the cause for forming pits.

6.4. Hardness measurement:

The hardness of the experiment varies between 73 to 94 HV.280/10 showing a maximum hardness of 94.42 on average of 15 readings in micro Vickers of 200 gm force and dwell time of 15 sec. Also, RRA280-15 show approximately maximum value.

RRA400-15 shows the minimum value of 71.54 on average of 15 readings is less hard then others.

Table.4: Hardness comparison of heat-treated sample.

Heat treatment	Hardness value
Base material	75.96
RRA210-10	73.54
RRA210-15	81.54
RRA280-10	94.42
RRA280-15	93.23
RRA400-10	83.44
RRA400-15	71.54

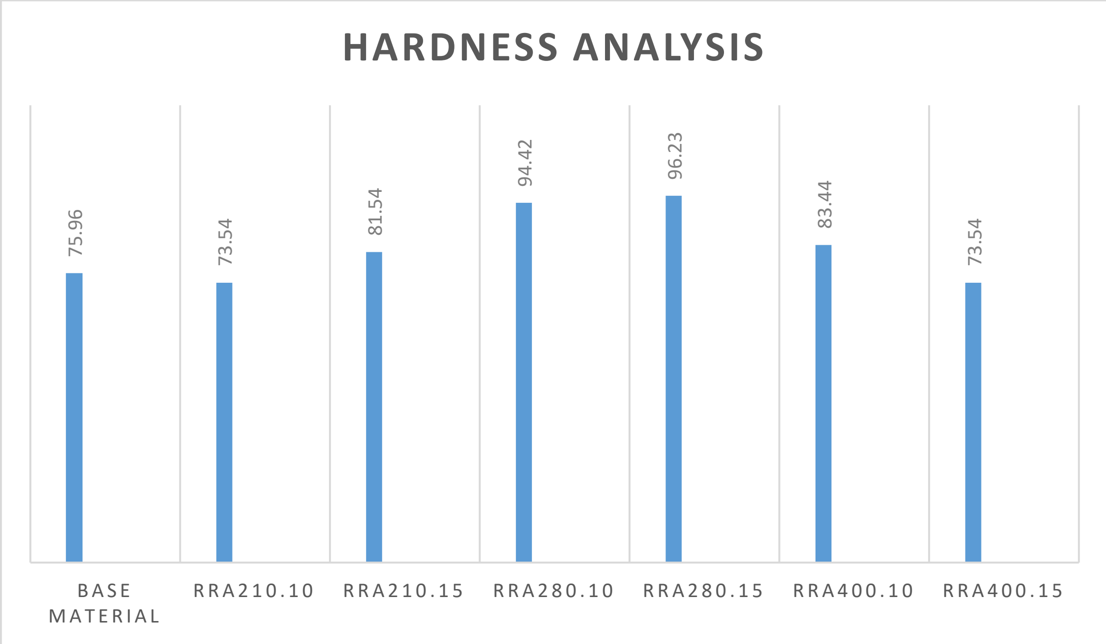

Fig.15: Hardness analysis of base material and aged sample.

Relation between heat treatment and hardness :

So here we can compare the relationship between the heat treatment procedure (retrogression and re-aging) of AA6063 as we increase the temperature and if it reaches 280 ^{0}C and 15 mins of retrogression and 175^{0} C of 4 hours re-aging achieves the maximum value. So it is better to use in high-temperature applications.

6.5. SEM analysis:

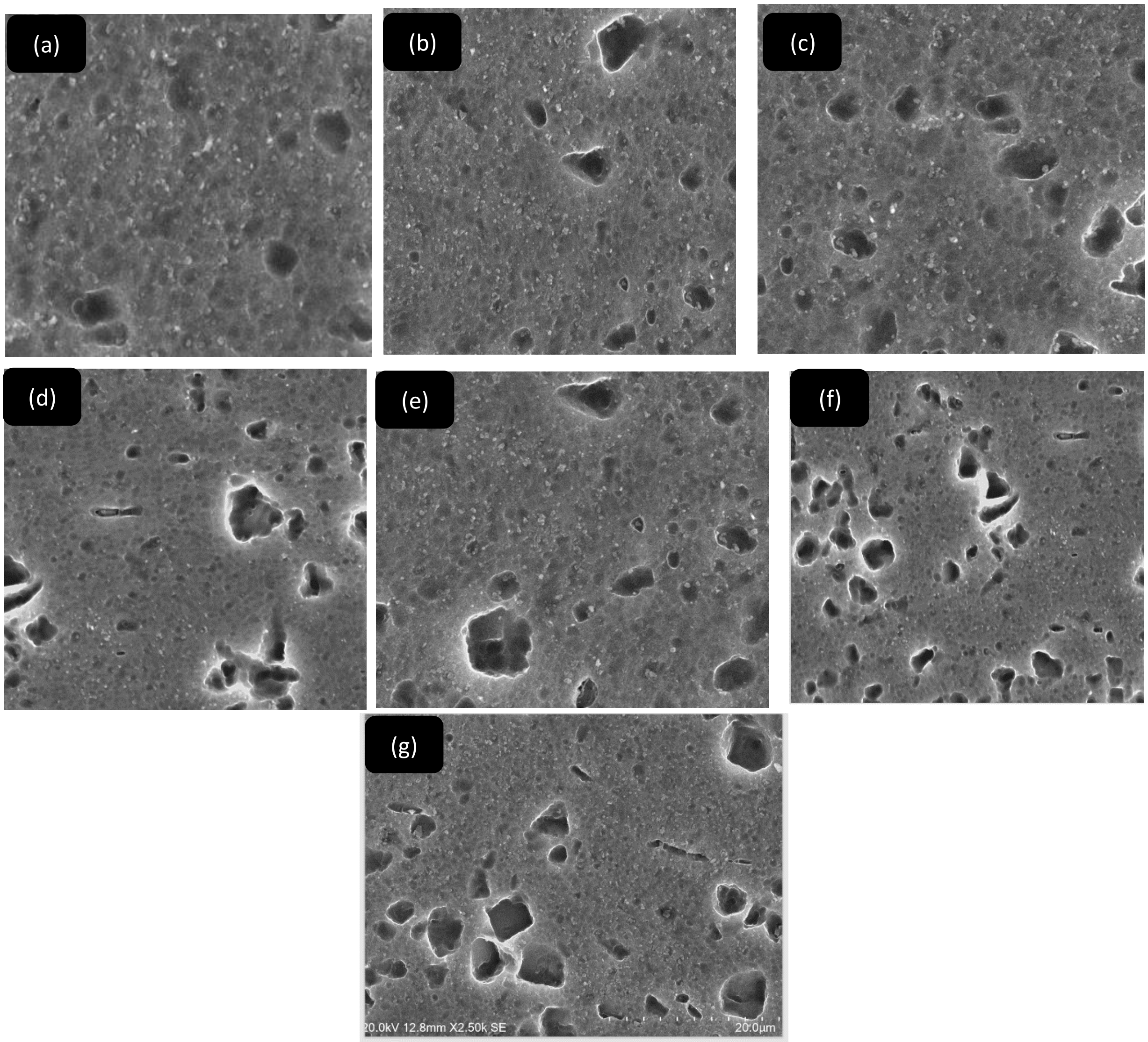

Fig: 16.(a) SEM image of base material (b) SEM image of RRA210.10 (c) SEM image e of RRA210.15 (d) SEM image of RRA280.10 (e) SEM image of RRA280.15 (f) SEM image of RRA400.10 (g) SEM image of RRA400.15

The image shows that the precipitation becomes larger for retrogression time and temperature. As the image of RRA400-15, it is the largest among all of the others. The density of precipitation RRA210-10 is less dense and the density of RRA400-10, and RRA400-15 is highly dense.

6.6. EDAX Analysis:

This is the detailed EDAX analysis of AA6063 RRA210-15

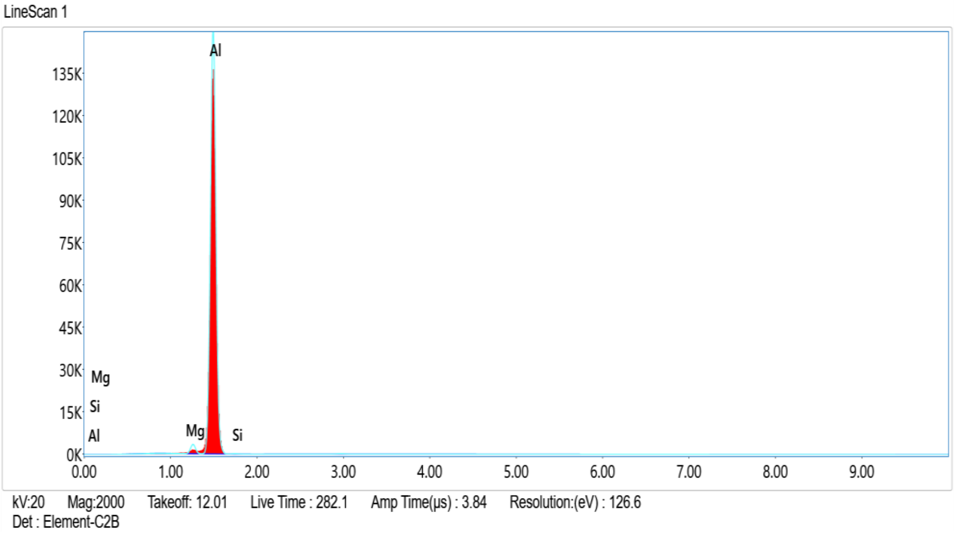

Fig.17 EDAX Spectrum of AA6063

Table. 5. Elemental Wt. in RRA210-15 AA6063

Element	Weight%	Atomic wt%
Mg	2.10	2.33
Ai	97.25	97.05
Si	0.62	0.62

In fig. and table. Shows that the EDAX spectrum and element present in RRA210-15 AA6063. Whereas the primary component is Al and two alloying element Mg and Si.

This is the EDAX analysis of AA06063 RRA280-15.

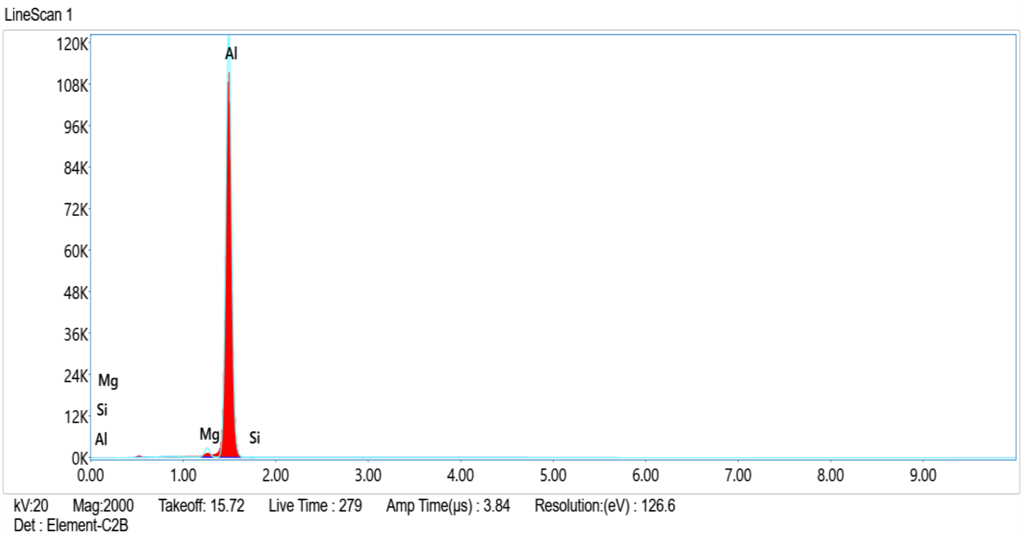

Fig.18 EDAX Spectrum of AA6063RRA280-15

Table. 6. Elemental Wt. in RRA280-15 AA6063

Element	Weight%	Atomic wt%
Mg	2.06	2.29
Ai	97.12	96.93
Si	0.81	0.78

In fig.17 and table.6 Shows that the EDAX spectrum and element present in RRA280-15 AA6063. Whereas the primary component is Al and two alloying element Mg and Si.

This is the EDAX analysis of AA06063 RRA400-15

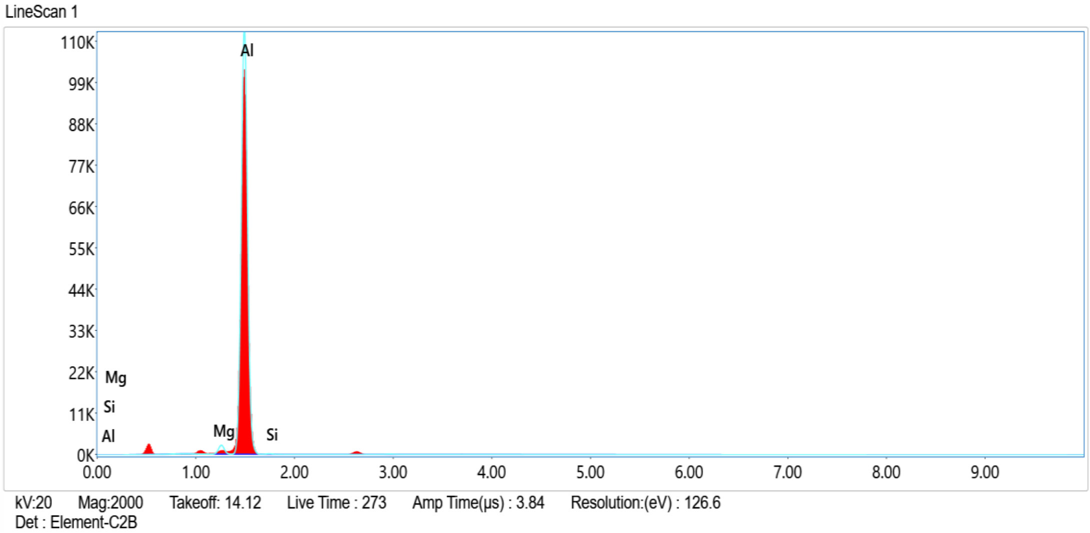

Fig.19 EDAX Spectrum of AA6063RRA400-15

Table. 7. Elemental Wt. in RRA400-15 AA6063

Element	Weight%	Atomic wt%
Mg	2.01	2.22
Ai	97.17	96.99
Si	0.82	0.79

In fig.18 and table.7 Shows that the EDAX spectrum and element present in RRA280-15 AA6063. Whereas the primary component is Al and two alloying element Mg and Si.

CHAPTER – 7
CONCLUSION

8. CONCLUSION:

The study on the corrosion behaviour and electrochemical impedance of AA6063 at different temperature aging conditions has provided valuable insights into the material's performance and response to thermal treatments.[21] The research aimed to understand how the microstructural changes induced by retrogression and reaging affect the corrosion resistance and electrochemical properties of AA6063. The following conclusions can be drawn from the study:

Corrosion Behaviour:

- The corrosion behaviour of AA6063 is influenced significantly by the retrogression and reaging treatment. The results showed that the aging temperature and duration have a profound impact on the material's susceptibility to corrosion.
- Retrogression and reaging treatments can lead to changes in the size, distribution, and morphology of precipitates within the alloy matrix, affecting its corrosion resistance.

Microstructural Changes:

- Microstructural analysis revealed that retrogression and reaging induced changes in grain size, precipitate distribution, and the density of dislocations.
- The microstructural modifications had a direct correlation with the material's mechanical properties, corrosion resistance, and electrochemical performance.

Optimal Aging Conditions:

- The study identified specific aging conditions that led to the most desirable microstructure and electrochemical properties. These conditions can be tailored to optimize the material's performance in different applications.

Practical Implications:

- The findings of this study have practical implications for industries using AA6063 in applications prone to corrosion or environmental degradation.
- The research provides guidelines for selecting appropriate aging parameters to achieve the desired balance between strength, corrosion resistance, and electrochemical stability.
- Sulfuric acid (H_2SO_4) is commonly used in industrial processes, including those involving aluminum alloys like AA6063. In the case of AA6063, sulfuric acid may be used for surface treatment or cleaning processes to improve adhesion, corrosion resistance, or to prepare the surface for subsequent treatments like anodizing or painting. It's often used in the aluminum industry for its ability to etch and clean metal surfaces effectively.

Future Research:

- The study has opened up avenues for further research in understanding the underlying mechanisms that control the corrosion and electrochemical behaviour of AA6063 during temperature aging.
- Investigating the influence of alloying elements and heat treatment parameters on corrosion behaviour would be valuable for enhancing the material's performance.

In conclusion, the study on the corrosion behaviour and electrochemical impedance of AA6063 at different temperature aging conditions has shed light on the material's behaviour during thermal treatments. The insights gained from this research can contribute to the optimization of AA6063's performance in various industrial applications, providing a foundation for future advancements in materials engineering and corrosion science.

CHAPTER – 8

FUTURE

SCOPE

7. FUTURE SCOPE OF AA6063

AA6063 is a common aluminium alloy that is used in a wide variety of applications, including the automotive, construction, and aerospace industries. It is known for its strength, lightweight, and corrosion resistance.

The future scope of AA6063 is bright. As the demand for lightweight and corrosion-resistant materials continues to grow, AA6063 is well-positioned to benefit. In particular, the following trends are likely to drive the future demand for AA6063:

- The growth of the automotive industry: The automotive industry is one of the largest consumers of aluminium, and AA6063 is a popular choice for use in cars, trucks, and other vehicles. As the automotive industry continues to grow, the demand for AA6063 is likely to increase.
- The growth of the construction industry: The construction industry is another major consumer of aluminium, and AA6063 is a popular choice for use in building facades, windows, and doors. As the construction industry continues to grow, the demand for AA6063 is likely to increase.
- The growth of the aerospace industry: The aerospace industry is a high-growth industry that is constantly looking for new ways to reduce weight and improve fuel efficiency. AA6063 is a lightweight and corrosion-resistant material that is well-suited for use in aerospace applications. As the aerospace industry continues to grow, the demand for AA6063 is likely to increase.

In addition to these trends, the future demand for AA6063 is also likely to be driven by advances in manufacturing technology. New manufacturing techniques, such as additive manufacturing, are making it possible to produce complex aluminium parts that were not possible to produce in the past. This is opening up new opportunities for AA6063 in a wide variety of applications.

Overall, the future scope of AA6063 is bright. As the demand for lightweight, corrosion-resistant, and high-performance materials continues to grow, AA6063 is well-positioned to benefit.

CHAPTER – 9
REFERENCES

1 REFERENCES:

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