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The Effect of Different concentration of Hydrochloric Acid (HCL) on the corrosion behavior of Several types of metals

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بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

{ قُلْ بِفَضْلِ اللّهِ وَبِرَحْمَتِهِ فَبِذَلِكَ فَلْيَفْرَحُواْ}

الآية [يونس: 58].

الاهـــــــداء

الى من كلله الله بالهيبة والوقار .. إلى من علمني العطاء بدون انتظار .. إلى من أحمل أسمه بكل افتخار .. أرجو من الله أن يمد في عمرك لترى ثماراً قد حان قطافها بعد طول انتظار وستبقى كلماتك نجوم أهتدي بها اليوم وفي الغد وإلى الأبد ..

(والدي العزيز).... إلى ملاكي في الحياة .. إلى معنى الحب وإلى معنى الحنان والتفاني .. إلى بسمة الحياة وسر الوجود

إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الحبايب (امي العزيزة)

الى القدوة الحسنة و القامة الشامخة اكتب هذه الكلمات من منطلق ما لمسته منك خلال الاعوام السابقة فقد كنت صديقا بتوجيهاتك , مرشدا بنصائحك ,موجها بعباراتك , عطوفا بكلامك و اخا حنونا لنا (م.م عادل اكرم محمود) ودكتورنا الفاضل الذي ذلل الصعاب (د. حذيفة رعد حمزة) و لا ننسى الذي ذلل كل الصعاب فقد كان أبا و صديقا لجميع الطلاب رئيس قسم هندسة التعدين (د.عزالدين الجوادي)...الى من كانوا ملاذي و ملجئي الى من تذوقت معهم اجمل اللحظات الى أولئك الذين جمعتنا معهم قاعات المعرفة الى الذين سأفتقدهم طلاب كليتي الافاضل .و أخيرا اسئل الله أن يوفقنا خدمة لوطننا الحبيب.

ABSTRACT

The corrosion behavior of metals immersed in hydrochloric acid (HCl) solution was investigated in this study. The objective was to understand the effects of HCl acid on different metals and their corrosion behaviors. The metals studied included CK-45, Brass, Carbon steel, 201-stain, Bronze and Aluminum. The experimental setup involved immersing metal samples in HCl solutions of varying concentrations. The range of these concentrations of HCl is 5%, 8% and 10%. The weight loss method was employed to determine the corrosion rates of the metals over a four weeks period. The samples were periodically removed from the acid solution, cleaned, and weighed to measure the extent of weight loss. The results showed that CK-45, Carbon steel, 201-stain, and Aluminum are the most affected metals in terms of losing weight after immersion in HCl acid. In contrast, Brass and Bronze are the least affected metals in terms of losing weight after immersion in HCl acid. Finally, the weight loss of each metal increases slightly with increasing HCl concentration.

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INTRODUCTION

INTRODUCTION

1.1. Corrosion

Corrosion refers to the gradual deterioration or destruction of materials, usually metals, through chemical or electrochemical reactions with their environment. It is a natural process that occurs when metals are exposed to substances such as oxygen, water, acids, or salts. Corrosion can result in the loss of material integrity, reduced functionality, and potential safety hazards [1].

The corrosion process involves the transfer of electrons from the metal surface, known as oxidation, and the corresponding reduction of another species in the environment. This electrochemical reaction occurs at localized areas on the metal surface, often referred to as corrosion sites or corrosion cells. The corrosion process can be influenced by various factors, including the type of metal, the specific corrosive environment, temperature, and the presence of impurities or surface defects [2].

1.1.1. Causes of Corrosion

Corrosion can be attributed to various causes, but the most common factors include: Electrochemical Reactions: The majority of corrosion processes involve electrochemical reactions between the metal, an electrolyte (such as water or an aqueous solution), and oxygen. This leads to the formation of anodes (sites where metal oxidation occurs) and cathodes (sites where reduction reactions occur).

1. Environmental Factors: Corrosion is influenced by environmental conditions such as temperature, humidity, presence of corrosive gases (e.g., sulfur dioxide), and exposure to chemicals or salts. These factors can accelerate or intensify the corrosion process [3].

1.1.2. Types of Corrosion

Several types of corrosion can occur, depending on the specific conditions and mechanisms involved. Some common types include

1. Uniform Corrosion: This type of corrosion occurs uniformly across the exposed surface of the material. It leads to a general loss of material thickness and can result in the weakening of structures or components.

2. Galvanic Corrosion: Galvanic corrosion occurs when two dissimilar metals are in electrical contact with each other in the presence of an electrolyte. The more active metal experiences accelerated corrosion, while the less active metal remains relatively unaffected.
3. Pitting Corrosion: Pitting corrosion involves the localized formation of small pits or holes on the material surface. It can penetrate deep into the material, leading to localized structural failures.
4. Crevice Corrosion: Crevice corrosion occurs in confined spaces or crevices, such as gaps, joints, or under deposits on the material surface. The stagnant environment within the crevice promotes corrosive reactions.
5. Stress Corrosion Cracking: Stress corrosion cracking occurs when a material is subjected to both tensile stress and a corrosive environment. It can lead to the formation and propagation of cracks, compromising the material's integrity [4].

1.1.3. Consequences of Corrosion

Corrosion has significant consequences across various industries, including

1. Safety Hazards: Corrosion can weaken structures, pipelines, and equipment, posing safety risks. Catastrophic failures, such as bridge collapses or pipeline ruptures, can occur due to corrosion-induced structural integrity loss.
2. Economic Impact: Corrosion-related costs are substantial, including repair, replacement, and maintenance expenses. Industries such as transportation, infrastructure, and manufacturing bear the brunt of these costs.
3. Environmental Impact: Corrosion processes, especially in industrial settings, can release pollutants into the environment, impacting ecosystems and human health.
4. Loss of Functionality: Corrosion can degrade the performance and functionality of materials and components, affecting their intended use and lifespan [5].

1.1.4. Corrosion Prevention

Developing effective strategies to prevent and mitigate corrosion is essential. This involves

1. Material Selection: Using corrosion-resistant materials or surface coatings can provide inherent protection against corrosion.
2. Protective Coatings: Applying protective coatings, such as paints, enamels, or corrosion-resistant films, can create a barrier between the material and the corrosive environment.
3. Cathodic Protection: Employing techniques such as sacrificial anode systems or impressed current systems can protect the metal by making it a cathode, reducing the corrosion rate.
4. Corrosion Inhibitors: Introducing chemicals that inhibit corrosion can slow down the electrochemical reactions occurring at the metal surface.
5. Design Considerations: Designing structures and equipment with corrosion prevention in mind [6].

1.2. Hydrochloric acid (HCl)

Hydrochloric acid (HCl) is a strong, highly corrosive acid with a wide range of applications in various industries and laboratory settings. It is a colorless, pungent liquid that is soluble in water. Hydrochloric Acid **(**HCl) is classified as a mineral acid and is known for its strong acidity and ability to react with many substances.

1.2.1. Uses of Hydrochloric Acid (HCl)

Industrial Applications: Hydrochloric Acid **(**HCl) is extensively used in industrial processes, including chemical manufacturing, metal processing, and oil refining. It is employed in pickling and etching processes to remove oxides, scale, and contaminants from metal surfaces [7].

1.2.1.1. pH Adjustment

Hydrochloric Acid **(**HCl) is commonly used to adjust the pH of solutions in laboratory experiments and industrial processes. It is highly acidic and can lower the pH of solutions effectively.

1.2.1.2. Regeneration of Ion Exchange Resins

HCl is used to regenerate ion exchange resins, which are widely used in water treatment and purification systems to remove impurities and ions.

1.2.1.3. Domestic Cleaning Products

Hydrochloric Acid **(**HCl) is a key ingredient in many household cleaning products, including toilet bowl cleaners and descaling agents. Its strong acidity aids in removing stubborn stains and mineral deposits.

1. 2.1.4. Laboratory Applications

HCl is a staple chemical in laboratory settings. It is used for chemical synthesis, pH adjustment, and as a reagent in various analytical procedures.

1.2.2. Effects of Hydrochloric Acid (HCl)

Hydrochloric acid (HCL) is highly corrosive to a wide range of materials, including metals, minerals, and organic compounds. When in contact with HCl acid, certain materials can undergo dissolution or chemical reactions, resulting in changes in their physical and chemical properties [8].

1.2.2.1. Effects on Metals

HCl acid can react with metals, particularly reactive metals like magnesium, zinc, or iron, resulting in the release of hydrogen gas and the formation of metal chloride salts. The reaction can cause corrosion and degradation of the metal surface.

1.2.2.2. Effects on Minerals

HCl acid can dissolve certain minerals, especially those composed of carbonates, such as limestone or marble. The acid reacts with the carbonate ions, leading to the formation of carbon dioxide gas, water, and soluble metal chloride salts.

1.2.2.3. Effects on Organic Compounds

HCl acid can react with organic compounds, such as alcohols or amines, to form organic chloride compounds. These reactions are often employed in organic synthesis and purification processes.

1.2.3. Safety Precautions

Hydrochloric acid is a highly corrosive and hazardous substance. It can cause severe burns upon contact with the skin, eyes, or respiratory system.

Therefore, appropriate safety precautions should be followed when handling HCl acid, including wearing protective clothing, gloves, and eye protection. Adequate ventilation should be ensured when working with HCl acid to avoid inhalation of fumes. Proper storage and handling procedures should be implemented to prevent accidental spills or releases.

1.3. Tested Metals

1.3.1. CK-45

CK-45, also known as C45 or 1.1191, is a medium carbon steel alloy. It is widely used in various industries due to its excellent mechanical properties and good machinability. CK-45 belongs to the class of steels known as carbon steels, which contain carbon as the primary alloying element [9].

1.3.1.1. Properties of CK-45:

1. Carbon Content: CK-45 has a carbon content ranging from 0.42% to 0.50%. The carbon content determines the hardness and strength of the steel.

2. Strength and Hardness: CK-45 exhibits high tensile strength and hardness, making it suitable for applications where strength and durability are required.
3. Machinability: CK-45 steel has good machinability, allowing for ease of cutting, shaping, and forming. It can be readily machined using conventional machining processes.
4. Weldability: CK-45 steel can be welded using various welding techniques such as arc welding and gas welding. However, preheating and post-weld heat treatment may be necessary to prevent cracking and improve the weld's mechanical properties.
5. Wear Resistance: CK-45 offers good wear resistance, making it suitable for applications where components are subjected to abrasive wear or impact.
6. Heat Treatment: CK-45 steel can be heat treated to enhance its mechanical properties. Common heat treatment processes include annealing, normalizing, quenching, and tempering.

1.3.1.2. Applications of CK-45

1. Machinery and Equipment: CK-45 is widely used in the manufacturing of machinery and equipment components, such as shafts, gears, sprockets, and hydraulic components, due to its excellent strength, hardness, and machinability.
2. Automotive Industry: CK-45 steel is employed in various automotive applications, including crankshafts, connecting rods, axles, and gears, where high strength and wear resistance are required.
3. Tool and Die Making: CK-45 is used for manufacturing tooling components such as dies, punches, and molds, thanks to its good hardness and wear resistance properties.
4. Construction: CK-45 steel finds applications in the construction industry, such as in the production of structural components, shafts, and supports, due to its high strength and durability.
5. General Engineering: CK-45 is utilized in a wide range of general engineering applications, including fasteners, bolts, nuts, and general-purpose machinery parts.

1.3.2. Brass

Brass is an alloy composed primarily of copper (Cu) and zinc (Zn), with varying proportions of each element depending on the desired properties. It is a versatile material with a wide range of applications due to its desirable combination of mechanical, electrical, and aesthetic properties [10].

1.3.2.1. Properties of Brass:

1. Copper-Zinc Composition: Brass typically contains copper as the base metal, ranging from around 55% to 95%, and zinc as the alloying element, ranging from around 5% to 45%. The proportion of copper and zinc influences the properties of the brass, such as its strength, ductility, and corrosion resistance.
2. Strength and Ductility: Brass exhibits good strength and ductility, making it suitable for applications that require both structural integrity and formability. The addition of zinc enhances the strength of brass compared to pure copper.
3. Corrosion Resistance: Brass has excellent corrosion resistance, especially in atmospheric and freshwater environments. The presence of zinc in the alloy provides protective properties against corrosion.
4. Electrical Conductivity: Brass is an excellent conductor of electricity, making it suitable for electrical and electronic applications. Its electrical

conductivity is lower than that of pure copper but higher than that of many other metals.

5. Machinability: Brass is known for its excellent machinability, which allows for ease of cutting, shaping, and forming using various machining processes. It produces excellent surface finishes and can be readily worked into complex shapes.
6. Aesthetic Appeal: Brass has an attractive golden appearance, making it a popular choice for decorative applications, architectural elements, jewelry, musical instruments, and artistic creations.

1.3.2.2. Applications of Brass

1. Plumbing and Fittings: Brass pipes, valves, connectors, and fittings are commonly used in plumbing systems due to their corrosion resistance, durability, and ease of installation.
2. Electrical and Electronics: Brass is used in electrical connectors, terminals, switches, and various components due to its good electrical conductivity and resistance to corrosion.

3. Automotive Industry: Brass is utilized in automotive applications, including radiators, connectors, terminals, and electrical components, due to its excellent combination of strength, corrosion resistance, and formability.
4. Musical Instruments: Brass instruments, such as trumpets, trombones, and saxophones, are made from brass alloys due to their acoustic properties and aesthetic appeal.
5. Decorative and Architectural Applications: Brass is widely used in decorative and architectural applications, including door hardware, furniture fittings, lighting fixtures, statues, and ornamental elements.
6. Marine Applications: Brass is resistant to corrosion in seawater, making it suitable for marine applications such as shipbuilding, marine fittings, and marine hardware.
7. Precision Engineering: Brass is employed in precision engineering applications, including precision components, instrumentation, and watchmaking, due to its machinability and dimensional stability.

1.3.3. Carbon steal

Carbon steel is a type of steel that primarily consists of iron and carbon as the major alloying elements. It is one of the most widely used materials in various industries due to its versatility, strength, and affordability. The carbon content in carbon steel typically ranges from 0.05% to 2.0%, although higher carbon contents can be present in certain specialized grades [11].

1.3.3.1. Properties of Carbon Steel

1. Strength and Hardness: Carbon steel exhibits high strength and hardness, making it suitable for structural applications that require durability and load-bearing capacity. The strength of carbon steel can be further enhanced through heat treatment processes.
2. Ductility and Toughness: Carbon steel possesses good ductility and toughness, allowing it to be easily formed and shaped without fracturing. It can withstand impact and withstand deformation without failure.
3. Machinability: Carbon steel generally has good machinability, allowing it to be easily machined, drilled, cut, and shaped using conventional machining processes. The machinability can vary depending on the carbon content and other alloying elements present.
4. Weldability: Carbon steel is typically weldable and can be joined using various welding techniques, such as arc welding, gas welding, and resistance

welding. However, precautions and proper welding procedures should be followed to avoid issues such as weld cracking and brittleness.

5. Corrosion Resistance: Carbon steel is susceptible to corrosion, particularly when exposed to moisture and aggressive environments. However, the addition of alloying elements, such as chromium or nickel, can enhance its corrosion resistance in specific applications.
6. Cost-Effectiveness: Carbon steel is relatively inexpensive compared to other alloyed steels, making it a cost-effective choice for many applications.

1.3.3.2. Applications of Carbon Steel

1. Structural Components: Carbon steel is widely used in the construction industry for structural components such as beams, columns, and frames due to its strength and durability.
2. Automotive Industry: Carbon steel is utilized in the manufacturing of automobile parts, including chassis components, engine components, and body panels, due to its strength and cost-effectiveness.
3. Pipelines and Plumbing: Carbon steel pipes and fittings are commonly used in oil and gas pipelines, water supply systems, and plumbing applications

due to their strength, corrosion resistance (with proper coating), and ease of installation.

4. Machinery and Equipment: Carbon steel is used in the production of various machinery and equipment components, including gears, shafts, bolts, and fasteners, due to its strength and machinability.
5. Tools and Cutting Equipment: High carbon steel is used for the production of cutting tools, drills, saw blades, and other tools that require hardness and wear resistance.
6. Structural Fasteners: Carbon steel bolts, screws, and nuts are widely used in construction, manufacturing, and infrastructure projects for fastening purposes.
7. Shipbuilding: Carbon steel is employed in shipbuilding for various structural components and hull construction due to its strength and weldability.

1.3.4. 201-stain

It seems that you are referring to "201 stainless steel." 201 stainless steel is a type of austenitic stainless steel that contains about 16-18% chromium, 3.5-5.5% nickel, and a lower carbon content compared to other stainless steel grades. It is a cost-effective alternative to 304 stainless steel and is commonly used in various applications [12].

1.3.4.1. Properties of 201 Stainless Steel

1. Corrosion Resistance: 201 stainless steel exhibits good resistance to corrosion in mild atmospheric and oxidizing environments. However, it is less resistant to corrosion compared to 304 stainless steel, particularly in chloride-rich environments.
2. Strength and Toughness: 201 stainless steel offers moderate strength and toughness, making it suitable for structural applications that require strength and durability.
3. Formability: 201 stainless steel has good formability, allowing it to be easily shaped and fabricated into different forms, such as sheets, coils, tubes, and wires.
4. Weldability: 201 stainless steel is generally considered to have good weldability. It can be welded using various methods, including arc welding, resistance welding, and spot welding. However, proper welding procedures should be followed to avoid issues such as sensitization and embrittlement.

5. Magnetic Properties: Unlike austenitic stainless steels like 304 and 316, 201 stainless steel is generally magnetic due to its microstructure.

1.3.4.2. Applications of 201 Stainless Steel

1. Decorative Applications: 201 stainless steel is commonly used in decorative applications, such as interior and exterior architectural elements, kitchen appliances, decorative trim, and automotive trim.
2. Utensils and Cookware: Due to its corrosion resistance and cost-effectiveness, 201 stainless steel is used in the manufacturing of utensils, cookware, and kitchen appliances.
3. Automotive Trim and Exhaust Systems: 201 stainless steel is utilized in the production of automotive trim, exhaust systems, and components due to its aesthetic appeal and moderate corrosion resistance.
4. Furniture and Fixtures: 201 stainless steel finds applications in the furniture industry, including handles, frames, hinges, and decorative accents.
5. Food Processing Equipment: The corrosion resistance and cost-effectiveness of 201 stainless steel make it suitable for food processing equipment, such as food storage containers, conveyor systems, and processing machinery.

6. Industrial Applications: 201 stainless steel is used in various industrial applications, including construction, chemical processing, and transportation, where moderate corrosion resistance and cost-effectiveness are required.

1.3.5. Bronze

Bronze is a type of alloy that primarily consists of copper (Cu) combined with other elements, most commonly tin (Sn). It is an ancient material that has been used for thousands of years due to its desirable properties, such as strength, durability, and corrosion resistance. Bronze is widely used in various applications, ranging from sculptures and decorative items to industrial components and machinery [13].

1.3.5.1. Properties of Bronze

1. Copper-Tin Composition: Bronze typically contains a significant amount of copper, usually in the range of 80% to 95%. The addition of tin, which ranges from 5% to 20%, provides the desired characteristics of bronze.

However, other elements, such as aluminum, zinc, and nickel, can also be added to create specific bronze alloys with enhanced properties.

2. Strength and Hardness: Bronze is known for its excellent strength and hardness compared to pure copper. The addition of tin and other alloying elements improves the mechanical properties of bronze, making it suitable for structural applications.
3. Corrosion Resistance: Bronze exhibits good corrosion resistance, particularly in atmospheric and freshwater environments. It forms a protective oxide layer on its surface that helps prevent further corrosion.
4. Wear Resistance: Bronze has excellent wear resistance, making it suitable for applications involving friction and mechanical stress. It is commonly used in bearings, bushings, gears, and other components that experience sliding or rotational motion.
5. Machinability: Bronze is relatively easy to machine, allowing for precision shaping, cutting, and forming. It produces good surface finishes and can be readily worked into intricate shapes.
6. Thermal Conductivity: Bronze has high thermal conductivity, making it useful for applications where heat transfer is important. It is commonly used in heat exchangers and cooling systems.

1.3.5.2 Applications of Bronze

1. Sculptures and Artworks: Bronze is widely used in the creation of sculptures, statues, and artistic pieces due to its durability, aesthetic appeal, and ability to retain intricate details.
2. Bearings and Bushings: Bronze bearings and bushings are used in various industries, including automotive, industrial machinery, and aerospace, due to their excellent wear resistance and low friction properties.
3. Electrical Contacts: Bronze alloys with high electrical conductivity are utilized in electrical connectors, terminals, and switches, where good electrical performance and corrosion resistance are required.
4. Marine Applications: Bronze is commonly used in marine environments due to its corrosion resistance and ability to withstand seawater. It is used for propellers, fittings, ship components, and marine hardware.
5. Musical Instruments: Bronze alloys, such as phosphor bronze, are used in the manufacturing of musical instruments, including cymbals, bells, and various brass instruments, due to their unique sound characteristics and durability.

6. Industrial Components: Bronze is employed in various industrial components, such as gears, valves, fittings, pump parts, and hydraulic components, due to its strength, wear resistance, and corrosion resistance.
7. Coins and Medals: Bronze is historically used for coinage and the production of medals and commemorative plaques due to its durability and aesthetic appeal.

1.3.6. Aluminum

Aluminum is a lightweight and versatile metal known for its excellent strength-to-weight ratio, corrosion resistance, and thermal conductivity. It is the third most abundant element in the Earth's crust and has a wide range of applications across various industries [14].

1.3.6.1. Properties of Aluminum

1. Lightweight: Aluminum is a lightweight metal, with a density about one-third that of steel. This makes it an ideal choice for applications where weight reduction is desired, such as in transportation (e.g., automobiles, aircraft, and trains) and portable structures.
2. Strength: Although aluminum is lightweight, it exhibits good strength. Its strength can be further enhanced through alloying and heat treatment

processes. Aluminum alloys offer a wide range of strength levels, allowing for the selection of the appropriate grade for specific applications.

3. Corrosion Resistance: Aluminum has excellent corrosion resistance due to the formation of a thin, protective oxide layer on its surface. This oxide layer acts as a barrier, preventing further oxidation and corrosion. In highly corrosive environments, aluminum can be further protected through coatings or anodizing processes.
4. Electrical Conductivity: Aluminum is an excellent conductor of electricity, making it suitable for electrical transmission lines, wiring, and various electrical applications.
5. Thermal Conductivity: Aluminum has good thermal conductivity, allowing for efficient heat transfer. It is commonly used in heat sinks, heat exchangers, and other cooling applications.
6. Ductility and Formability: Aluminum is highly ductile and can be easily formed into different shapes and profiles using various manufacturing processes, such as extrusion, rolling, and forging. It can be formed into complex shapes, making it suitable for intricate designs and applications.

7. Recyclability: Aluminum is 100% recyclable without any loss of its original properties. Recycling aluminum requires significantly less energy compared to primary production, making it an environmentally friendly material.

1.3.6.2 Applications of Aluminum

1. Transportation: Aluminum is extensively used in the transportation industry, including automobile bodies, aircraft structures, train carriages, bicycles, and marine vessels. Its lightweight nature helps improve fuel efficiency and reduce emissions.
2. Construction and Architecture: Aluminum is used in various construction applications, such as window frames, curtain walls, roofing, siding, and structural components. Its lightweight nature, corrosion resistance, and aesthetic appeal make it a popular choice in architectural design.
3. Packaging: Aluminum is widely used for packaging purposes, such as aluminum cans for beverages, food containers, and foil packaging. Its lightweight, impermeability to moisture and light, and recyclability make it suitable for preserving and protecting a wide range of products.

4. Electrical and Electronics: Aluminum is used in electrical conductors, power cables, electrical enclosures, and heat sinks for electronic devices due to its electrical conductivity and thermal properties.
5. Consumer Goods: Aluminum is found in various consumer goods, including appliances, cookware, furniture, sports equipment, and handheld devices, due to its lightweight nature, durability, and aesthetic appeal.
6. Renewable Energy: Aluminum is used in the renewable energy sector, particularly in the manufacturing of solar panels, wind turbine components, and heat exchangers for geothermal systems.
7. Industrial Applications: Aluminum finds application in various industrial sectors, including machinery and equipment, chemical processing, and aerospace, due to its corrosion resistance, strength, and formability.

1.3.7. Reasons for study corrosion

We study corrosion because of the damage causes which include the following:

1- Dimensional change and loss of mechanical properties:

Corrosion leads to a loss of weight due to the dissolution of the metal and consequently to its dimension change. Therefore, corrosion Allowance is often given when it is present and at design. These areas are thicker in the medium in which the wear rates are higher than in those in which the wear rates are low. Dimensions of the metal part due to corrosion have an impact on mechanical properties, as they are less tolerant to external loads, i.e. increasing their plastic deformation and Elastic Deformation. The use of metal in corrosive media causes low values for many mechanical properties, especially fatigue strength and cracks that lead to fast fracture.

2- Appearance: The appearance of the metal is highly affected when it is corroded, as the metal always looks bad. Therefore, corrosion-resistant metals such as aluminum or stainless steel should be used in place of carbon steel, as building materials such as windows and materials, especially in the facades of external buildings, and the good appearance of these materials is due to their resistance to air corrosion. As for metals with weak resistance to corrosion, they are coated with different types of coatings to improve their appearance by reducing their wear.

3- Economic damages due to preventive measures: The economic damages resulting from corrosion are numerous and important, as this failure often causes productive facilities to stop work unprogrammed, and the corresponding additional unforeseen economic costs. Likewise, the occurrence of corrosion leads to a high cost of periodic maintenance, as in many cases it is necessary to replace the damaged metal part with another new part. There are many examples that indicate that choosing a relatively high-cost material but with good economic resistance to corrosion is preferable to using a particular material that is cheaper but is subject to rapid damage due to corrosion. What requires that it be changed periodically, and in both cases it is observed that corrosion causes economic damage due to increased costs. Also, preventive measures to reduce corrosion are included in the costs of operation and maintenance. Corrosion sometimes leads to an unexpected failure of metal parts in production complexes, and here lies mainly the seriousness of the problem of corrosion. As failure occurred suddenly, it may lead to significant damage greater than that caused by the expected erosion. In this regard, we must carefully determine the rates of wear in the metal parts during the course of the production process, through continuous measurements, periodic checks of rates of wear and continuous examination of metal parts to take preventive measures before the degree of corrosion reaches the extent that causes production to stop working or affect the course of the production process.

4- Production pollution: The corrosion products change the chemical nature of the medium, i.e. its pollution and it is often not desirable as the commercial requirements are obtaining a pure product with specific specifications and free from pollution.

5- Safety loss: Corrosion sometimes or often leads to disasters if preventive measures are not taken to prevent or reduce it, for example dealing with hazardous materials such as toxic gases such as hydrogen sulfide gas (H_2S) and concentrated acids such as sulfuric and nitric acid, flammable materials, radioactive materials and chemicals at high temperatures and when High pressure requires the use of certain mineral substances that do not corrode significantly under such conditions, For example, the occurrence of corrosion between gases and acids formed as a result of interactions with tank surfaces may lead to the collapse of these tanks and consequently the release of gases as hydrogen sulfide gas, which leads to economic and human losses, and in many cases the occurrence of corrosion in a small metal part leads to the collapse or fall of your entire structure, and has caused Corrosion products are sometimes converted to non-harmful substances into explosives [15].

1.3.8. Project Objective

The main objective of this project is to know the corrosion effect of Hydrochloric Acid (HCL) on the mechanical properties of minerals, and to develop effective protection measures for these minerals.

1.3.9. Summary

This chapter covers the definition and causes of corrosion on metals by Hydrochloric Acid (HCL). It lays down the classification of corrosion, the damage it causes, the reasons for its study, and the main objective of this project.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

This chapter outlined the existing literature which is directly relevant to the topic of this research .

TFH Mohamed , Abed El Rahim and MAM Ibrahim: Studied the Improving the Corrosion Behavior of Ductile Cast Iron in Sulphuric Acid (Heat Treatment), the investigation studied appears the effect of heat treatment on the corrosion behavior of ductile cast iron (DCI) in H2SO4 environment through the tempered specimens at different tempering times show better corrosion resistance in H2SO4 solution than that without heat treatment. In the additions the mechanical properties such as tensile strength also appears positives results. [16]

Zainab Azeez Betti Corrosion-fatigue occurs by the combined actions of cyclic loading and corrosive environment. The effect of shot peening on cumulative corrosion-fatigue life of 1100-H12 Al alloy was investigated. Before fatigue testing, specimens were submerged in 3.5%NaCl solution for 71 days. Constant fatigue tests were performed with and without corrosive environment. Cumulative corrosion-fatigue tests were also carried out in order to determine the fatigue life before and after shot peening. The constant fatigue life was significantly reduced due to corrosive environment and the endurance fatigue limit was reduced by 13% compared with dry fatigue. In case of shot peening the cumulative, corrosion -fatigue life was increased by a factor of about (2) compared with cumulative corrosion-fatigue life without shot peening. It was found that the CFLIF% (Cumulative Fatigue Life Improvement Factor) was about (2-6) due to shot peening surface treatment [17].

Branch, M., & Mahshahr, I. (2012) Corrosion is one of the major problems in the oil and gas industry is one that automatically allocates huge sums annually. Polyurethane is a thermoses polymer with various applications. Using form this polymer has spread for military applications by Otto Bayer in 1930. In one general look polyurethane is product of Iso Syanate and ploy with each other, So that: Iso + ploy = polyurethane. Spend large cost for application and launching oil and gas transitions, has cleared the necessity protection from them agonist corrosion. In this direction protection coating with specific properties such as high electricity resistance presented to market by various companies that each of them has special advantage and disadvantages.

In this research has tried while analysis coatings specifications of gas and oil transitional pipelines, has compared properties and common qualities of them with each other.[18]

Lilly, M. T., Ihekwoaba, S. C., Ogaji, S. O. T., & Probert, S. D. (2007) the corrosion of the external surfaces of such pipelines is a major problem ,which are not usually adequately safeguarded during construction. A cathodic- protection (CP) system should be applied to the pipeline before this period.[19]

Wang, X., Qi, X., Lin, Z., & Battocchi, D. (2018) Corrosion and corrosion-induced damage have resulted mostly in malfunctions and sometimes even in failures of metallic structures, including oil and gas pipelines. In this study, new high-performance composite coatings were developed by incorporating nanoparticles in the polymer resins with applications to oil and gas pipelines. The graphene nanoplatelets under different concentrations were used to prepare the epoxy-based nanocomposites and were then evaluated through mechanical and electrical tests. The integration of high-speed disk and ultrasonication were adopted as the dispersion technique to overcome nanoparticle agglomeration. Electron microscopy techniques were used to investigate the agglomeration. The new composites were qualitatively and quantitatively evaluated in terms of contact angle, surface roughness, adhesion to the substrate, corrosion resistance, and abrasion resistance. The results suggested that the composite with 0.5~1.0 wt.% of the graphene nanofillers led to the largest improvement in both mechanical and electrochemical properties. Distribution of nanoparticles in the matrix was observed using scanning electron microscopy and surface roughness using atomic force microscopy. Large agglomeration that was observed at the higher concentrations mainly resulted in the reduction of corrosion resistance and abrasion resistance.[20]

Wang, X., Tang, F., Qi, X., Lin, Z., Battocchi, D., & Chen, X. (2019) Corrosion accounts for huge maintenance cost in the pipeline community. Promotion of protective coatings used for oil/gas pipeline corrosion control, in terms of high corrosion resistance as well as high damage tolerance, are still in high demand. This study was to explore the inclusion of nanoparticle fullerene-C60 in protective coatings for oil/gas pipeline corrosion control and mitigation.

Fullerene-C60/epoxy nanocomposite coatings were fabricated using a solvent-free dispersion method through high-speed disk (HSD) and ultrasonication. The morphology of fullerene-C60 particles was characterized by transmission electron microscopy (TEM), and dynamic light scattering (DLS). The data analysis indicated that the nanoparticles were effectively dispersed in the matrix. The performance of the nanocomposites was investigated through their mechanical and electrochemical properties, including corrosion potential, tensile strength, strain at failure, adhesion to substrate, and durability performance. Dogbone shaped samples were fabricated to study the tensile properties of the nanocomposites, and improvement of strength, ultimate strain, and Young's modulus were observed in the C60/epoxy specimens. The results demonstrated that the C60/epoxy composite coatings also had improvements in adhesion strength, suggesting that they could provide high damage tolerance of coatings for engineering applications. Moreover, the electrochemical impedance spectroscopy (EIS) results generated from the accelerated durability test revealed that the developed fullerene-C60 loaded composite coatings exhibited significantly improved corrosion resistance. The nanocomposite with 0.5 and 1.0 wt.% of C60 particles behaved as an intact layer for corrosion protection, even after 200-h salt spray exposure, as compared to the control coating without nanofiller in which severedamage by over 50% reduction was observed.[21]

Ammar, A. U. Shahid& Khan, Z. A. (2018) Coating is one of the most effective measures to protect metallic materials from corrosion. Various types of coatings such as metallic, ceramic and polymer coatings have been investigated in a quest to find durable coatings to resist electrochemical decay of metals in industrial applications.

Many polymeric composite coatings have proved to be resistant against aggressive environments.

Two major applications of ferrous materials are in marine environments and in the oil and gas industry. Knowing the corroding behavior of ferrous-based materials during exposure to these aggressive applications, an effort has been made to protect the material by using polymeric and ceramic-based coatings reinforced with nano materials. Uncoated and coated cast iron pipeline material was investigated during corrosion resistance by employing EIS (electrochemical impedance spectroscopy) and electrochemical DC corrosion testing using the "three electrode system". Cast iron pipeline samples were coated with Polyvinyl Alcohol/Polyaniline/FLG (Few Layers Graphene) and TiO2/GO (graphene oxide) nanocomposite by dip-coating. The EIS data indicated better capacitance and higher impedance values for coated samples compared with the bare metal, depicting enhanced corrosion resistance against seawater and "produce water" of a crude oil sample from a local oil rig; Tafel scans confirmed a significant decrease in corrosion rate of coated samples.[22]

Fan, L. (2019) This study is to explore and develop chemically-bonded enamel coating (200-300 um) on steel pipes, when subjected to soil and thermal environments, in order to improve the corrosion protection and safety of hazardous liquid and natural gas pipelines while reducing pressure loss. Out of five types of enamels and their various mixtures, Tomatec slurry and GP2118 powder were selected for steel pipeline applications. They were applied at approximately 810 °C to the inside surface of steel pipes in wet and electrostatic processes, respectively. The thickness and surface roughness of the enamel coating were measured using a gauge and an optical microscope, respectively. The microstructure and porosity of the coating, and coating-steel bond strength were characterized using scanning electron microscopy and PosiTest, respectively. The corrosion resistance of enamel-coated pipelines, with and without cathodic protection (CP), is evaluated using salt spray and electrochemical tests. The stress distribution of enamel-coated pipes and their susceptibility to stress corrosion cracking (SCC) were studied with finite element analyses and slow strain rate tests, respectively. The surface roughness of the two coatings were ~ 1 μm and quite desirable in oil and gas transmission. Small Fe protrusions grew into each coating to form anchor points with a bond strength of 17 MPa between the enamel and its steel substrate. The residual thermal stress remained at the coating-steel interface is 2.5 MPa and thus negligible. Both enamel coatings increased the corrosion resistance of steel pipes in NaCl solution by three orders of magnitude. CP neither caused debonding at the coating-steel interface nor accelerated degradation process of the coating. The more negative the applied CP potential, the more susceptible to SCC the enamel-coated steel.[23]

Abd El-Lateef H. M. & Ismayilov T. A. (2012) One of the serious problems of oil extracting industry is the corrosion process. The successful application of carbon steels in oil and gas pipelines and production tubular in Carbon Dioxide (CO2) containing environments depends mainly on either the formation of protective corrosion product film or the use of corrosion inhibitors. The mechanism of corrosion of carbon steel in media containing CO2 is complex, and in dependence on the prevailing conditions it may lead to general or local corrosion and corrosion cracking. The inhibition mechanism is attributed to the strong adsorption ability of the selected inhibitors on steel surface, forming a good protective layer, which isolates the surface from the aggressive environment.

The current state of research in corrosion protection of steel pipelines against CO2 corrosion is surveyed. The review covers CO2 corrosion and its inhibition. The influence of inhibitors molecular structure on corrosion layers in CO2 corrosion is discussed.[24]

Nikitin E., Shumatbaev G., Sinyashin K., & Kazimova, K. (2019) The problem of corrosion of metal equipment is one of the most actual problems in oil industry. One of the methods to solve this problem is the development of new low-toxic, accessible and effective corrosion inhibitors. For this purpose, we carried out the synthesis of the new α-aminophosphonates based on syntanyl phosphites, formalin and diethanolamine according to the Kabachnik-Fields reaction. The resulting products are characterized by 1H, 31P, 13C NMR, IR and mass spectroscopy methods. The obtained compounds contain a long radical chain of industrial (poly) ethoxylated alcohol residue with different length of the hydroxyethyl fragment, as well as an active center containing O-P-C-N fragment, which impart them inhibitory properties toward corrosion processes. The anticorrosive activity of the new aminophosphonates was studied by gravimetric analysis method. In the article the effect of concentration, time and degree of ethoxylation of the hydrocarbon radical in alpha-aminophosphonates on the protective effect of inhibitors was studies. It was shown that the obtained aminophosphonates exhibit high values of the protective effect of steel in a highly mineralized medium containing 250 g/m3 CO2 and 200 g/m3 H2S. The high value of the protective effect (82-85%) at inhibitor concentration of 25 mg/l was found. The maximum protective effect at 50 mg/ml dosage of the inhibitor is 94.3%, while there is a decrease of the corrosion rate (less than 0.04 mm/year).[25]

Deyab, M. A., Mohamed, N. H., & Moustafa, Y. M. (2017) A wax coating was prepared using waste materials (isolated microcrystalline waxes) to protect petroleum pipelines against corrosion in 0.6 M NaCl solution. The corrosion protection performance of isolated microcrystalline wax coating was detected by electrochemical impedance spectroscopy (EIS) and open circuit potential (OCP) measurements. EIS spectra confirmed that the corrosion of carbon steel in 0.6 M NaCl solution significantly inhibited by isolated microcrystalline wax coating. Positive shift of OCP also indicated that the microcrystalline wax acts as a protective coating. The effect of temperature on the performance of isolated microcrystalline wax coating was investigated and discussed.[26]

Lervik, J. K., Børnes, A. H., Kulbotten, H., & Nysveen, A. (2004) Application of AC direct electrical heating (DEH) on subsea pipelines requires a special design of the corrosion protection system. The first electrically heated pipelines in the North Sea were supplied with anodes banks at the ends for AC current transfer in addition to single anodes distributed along the heated pipeline according to CP-design requirements from standards and class societies. Anodes were also installed at pipejoints where pipes sections with different magnetic properties are connected, as current transfer between pipe and seawater will occur at these locations. In case of buried pipelines high temperatures for the anodes implies reduced cathodic protection. For these installations modified solutions for cathodic protection are required. Measurements have been made on a scale test installation without distributed anodes in a project initiated by an oil company. In this case the anode banks at the ends must be designed both for cathodic protection and AC current transfer to seawater. For Cr13 (13% Chromium content) pipelines welding of the anode connections should be avoided related to hydrogen embrittlement. A design with clad steel carbon pipes for the current transfer zones at the ends where anodes are connected has been chosen to solve this problem. For economical and practical reasons, the length of the clad steel sections should be as short as possible. This is especially true for a reeled installation method. It has been verified by tests that the minimum length of the clad steel section depends on the material characteristics of both the clad steel carbon pipe and Cr13 pipes. When the magnetic and electrical properties of Cr13 pipes are known, carbon steel pipes can be selected to obtain a minimum current transfer length. These material data are not available from the manufacturer and must be determined by measurements.[27]

Amir Samimi، Soroush Zarinabadi (2011) proceeds to investigate the reason for corrosion in steel pipes with three poly ethylene layers, Corrosion in industries is controlled by one of the following methods.A-Corrosion-resistant alloys, B- Corrosion inhibitors, C- Stabilization method, D- Corrosion-resistant alloys. First layer Immediately after the pipe one form of film of liquid or gum of epoxy is created. Minimum dryer thickness must be between 20-60 micron, Second layer polymer creates adhesiveness between layers 1 and 3 and must be compatible with both layers. Minimum thickness must be between 160-200 micron. Thickness may increase or reduce according to the mutual agreement with customer but minimum thickness must be investigated safely, Third layerPolyethylene coating must be formed in this layer. Thickness must be uniform in all through the pipe and minimum general thickness must be acceptable, they concluded an analysis of reasons for three-layered poly ethylene coating separation.Good function of coating depends to a high extent to its adhesiveness rate to metal surface. Initial adhesiveness and its durability in contact condition are of those factors that result in high efficiency of coating in long term. The extent of initial adhesiveness has a very high relationship with coating flow and its wetting when applying coating and also with cleanliness of surface and its readiness. [28]

CHAPTER 3

Experimental Work

3.1 Introduction

Throughout the present work, the project was conducted on a set of samples (metals) that were immersed in HCl with different concentrations.

3.2 The Experimental Plan Work Can Be Summarized Below

1. Material selection(metals).
2. preparing selected specimen for experimental work.
3. After diluting the acid, we put each metal separately in the beaker.
4. every Seven days each specimen should be cleaned then compare the original weight

Six types of minerals have been selected (Copper, Brass, Bronze, Ck-45, Stainless steel, Aluminum), Its mechanical properties such as good mechanical strength, excellent machinability and high in corrosion strength.

3.3 Preparation of Specimens

The specimens are made according to standard specification 50 mm (length) 10 mm dimeter, Figure (3-1).

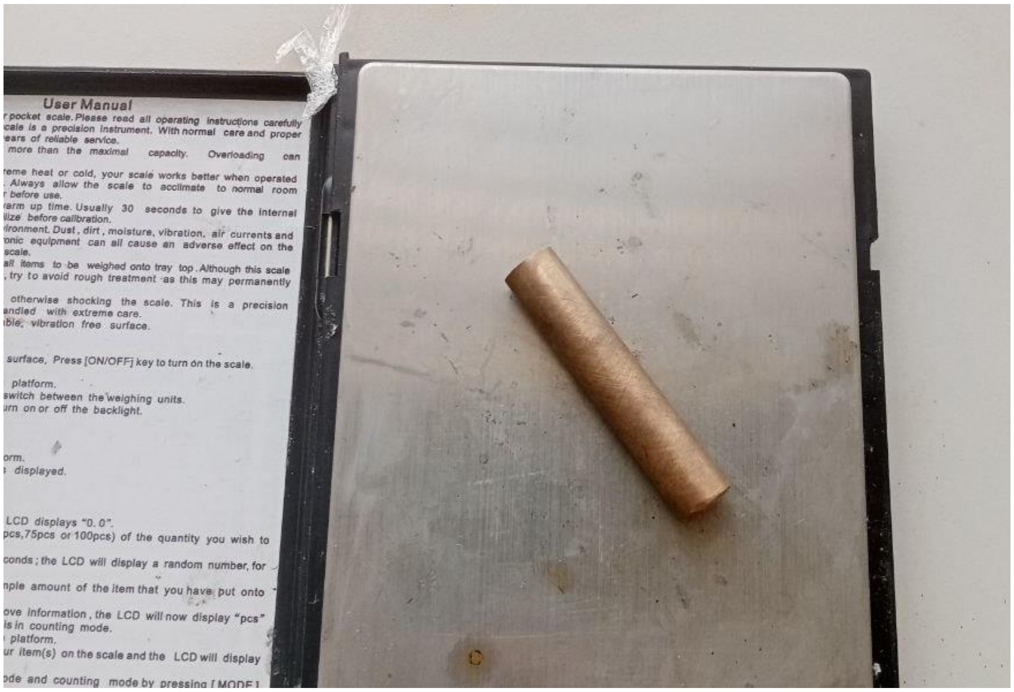

Fig. (3-1): shape of Specimen

The preparation of specimens is made by (CNC) machine in – northern – technical university – mechanical workshop.

The figure below explains the machine that used in the preparation of specimens.

Fig. (3-2) CNC Machine.

In the next step after the specimens are prepared, the specimens must be purifying from calculation and impurities by water to get a pure metal (in general the substances increasing the weight of the specimens).

The measurement of weight of each specimen is fundamental by accurate balance.

Fig. (3-3) Accurate Balance.

3.4 The Preparation of for Hydrochloric Acid **Corrosion Test**

In this step the specimens will be divided into three groups for each metal (copper, brass, bronze, ck-45, bronze, carbon steel, and aluminum)

- The first group will be put in the 5% (HCl) as shown in figure below
-

Fig. (3-4) Shows the Specimens into 5% Hydrochloric Acid **(**HCl).

- The second group will be put in the dilute solution 8% (HCl) as shown in figure (3-6)

Fig. (3-5) Shows the Specimens into 8% Hydrochloric Acid **(**HCl).

- The third group will be put in the dilute 10% (HCl) as shown in figure (3-7)

Fig. (3-6) Shows the Specimens into 10% Hydrochloric Acid (HCl).

For period of twenty-eight days, in every Seven days each specimen should be cleaned then compare the original weight with the current weight to determine the loses amount of the weight for each specimen as shown in figures below.

Fig. (3-7) Measure the weight of the sample after it has been thoroughly cleaned

Fig. (3-8) Shows the Corrosion of The Specimens.

CHAPTER 4
RESULTS AND DISCUSSION

4. Introduction

When metals are immersed in hydrochloric acid (HCl), their behavior and reactions can vary depending on the specific metal and the concentration of the acid. This study examined the corrosion behavior of 6 different metals when immersed in HCl acid. These metals are CK-45, Brass, Carbon steel, 201-stain, Bronze and Aluminum. Moreover, three different concentrations of Hydrochloric Acid (HCl) were considered for each metal. The weight of each mineral was measured after one week, then after two weeks, then after three weeks, and finally after four weeks. Accordingly, each weight was compared to its original weight before being immersed in Hydrochloric Acid **(**HCl).

4.1. Effect of Hydrochloric Acid (HCl) on CK-45

Figure 4-1 presents the variation in CK-45 weight over time after immersion in Hydrochloric Acid **(**HCl) acid at three different concentrations. This figure clearly shows that the weight of CK-45 decreases significantly after one week. This corrosion behavior occurred at all the concentrations tested. In the second, third and fourth week, the weight of the CK45 steel decreases, but with a slight ratio. Therefore, it can be stated that the greatest weight loss occurs within the first week. Moreover, the maximum loss in weight occurs at 10% of Hydrochloric Acid

(HCl) in comparison with the other concentrations. The weight of metals can decrease when they are immersed in hydrochloric acid (HCl) due to a process called corrosion or dissolution. When a metal reacts with Hydrochloric Acid (HCl), it can undergo a chemical reaction that results in the formation of metal chloride salts and the release of hydrogen gas (H2).

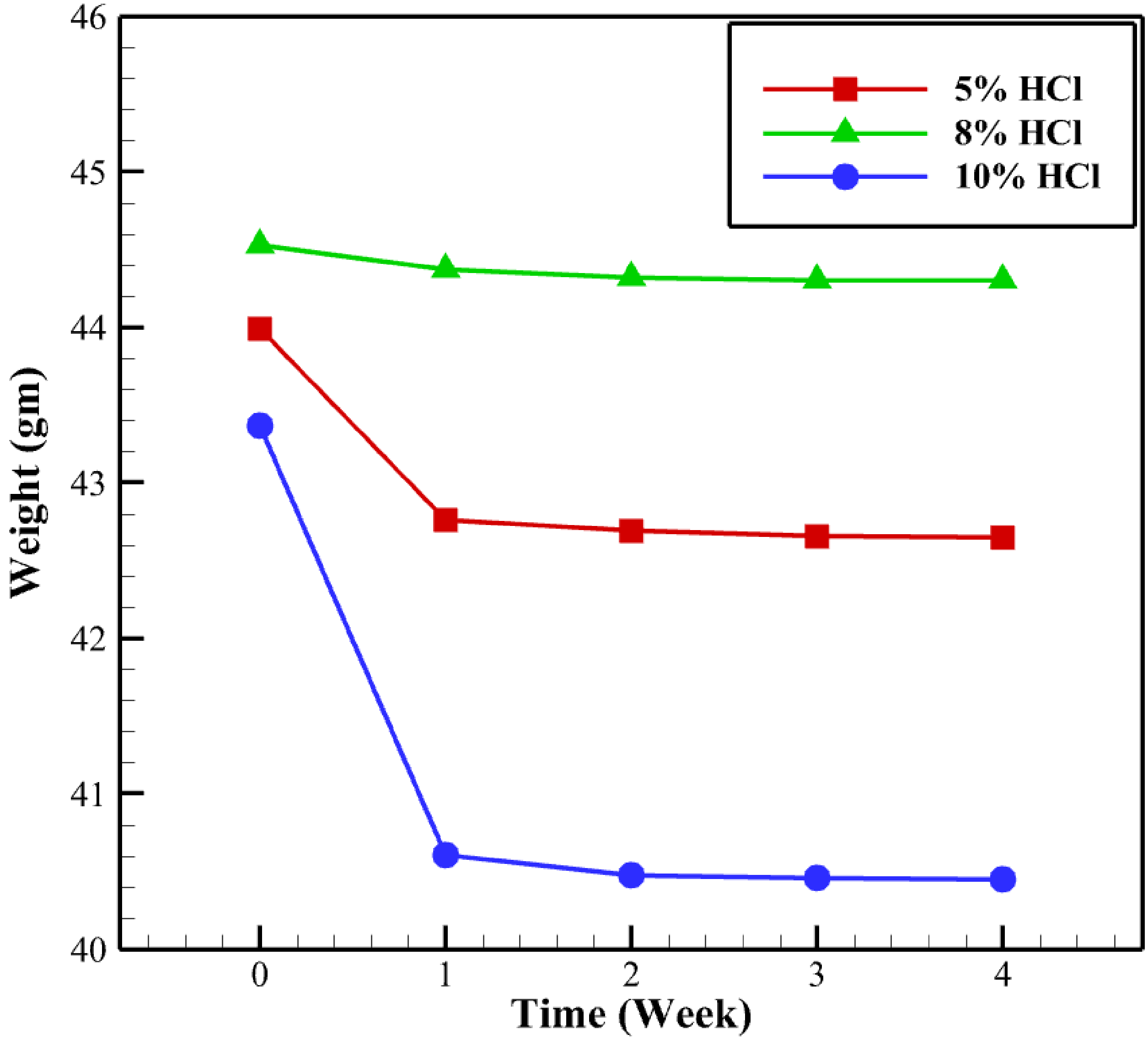

Fig. (4-1) Variation in CK-45 weight over time after immersion in Hydrochloric Acid (HCl) at different concentrations.

4.2. Effect of Hydrochloric Acid (HCl) on Brass

Figure 4-2 presents the variation in Brass weight over time after immersion in Hydrochloric Acid **(**HCl) at three different concentrations. This figure shows that the weight of the brass decreases slightly after being immersed in Hydrochloric Acid **(**HCl) acid. In contract to the CK-45, there is no big change in Brass weight with time. This behavior occurred for all the testes concentrations.

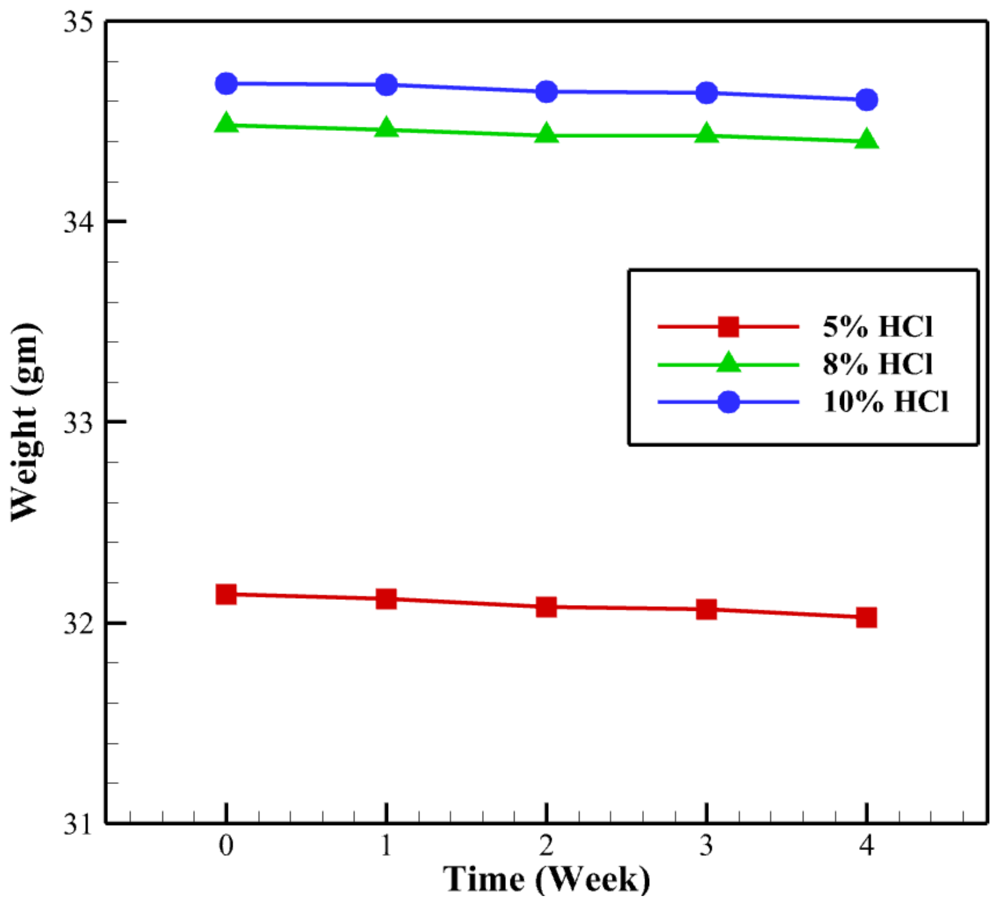

Fig. (4-2) Variation in Brass weight over time after immersion in Hydrochloric Acid **(**HCl) acid at different concentrations.

4.3. Effect of Hydrochloric Acid (HCl) on Carbon steel

Figure 4-3 presents the variation in Carbon steel weight over time after immersion in Hydrochloric Acid (HCl) at three different concentrations. This figure shows that the weight of the carbon steel decreases significantly within the first and second weeks. Thus, within the third and fourth weeks the weight decreases slightly. In general, it can be said that this behavior occurs at all the tested concentrations of HCl acid.

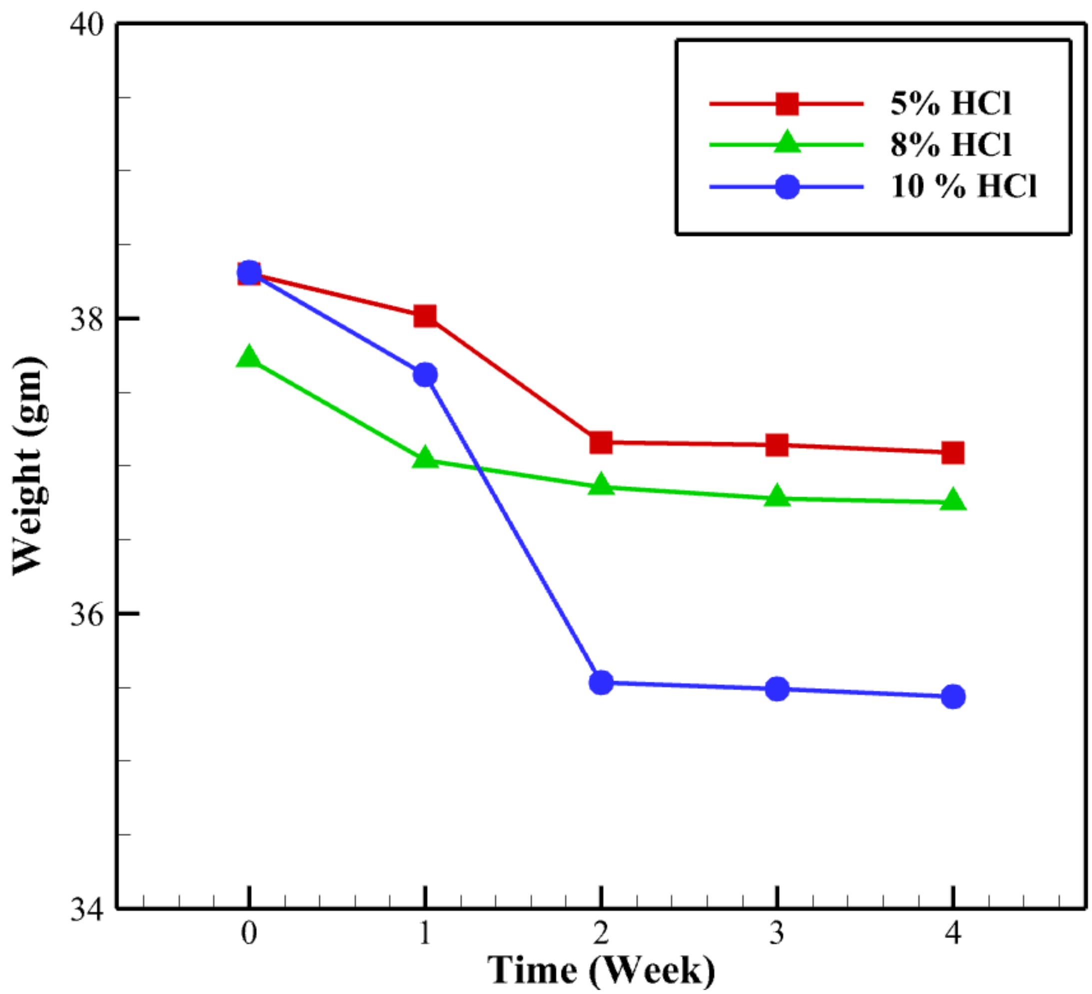

Fig. (4-3) Variation in Carbon steel weight over time after immersion in Hydrochloric Acid (HCl) at different concentrations.

4.4. Effect of Hydrochloric Acid (HCl) on 201-stain

Figure 4-4 presents the variation in 201-stain weight over time after immersion in Hydrochloric Acid (HCl) at three different concentrations. This figure clearly shows that the weight of 201-stain decreases significantly after one week. This corrosion behavior occurred at all the concentrations tested. In the second, third and fourth week, the weight of the CK45 steel decreases, but with a slight ratio. This behavior similar to that happened for Ck-45.

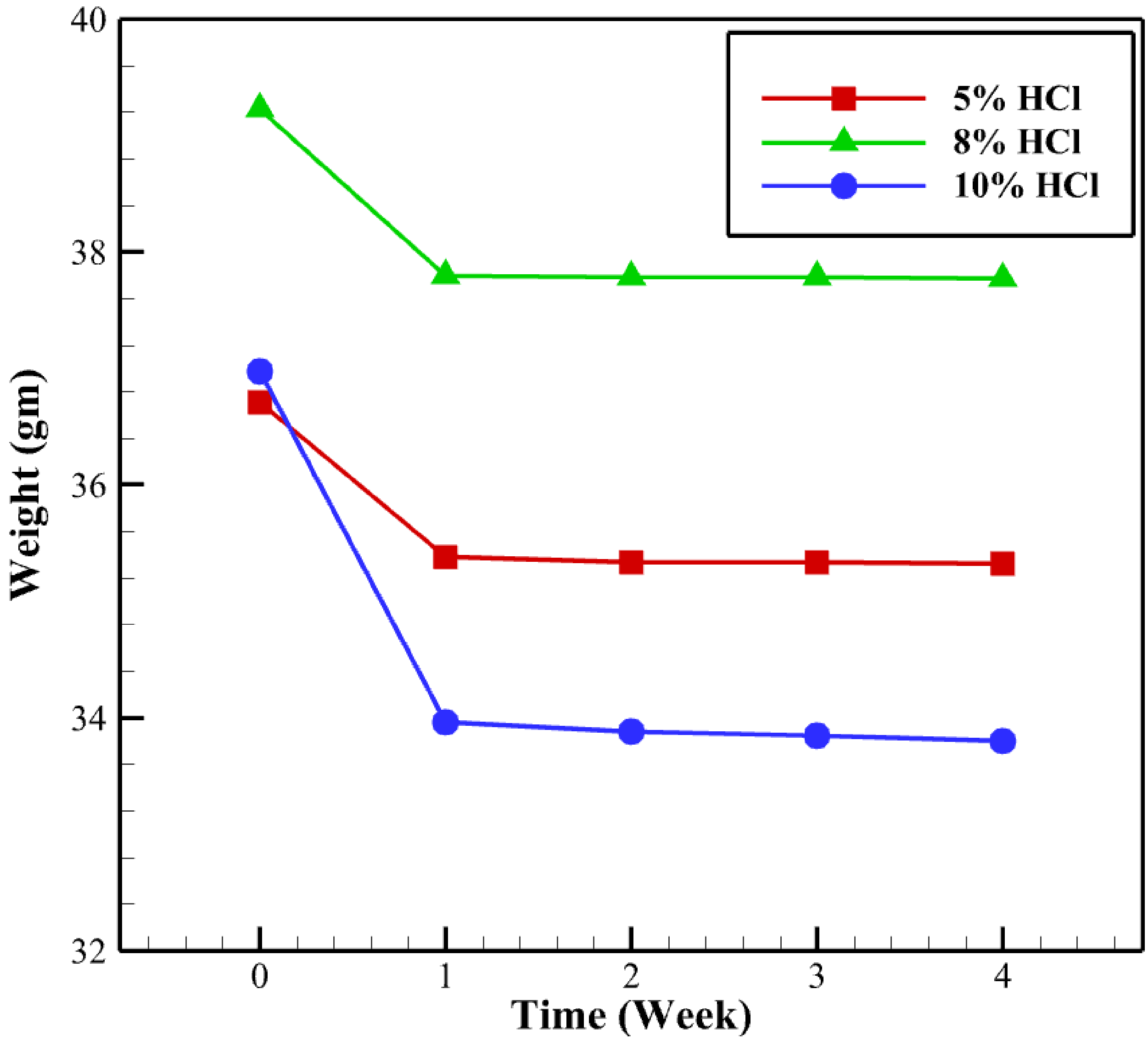

Fig. (4-4) Variation in 201-stain alloy weight over time after immersion in Hydrochloric Acid **(**HCl) at different concentrations

4.5. Effect of Hydrochloric Acid (HCl) on Bronze

Figure 4-5 illustrates the variation in bronze weight over time after immersion in Hydrochloric Acid **(**HCl) at three different concentrations. Along the tested times, this figure shows that the weight of the bronze decreases slightly after being immersed in Hydrochloric Acid (HCl). This behavior similar to that happened for brass.

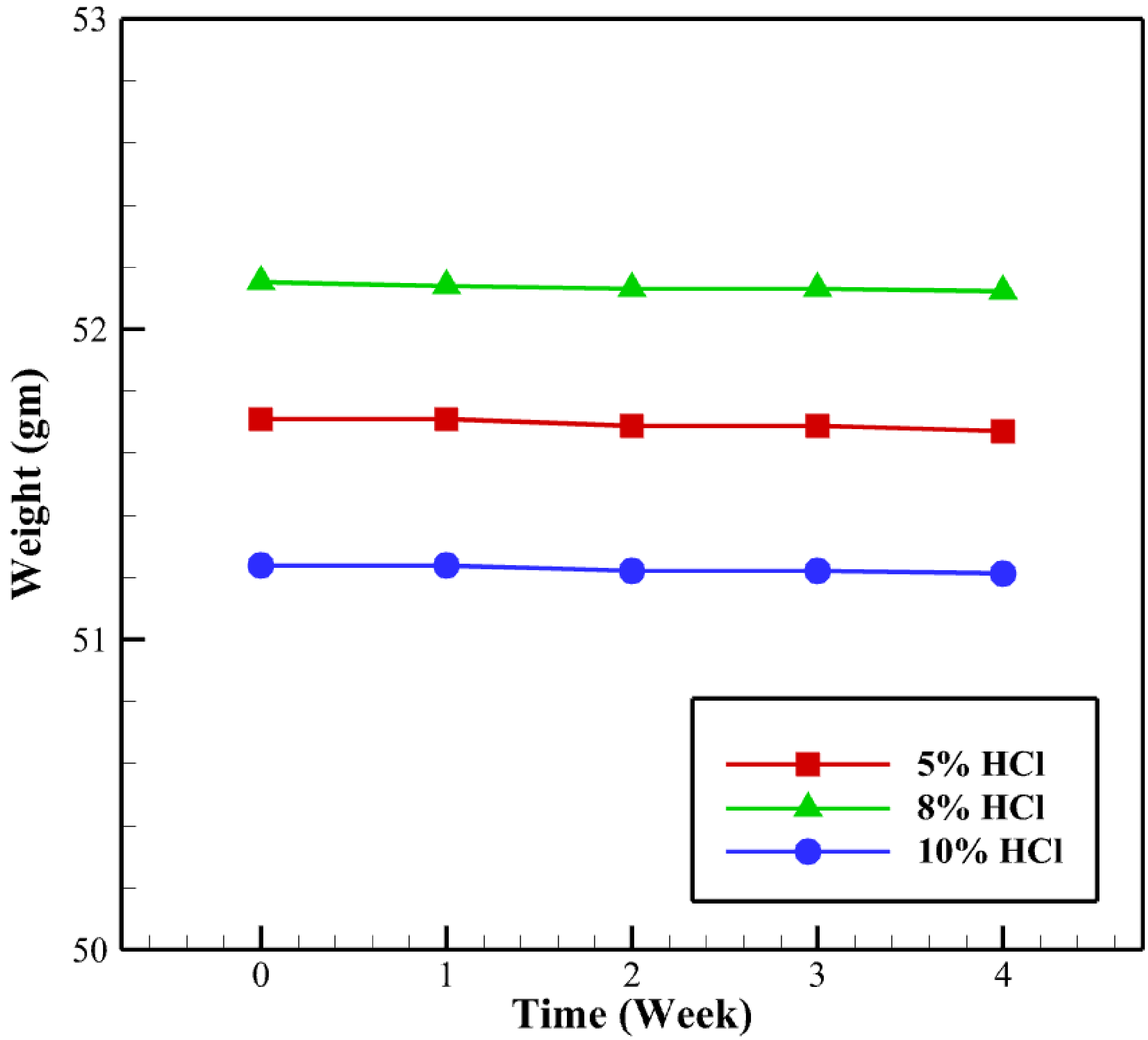

Fig. (4-5) Variation in Bronze weight over time after immersion in Hydrochloric Acid (HCl) at different concentrations.

4.6. Effect of Hydrochloric Acid (HCl) on Aluminum

acid at three different concentrations. This figure shows that the Aluminum weight decreases Figure 4-6 illustrates the variation in Aluminum weight over time after immersion in HCl significantly with passing time for all the tested concentrations. Further, the highest lost in Aluminum weight accrued within the first week.

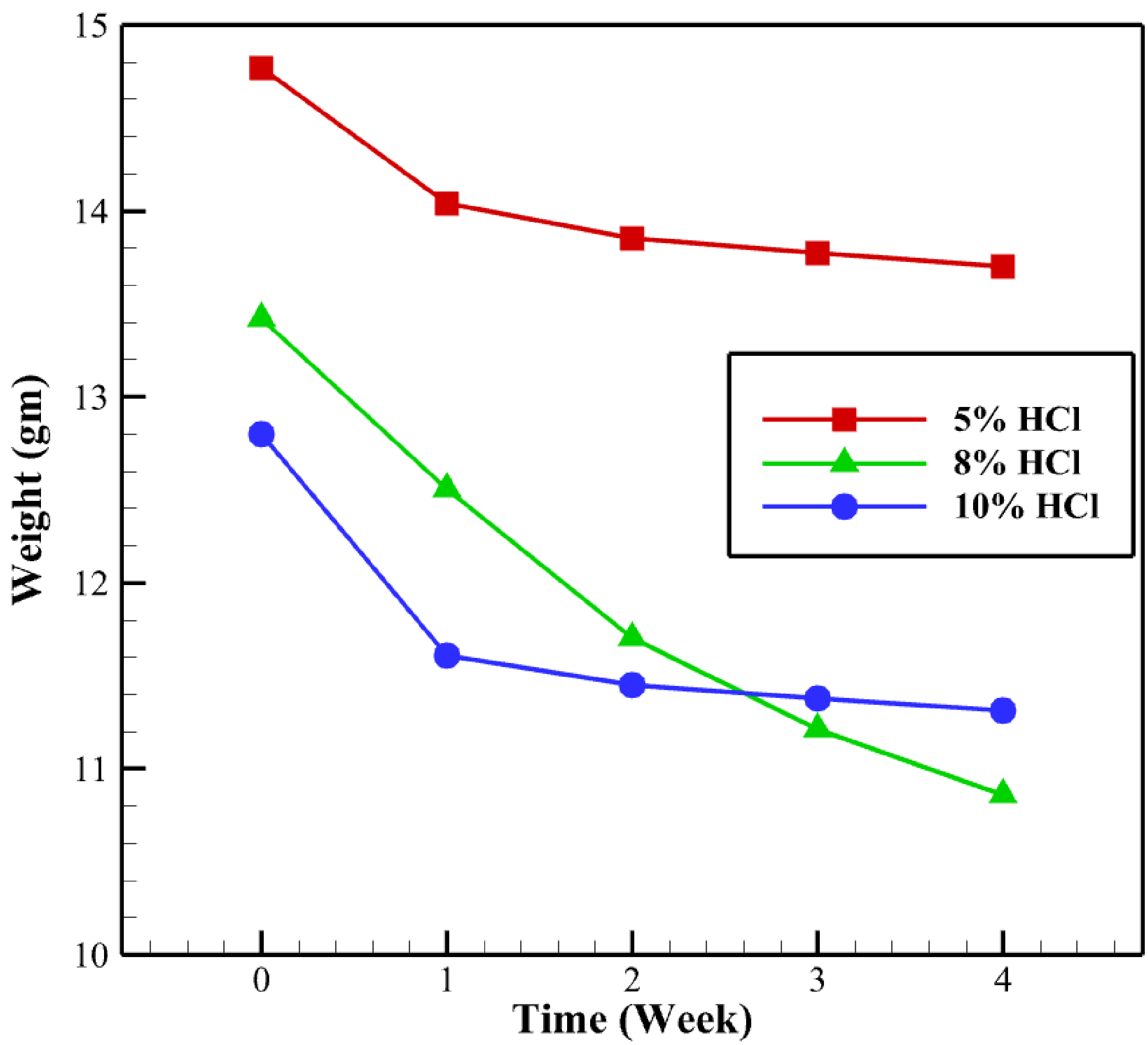

Fig. (4-6) Variation in Aluminum weight over time after immersion in Hydrochloric Acid (HCl) at different concentrations.

TABLE 4-1 IMMERSED SAMPLES IN HYDROCHLORIC ACID **(**HCL) AT (5%).

Metal type	weight before immersion	A week later	Two weeks later	Three weeks later	Four weeks later
CK-45	43.99	42.76	42.69	42.66	42.65
Brass	32.14	32.12	32.08	32.07	32.03
Carbon steel	38.30	38.02	37.16	37.14	37.09
201-stain	36.71	35.38	35.34	35.34	35.33
Bronze	51.71	51.71	51.69	51.69	51.67
Aluminum	14.77	14.04	13.85	13.77	13.70

TABLE 4-2 IMMERSED SAMPLES IN HYDROCHLORIC ACID **(**HCL) AT (8%).

Metal type	weight before immersion	A week later	Two weeks later	Three weeks later	Four weeks later
CK-45	44.53	44.37	44.32	44.30	44.30
Brass	34.48	34.46	34.43	34.43	34.40
Carbon steel	37.72	37.04	36.86	36.78	36.75
201-stain	39.23	37.80	37.78	37.78	37.77
Bronze	52.15	52.14	52.13	52.13	52.12
Aluminum	13.42	12.50	11.70	11.21	10.86

TABLE 4-3 IMMERSED SAMPLES IN HYDROCHLORIC ACID **(**HCL) AT (8%).

Metal type	weight before immersion	A week later	Two weeks later	Three weeks later	Four weeks later
CK-45	43.37	40.61	40.48	40.46	40.45
Brass	34.69	34.68	34.65	34.64	34.61
Carbon steel	38.31	37.62	35.53	35.49	35.44
201-stain	36.98	33.96	33.88	33.85	33.80
Bronze	51.24	51.24	51.22	51.22	51.21
Aluminum	12.80	11.61	11.45	11.38	11.31

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1. Conclusion

This study experimentally examined the corrosion behavior of six different metals after being immersed in Hydrochloric Acid (HCl) for four weeks. These metals are CK-45, Brass, Carbon steel, 201-stain, Bronze and Aluminum. Further, three different concentration was taken into our consideration. These concentration of Hydrochloric Acid (HCl) are 5%, 8% and 10%. The main conclusion of this study is listed below:

1- The weight of all considered metals decreased in different ratios after immersion in Hydrochloric Acid (HCl).

2- The weight loss of each metal increases slightly with increasing Hydrochloric Acid (HCl) concentration.

3- CK-45, Carbon steel, 201-stain, and Aluminum are the most affected metals in terms of losing weight after immersion in Hydrochloric Acid (HCl).

4- Brass and Bronze are the least affected metals in terms of losing weight after immersion in Hydrochloric Acid (HCl).

5- For CK-45, Carbon steel, 201-stain, and Aluminum, the maximum losses in weight occurred within the first week.

5.2. Future works

1- Investigate the corrosion behavior of the metals under consideration after immersion in a different acid.
2- Study the cumulative fatigue damage under corrosion and laser peening.
3- Study the effects of Shot Peening on corrosion in metals.

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