



**KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY**

Mazahir Huseynov

**ANALYSIS OF CORROSION RESISTANCE PROPERTIES AND
CONTROL PROCESS OF STEEL STRUCTURES**

Master's Degree Final Project

Supervisor

Assoc. prof. dr. Antanas Čiuplys

KAUNAS, 2018

KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

**ANALYSIS OF CORROSION RESISTANCE PROPERTIES AND
CONTROL PROCESS OF STEEL STRUCTURES**

Master's Degree Final Project

Industrial Engineering and Management (code 621H77003)

Supervisor

(signature) Assoc. prof. dr. Antanas Čiuplys
(date)

Reviewer

(signature) Assoc. prof. dr. Regita Bendikienė
(date)

Project made by

(signature) Mazahir Huseynov
(date)

KAUNAS, 2018

**KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN**

Approved:

Head of
Production engineering
Department

(Signature, date)

Kazimieras Juzėnas

(Name, Surname)

**MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT**

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Analysis of corrosion resistance properties and control process of steel structures

Approved by the Dean Order No. V25-11-12, 11 December 2017

2. Aim of the project

To investigate several types of corrosion processes and find which solution would suit best to preserve the steel structures.

3. Structure of the project

Introduction
1. Literature review
2. Experimental part
3. Results
Conclusions and Recommendations
References
Appendices

4. Requirements and conditions

The literature review must be made using scientific sources. According to the topic, some testing methods must be carried out to find the solutions to the tasks and the final results have to be compared and analyzed. KTU regulations and requirements should be considered for the final project.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 21 December 2017

Student

(Name, Surname of the Student)

(Signature, date)

Supervisor

(Position, Name, Surname)

(Signature, date)

Mazahir, Huseynov. Analysis of Corrosion Resistance Properties and Control Process of Steel Structures. *Master's Final Project* / supervisor assoc. prof. dr. Antanas Čiuplys; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Mechanical Engineering, Technological Sciences.

Keywords: *Corrosion protection, Corrosion control, Protective coatings, Passivation, Structural steel.*

Kaunas, 2018. 51 p.

SUMMARY

Nowadays, the increasing number of failed projects due to the corrosion lead people to take preventative measurements against corrosion process. Many scientific studies and testing methods have been carried out about the corrosion but still, people are facing some difficulties to prevent the degradation process of metals. Such studies play a crucial role in understanding the corrosion mechanism and finding possible solutions to corrosion process.

The project mainly consists of three parts, including literature review, experimental and conclusion parts. The main objectives of the project are to investigate the corrosion deeply, analyze the effects of corrosion and find possible solutions to detected problems due to the corrosion process. In order to implement these objectives, the scientific investigations and the experimental methods, such as salt spray and passivation test have been carried out in different libraries and laboratories. Additionally, the preventative and protective ways of corrosion process have been suggested in conclusion part.

Mazahir, Huseynov. Plieno Konstrukcijų Atsparumo Korozijai ir Kontrolės Proceso Analizė. Magistro baigiamasis projektas / doc. dr. Antanas Čiuplys; Mechanikos inžinerijos ir dizaino fakultetas, Kauno technologijos universitetas.

Mokslo kryptis ir sritis: Mechanikos inžinerijos, Technologijos mokslai.

Reikšminiai žodžiai: *Apsauga nuo korozijos, Korozijos kontrolė, Apsauginės dangos, Pasyvacija, Konstrukcinis plienas.*

Kaunas, 2018. 51 p.

SANTRAUKA

Šiuo metu vis daugiau nesėkmingų projektų dėl korozijos verčia imtis prevencinių būdų apsaugoti plieno konstrukcijas nuo korozijos. Dauguma mokslinių bei teorinių tyrimų ir įvairių metodų buvo įgyvendinti ieškant antikorozinių dangų, tačiau vis dar susiduriama su tam tikrais sunkumais, norint išvengti metalų degradacijos procesų. Tokie tyrimai atlieka esminį vaidmenį, kad būtų suprastas korozijos mechanizmas ir rasti galimi korozijos apsaugos sprendimai.

Projektą sudaro šios dalys: įvadas, literatūros apžvalga, eksperimentinė dalis, rezultatų aptarimas, išvados ir rekomendacijos, literatūros sąrašas bei priedai. Pagrindiniai projekto tikslas – detaliai ištirti korozijos procesus, korozijos padarinius ir rasti galimus problemų sprendimus. Norint įgyvendinti šiuos tikslus, buvo atlikti teoriniai tyrimai bei moksliniai eksperimentai, siekiant išsiaiškinti kokie metodai padeda geriau apsaugoti metalo paviršinius sluoksnius nuo korozijos. Išvadose ir rekomendacijose buvo pasiūlyti prevenciniai sprendimai siekiant išvengti korozijos.

Table of Contents

INTRODUCTION	8
1. LITERATURE REVIEW	10
1.1 CORROSION.....	10
1.2 TYPES OF CORROSION	11
1.2.1 General corrosion	11
1.2.2 Localized corrosion	11
1.3 FACTORS AFFECTING RATE OF CORROSION	15
1.4 CORROSION DETECTION TECHNIQUES	16
1.5 METHODS OF PROTECTION AGAINST CORROSION.....	18
1.6 PROTECTIVE METALLIC COATING	20
1.6.1 Methods of applying protective coatings on steel structures.....	21
1.6.2 Types of protective metallic coating for corrosion.....	22
2. EXPERIMENTAL PART	24
2.1 MATERIALS AND METHODS	24
2.1.1 Preparation of samples.....	24
2.1.2 Properties and application of structural steel.....	25
2.1.3 Applications of structural steel	27
2.2 SALT SPRAY TEST	28
2.3 PASSIVATION TEST	31
3. RESULTS.....	34
3.1 SALT SPRAY TEST	34
3.1.1 Penta color test results	35
3.1.2 Hammerite test results	36
3.1.3 Ferox test results.....	37
3.1.4 Normal sample test result	37
3.2 PASSIVATION TEST	39
3.2.1 Acetone test results.....	39
3.2.2 Tosol test results	40
3.2.3 Autoserio test results	40
3.2.4 Defender (engine oil) test results.....	41
3.2.5 Distilled water test results.....	42
3.2.6 Hammerite (outside) test results	43
3.2.7 Penta colour (outside) test results	44
3.2.8 Normal sample (outside) test results	45
CONCLUSIONS AND RECOMMENDATIONS	47
REFERENCES	49
APPENDICES	52

INTRODUCTION

Corrosion leads to huge irrecoverable losses of metals, about 10% of the iron is destroyed every year. The destruction of metal structures, agricultural and transport machinery, industrial equipment is the cause of downtime, accidents, deterioration in product quality. Accounting for possible corrosion leads to increased costs of metal in the manufacture of high-pressure apparatus, steam boilers, metal containers for toxic and radioactive substances, etc. This increases the total loss of corrosion. Considerable resources must be spent on anticorrosion protection. In industrially developed countries, the damage from corrosion reaches 4% of the national income.

Problems of corrosion are constantly exacerbated due to the continuous increase in the production of metals and tougher conditions for their operation. The environment in which metal structures are used becomes more and more aggressive, including through contamination. Metal products used in engineering work in conditions of ever higher temperatures and pressures, powerful flows of gases and liquids. Therefore, the issues of protecting metal materials from corrosion are becoming more urgent. Completely prevent corrosion of metals is impossible, so the only way to combat it is to find ways to slow it down.

The problem of protecting metals from corrosion arose almost at the very beginning of their use. People tried to protect metals from atmospheric exposure by means of fat, oils, and later by coating with other metals. In the works of the ancient Greek historian Herodotus (5th century) there are already references to the use of tin to protect iron from rusting. Currently, the fight against corrosion is conducted in several directions at once - trying to change the environment in which a metal product works, to affect the corrosion resistance of the material itself, to prevent contact between the metal and aggressive substances of the external environment.

Completely prevent corrosion is possible only in an inert environment, for example, in an argon atmosphere, but it is impossible to create such an environment in the operation of structures and mechanisms in most of cases. In practice, to reduce the corrosive activity of the medium, the most reactive components are stripped from it, for example, reduce the acidity of aqueous solutions and soils with which metals can contact. One of the methods to combat the corrosion of iron and its alloys, copper, brass, zinc, lead is the removal of aqueous solutions of oxygen and carbon dioxide. In energy and some branches of technology, water is also released from chlorides, which stimulate local corrosion. Liming is used to reduce the acidity of the soil.

The aggressiveness of the atmosphere depends heavily on humidity. For any metal, there is some critical relative humidity below which it is not exposed to atmospheric corrosion. For iron, copper, nickel, zinc, it is 50-70%. Sometimes for the preservation of products of historical value,

their temperature is artificially maintained above the dew point. In closed spaces, humidity is reduced with silica gel or other adsorbents.

Corrosion processes are irreversible and often lead to failures of various machines and apparatuses, metal structures so, they must be detected in the initial stages, and quantitative assessment of corrosion damage must be done.

Main aim and objectives

The main aim of this project is to investigate the possible solutions to corrosion process of steel and develop a corrosion control plan for the prevention and protection from the negative effects of corrosion process on steel structures. This aim can be achieved through the following scientific and technological objectives:

1. Investigate the main factors, which affect the rate of corrosion;
2. Carry out salt spray test to reveal the best protection method for corrosion;
3. Carry out passivation test to determine whether the product is suitable for use in a different environment;
4. Reveal the reduction ways and methods to eliminate negative effects of corrosion.

1. LITERATURE REVIEW

1.1 CORROSION

Corrosion is the process of natural destruction of metal because of chemical interactions with the environment. The environment in which the destruction of metals occurs is called corrosive. Chemical compounds formed because of corrosion, are called corrosion products. The ability of metals resists corrosion of the air is called corrosive resistance. Corrosion of metals is classified according to the mechanism and situation. The process and the nature of the corrosion failure according to the mechanism of corrosion process, depending on the nature of the external environment with which the metal interacts, distinguish between chemical and electrochemical corrosion. Chemical corrosion is typical for dry gas media and liquid form that do not conduct electrical current (gasoline, alcohol,). In the case of chemical corrosion, such interaction occurs and corrosive medium, in which the oxidation of the metal and the formation of an oxidized component of the corrosive medium flow in one act. This is a process which called heterogeneous chemical reaction.



Fig. 1.1 Corrosion process on metal [1]

1.2 TYPES OF CORROSION

There are mainly two types of corrosion of metals: **general and localized**. In both cases, the destruction of steel occurs due to its interaction with external circumstance.

1.2.1 General corrosion

General corrosion is distinguished by the fact that corrosion covers the entire surface of a metal sheet, destroying it almost entirely. This kind of corrosion is quite easy to control and evaluate. General corrosion is assumed to be a most common form of corrosion and particularly responsible for most the materials loss. However, it is not recognized as a dangerous form of corrosion, because:

- Prediction of thickness reduction rate can by means of simple tests. Corresponding corrosion allowance can be added taking into account strength requiring and lifetime.
- Available protection methods are usually so efficient that the corrosion rate is reduced to an acceptable level. Actual methods are the application of coatings, cathodic protection or possibly a change of environment or material.



Fig. 1.2. General corrosion [2]

1.2.2 Localized corrosion

Localized corrosion is mainly concentrated on some parts of the surface of the material. This is a more dangerous type of rusting since it has a significant depth, which leads to the failure of the product. This type of corrosion mainly appears as a result of mechanical damage to the surface of the steel product and occurs in areas that are very difficult to inspect.

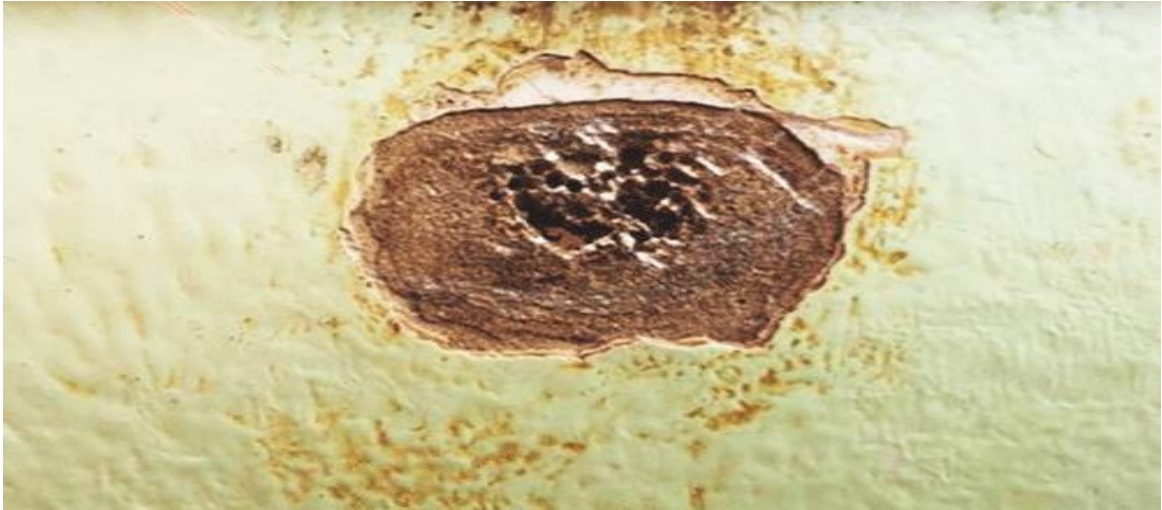


Fig. 1.3. Localized corrosion [3]

1.2.2.1 Pitting corrosion

In Pitting corrosion, the destruction of the metal starts from its surface and extends deep into the product, usually along the grain boundaries. This type of corrosion significantly reduces the load-carrying capacity of steel and causes brittleness of the metal. Pitting corrosion is often encountered in practice and it is also very dangerous in main industries. In pitting corrosion, rusting usually occurs after heat treatment or welding process of metals.



Fig. 1.4. Pitting corrosion [2]

Types of pitting corrosion

Through Pit

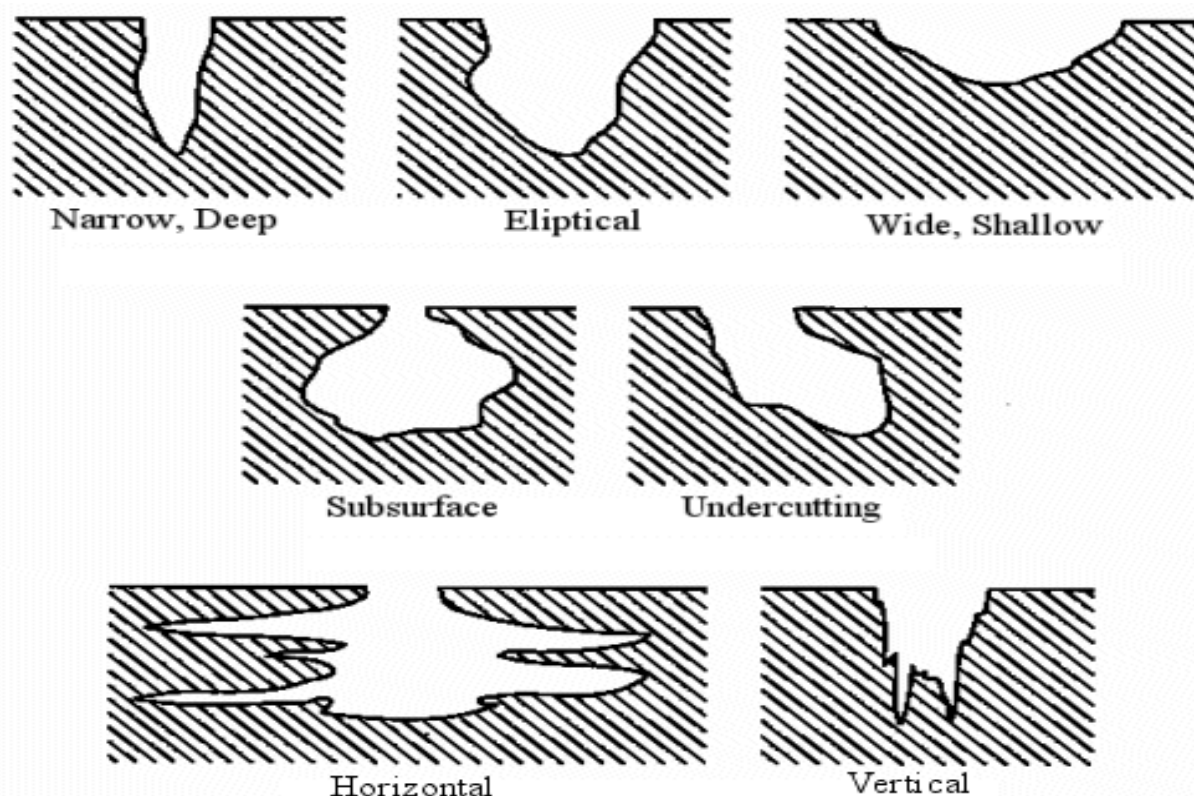


Fig. 1.5. Standard visual chart for rating of pitting corrosion [4]

1.2.2.2 Crevice corrosion

Crevice corrosion is one of the types of localized corrosion. Crevice corrosion indicates increased corrosion damage in cracks, gaps (flanged, joints, or other cushioning materials). Crevice can occur either in an atmosphere of air or a gas mixture or under wetting conditions with electrolyte (sea water). Mostly, in the marine atmosphere, the crevice corrosion is observed in the crevices and gaps between the metal and the fouling organisms (algae, polyps, various microorganisms). At atmospheric crevice corrosion in gaps and crevices is constantly accumulated and retained, which causes its flow. Crevice corrosion is commonly called enhanced corrosion damage to metal structures in the slots and gaps between metals as well as in places of loose contact metal with materials, and in marine conditions.



Fig. 1.6. Crevice corrosion [2]

Other forms of corrosion

According to the conditions of corrosion, there are the following types:

- Uniform - the corrosion process starts at the surface and continues uniformly.
- Transgranular or intragranular - The grain boundary material is maintained, but the corrosion proceeds within the grain.
- Galvanic - Mainly occurs in deformed materials
- Gas - corrosion of steel at high temperatures in gases.
- Atmospheric - corrosion of various structures of metal in the air.
- Contact - electrochemical destruction of steel, occurring during the contact of several metals in the electrolyte.
- Biocorrosion - corrosion of steel under the influence of products released by microorganisms.
- Electrolytes - is a process that takes place in a liquid form that conducts electricity.
- Corrosion in non-electrolytes (an example is the corrosion of metals in gasoline).
- Electrocorrosion or corrosion by external current (an example is the corrosion of a subterranean tube under the influence of stray currents).
- Corrosion in friction; an example is a destruction when the shaft neck rotates in seawater.
- Corrosion under stress, which changes in sign and value, which often causes a decrease in the endurance of the metal - corrosion fatigue.

1.3 FACTORS AFFECTING RATE OF CORROSION

The mechanism of corrosion is damaged by additional factors, such as the existence of oxygen and elevated temperature, which can significantly affect the destruction of the material. Below is a brief overview of the impact of these factors. These factors are:

- **Oxygen:** The most important element contained in tap water, which leads to corrosion, is atmospheric oxygen. It can be dissolved in water in an amount up to 10 mg / dm³. Its presence should be paid special attention to water saturated with oxygen, and ozonized water, as ozone artificially saturates the water with oxygen and as a result, water becomes more aggressive. The onset and continuation of the corrosion reaction depend mainly on the aggressive elements contained in water, which oxygen is the most common cause of the processes of metal corrosion. Dissolved oxygen reacts with hydrogen present in the cathode area of the corrosion surface.
- **Humidity (or wetness):** Humidity and time-of-wetness play a significant role in promoting and accelerating corrosion rates. Time-of-wetness refers to the length of time an atmospherically exposed substrate has sufficient moisture to support the corrosion process. The wetter the environment, the more corrosion is likely to occur. Rain also may have a beneficial effect in washing away atmospheric pollutants that have settled on exposed surfaces. This effect has been particularly noticeable in marine atmospheres. On the other hand, if the rain collects in pockets or crevices, it may accelerate corrosion by supplying continued wetness.
- **Chemical salts:** Chemical salts are estimated as the main result of corrosion processes of metals. It fact that the chemical salts influence the rate of corrosion by growing the effectiveness of the electrolyte. The most familiar chemical salt is sodium chloride, which is a major element of sea-water. Sodium chloride placed on atmospherically subjected surfaces and behaves as a hygroscopic material which then grows the corrosion rate in non-saturated areas.
- **Pollutants and acid gases:** Acid rain and chlorides increase corrosion rate. Acid gases, such as carbon dioxide, can also dissolve in a film of dampness in contact with the metal. In addition to the direct effect of the chemical attack, these materials decrease the electrical resistance of the electrolyte. Reduction of resistance in the corrosion cell permits higher corrosion currents so enhanced the corrosion rates. Corrosion is the degradation of engineered materials in contact with a corrosive environment. The corrosive environment is usually defined by the characteristics of the electrolyte.

- **Temperature:** In general, a rise in temperature means an energy supply that leads to increased dissociation, and as a result, ion motion also increases. This contributes to a general increase in the reaction rate, and, consequently, an increase in the corrosion rate of the metal. When the temperature is increased by 1 K, as a result of increased dissociation, the pH value decreases by 0.01, which increases the effect of corrosion. The concentration of hydrogen ions, even in neutral water, is about 6.12×10^{-8} at 100°C , compared with 7.46×10^{-8} at 0°C . Both in the presence of oxygen and carbon monoxide in hot water make the corrosion rate increase.



Fig. 1.7. Marine + high humidity environment [2]

1.4 CORROSION DETECTION TECHNIQUES

A variety of environmental conditions requires the use of various means to determine corrosion resistance in different cases, both laboratory testing and practical tests. Each method of corrosion testing should be based on this fundamental view of the mechanism of corrosion of steel.

In the most general form, the practical purpose of a corrosion test can be expressed as determining the longevity of a given metallic material under given conditions. The results of corrosion tests should provide an opportunity to make a conclusion about the corrosive behavior of a metal or alloy under operating conditions.

In more detail, the problems of corrosion testing can be characterized as follows:

1. Disclosure of the mechanism of the corrosion process, which can be general, localized.
2. The establishment of an aggressive component of the external environment that causes the general destruction of the metal, or a responsible for the localized corrosion of the metal.
3. Determining the influence of the main internal and external factors on the corrosion resistance of a metal.
4. Choosing the best metal for use under certain operating conditions. In this case, it is necessary to take into account not only the corrosion resistance of the material but also its strength, technological properties, cost and etc.
5. Comparison of corrosion activity of media with respect to one or several metallic materials.
6. Verification of methods for protecting metals from corrosion: determining the effectiveness of anti-corrosion protection, the use of corrosion inhibitors or electrochemical protection, checking the reliability of protective coatings, etc.
7. Quality control of the products with respect to corrosion resistance, for example, control of steel structures for lack of strength to pitting corrosion, quality control of protective coatings, etc.

The complexity and variety of the corrosive environment and corrosion conditions make it necessary to develop a system of research and test methods that would answer the questions posed by theory and practice.

The formulation of the following requirements for the method:

1. The method must meet the stated goal. The simplest and shortest way is to give the method a solution to the problem. If the method proves too complicated, it is necessary to differentiate the problem into a number of simpler ones and create an appropriate system of methods.
2. The method should correspond to modern ideas about the mechanism of corrosion, which must be at the modern level of science.
3. The method should provide an opportunity for strict control of all factors. Only under this condition can obtain reproducible results, hence the requirement of comparative simplicity of the method.
4. The method should reproduce exactly the kind of corrosion that is practically important for a given material. For example, stainless steels in practical conditions when operating in humid air and in neutral or slightly acidic brine solutions often exhibit either pitting or crevice failure. If the test method is constructed in such a way that corrosion of stainless steel will be uniform, then such a method will not be practically usable.

5. The method should provide the possibility of comparatively simple interpretation of test results, even if they were not direct, that is, they did not directly represent the amount of metal destroyed by corrosion from unit area per unit time. This possibility appears only if the method is built on a solid scientific basis, which is in accordance with the theory of corrosion processes.

According to the general nature of research, these methods are divided into three groups:

1. Laboratory studies - corrosion tests of metal samples in the laboratory, artificially created conditions;
2. Non-laboratory studies - corrosion studies of metallic samples under natural, operational conditions (including research under natural conditions: in the atmosphere, in the sea, in the ground, etc.);
3. Operational research - testing of machines, apparatus, structures and protective equipment under operating conditions. Thus, their object-samples are common for laboratory studies, but they differ in the conditions of research, while the general conditions for non-laboratory and operational research are their conditions, and they differ in the object of research. Usually, laboratory tests are carried out first, then non-laboratory tests and the last ones are operational tests.

According to the duration of research methods are divided into two groups:

1. Long-term - appropriate for the duration of the operational conditions.
2. Accelerated - conducted in artificial conditions, accelerating the corrosion processes occurring under operating conditions. The acceleration of testing is usually achieved by facilitating the flow of controlled processes, but without changing the nature of the corrosion process.

1.5 METHODS OF PROTECTION AGAINST CORROSION

Methods for protecting metal structures from corrosion are based on targeted impact, resulting in a full or partial reduction in the activity of factors contributing to the development of processes. They can be conditionally divided into methods of action on the metal and ways of influencing the environment, as well as combined methods. The most reliable method of protection against corrosion is the preparation of building structures, machine parts, apparatus and equipment from corrosion-resistant, both metallic and non-metallic materials. However, this method of protection is not always used because of economic, technical or technological reasons. Therefore, building structures, whether machines and aggregates are made from cheap and affordable materials. Among the most common methods of protection of metal structures from corrosion is the application of paint and varnish coatings. The most widely used paint and varnish anticorrosive coatings that

have undeniable advantages, such as pre-application, the possibility of coating almost unlimited areas of any structures, as well as cheapness.

Another way in the prevalence of application is the creation of corrosion-resistant materials by various methods of external effects on the metal. The methods of action on a metal include electrochemistry protection and several types of coatings created on top of the of the protected product. When electrochemical protection to metal structure connect an anode that causes the surface of the protected metal to be a cathodic field. As a result, the anodic sections of the metal structure turn into cathode ones. This means that there will be a breakdown that is not a metal structure, but it is a connected anode. Methods of action on metal include protective coatings. Essentially, a significant number of protective coatings are divided into metal and non-metallic. Regardless of their type, the protective coating should be continuous. impervious to aggressive media, have a high adhesion to the metal and have high corrosion resistance. The application of protective metal coatings is one of the most effective methods of protection against corrosion. These coatings do not only protect the metal from corrosion but also ensure a surface with a higher property, hardness, strength, wear and corrosion resistance. By the protective effect method, the metal coatings divided into anodic and cathodic. Cathodic coatings have a more positive, but anodic has more electronegative potential in comparison with the potential of the metal for which they are applied. It should be noted that the type of coverage depends on not only nature of metals but also the composition of the corrosive medium. In cases where the application of protective coatings is not ensured necessary protection, a decrease in the corrosion rate can be achieved with the help of inhibitors. The inhibitors are the substance that the small addition to the corrosive medium is reducing the corrosion rate of the metal. It is removed by removing substances that enhance the rate of the corrosion, the introduction of ecologically safe inhibitors into the environment and speed of corrosion processes.

Anode inhibitors are often called passivators since their action is based on the passivation of the anodic areas of the corroding surface. Cathode inhibitors decrease the corrosion rate by reducing the efficiency of the cathode process or reducing cathode sections. It should be kept in mind that in addition to affecting the design, it can also have a significant effect on the corrosive environment, which creates a significant obstacle in the way of using this method in the de chemical industries. It should be noted that the protection option for a particular object should be selected based on an analysis of the situations of its operation. When this should take into account the requirements for indicators that characterize the necessary quality of the facility, technological application of the chosen method of protection and at the same time, the economic effect.

1.6 PROTECTIVE METALLIC COATING

The protective coating is extremely important to protect steel structures from degradation process. Protective coatings are used in anticorrosive practice to insulate the metal from aggressive media. To provide good protection against corrosion, the coating should be continuous, have good adhesion to the base metal, be waterproof to aggressive media have high wear resistance, heat resistance, and hardness. Protective coatings are very common because they do not only protect the substrate from corrosion, but also give the surface a number of important and useful properties. The protective coatings are also widely used to improve the decorative appearance of products. With the help of metal coatings, the shape and dimensions of the worn parts are restored. Protective coatings are divided into metallic and non-metallic.

Metallic protective coating

Metal protective coatings are applied to metal surfaces in order to protect them from corrosion, hardness, electrical conductivity and decorative purposes. Protection against corrosion by metal coatings is carried out in the following ways:

According to the method of protection, the metallic protective coatings are divided into cathode and anode. The nature of such protection against corrosion is due to the fact that the metal coating, with respect to the article to be coated, can be an anode or cathode.

Electrochemical corrosion protection is carried out only anode coatings. On the surface of the protected product, in the presence of moisture in the environment, a closed galvanic cell is formed. A metal with a more electronegative electrochemical potential will play the role of an anode, with the substrate being a cathode. Due to the operation of the galvanic cell, the metal, which is an anode, will gradually deteriorate under the influence of the environment, thereby protecting the product. When protecting against corrosion with the help of anodic coatings, an important aspect can be considered that the metal coating will be protective even if there are pores and scratches on it. A good example of an anodic coating is a zinc coating.

Protection against corrosion by cathode coatings is less frequent since the cathode coating protects the product only mechanically. The cathode protective coating has a more positive electrode potential. At the same time, the base metal of the product is an anode and, when the moisture is supplied to it, intensive dissolution begins. That is why the cathode coating should be continuous, without the slightest signs of pores and, preferably, uniform, relatively large thickness. An example of a cathodic coating is a tin or copper continuous layer of the steel.

Non-metallic protective coatings

Non-metallic protective coatings are used for the insulation of metal products, their protection from the influence of the external environment, giving a beautiful appearance. Non-metallic protective coatings are usually divided into paint and varnish and polymer coatings.

Paint and varnish protective coatings are widely used in the world. The coating composition includes film-forming substances, fillers, pigments, plasticizers, solvents, catalysts. Coverage of this kind not only protects the product well in different atmospheres but also gives it a pleasant appearance. In addition, varying the composition and materials used, they receive coatings with specific properties. Paint and varnish protective coatings, are divided into varnishes, paints, enamels, primers, varnish, and putties.

Polymer protective coatings are applied to the surface of the product in the form of hot resin to protect it from the external environment. The resin coating can be carried out by dipping, gas-thermal or vortex spraying, as well as with a normal brush. After cooling, a protective continuous film of polymer is formed on the surface, usually a couple of millimeters thick. The most common polymers used to protect against corrosion are polystyrene, polyethylene, polypropylene, polyisobutylene, epoxy resins, etc.

1.6.1 Methods of applying protective coatings on steel structures

There are several methods for applying metal coatings on the metal surface of parts, including dipping method, roller application method, and spray application.

Dipping method is applied to the film, immersing the part in a bath with a protective coating. Dipping coating method is applied to finished products. In aircraft structures, this method is most often used for tinning electrical wires. A significant drawback of this method is the impossibility of obtaining a guaranteed coating thickness, as well as a large consumption of the deposited coat.

The roller application is used to protect the corrosion of the base metal or alloy with a protective coating that is sufficiently resistant to the environment. The connection between the metals of the coating and the substrate is obtained by rolling. A thin sheet of the protective coating is applied to the base sheet by rolling.

Spray application. A molten protective coating is sprayed onto the base metal by means of an air jet. Protecting metal from corrosion by spray application methods is one of the most reliable ways to prevent corrosion of steel. The protective properties of zinc, aluminum or their alloys guarantee anti-corrosion protection for at least 20 years. Electric arc metallization can be carried out both in the conditions of stationary production and after installation or during the repair of metal structures.

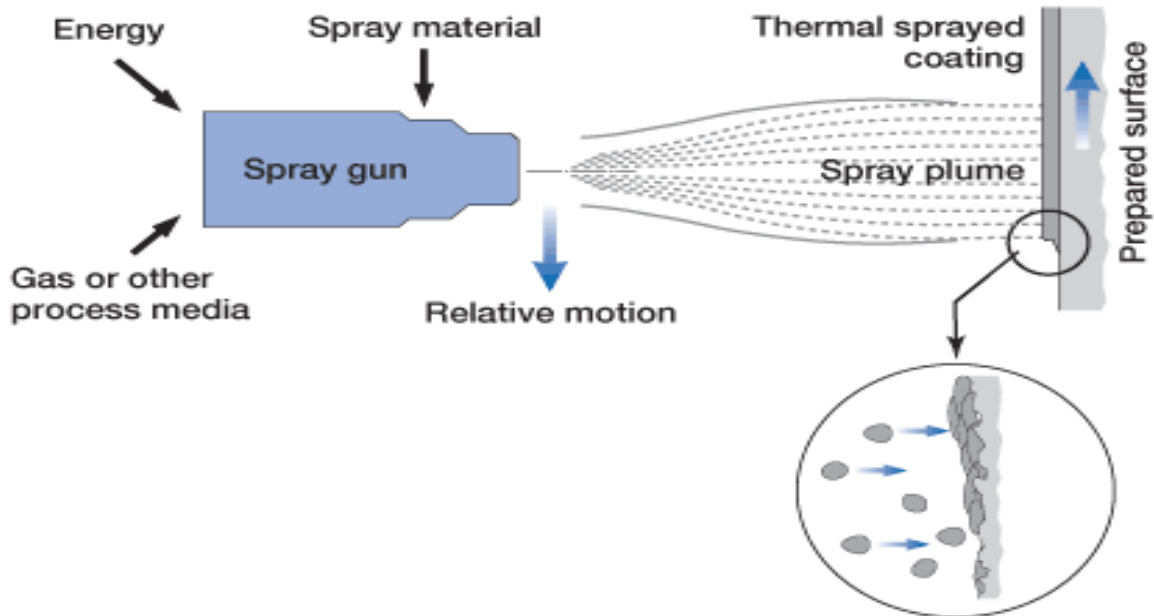


Fig. 1.8. Coating application by spray method [5]

1.6.2 Types of protective metallic coating for corrosion

The type of protective metal coating should be chosen with an exact account of the conditions in which the metal to be protected will be located. There are mainly five types of metallic coating, such as galvanic, epoxy, zinc, cadmium and aluminum.

Zinc coating gives an opportunity to obtain anodic zinc coating. Wide application of such a coating is due to the cheapness of zinc. There are a large number of electrolytes used for galvanizing. However, in all cases, these zinc salts are used. Zinc coatings have satisfactory surface hardness, wear, and water resistance, bending strength. The durability of galvanized pipes depends on the thickness of the coating. For commercially available pipes per m², 400 g of zinc are consumed, the thickness of the coating is 43 - 46 μm . Domestic industry produces galvanized water and gas pipes with a diameter of 10 - 159 mm, length up to 8 m.

The epoxy coating allows to obtain high hardness of coating, low coefficient of friction, high wear resistance, and corrosion resistance. Despite the fact that epoxy refers to electronegative metals, it can be strongly passivated, due to what it acquires the properties of noble metals.

The galvanic coating has several advantages compared to others. Galvanic coatings are characterized by good chemical and mechanical properties. It has some advantages, such as increased wear resistance and hardness, low porosity, high corrosion resistance. Some metals can be coated with this paint only so, it has become quite widespread.

The cadmium coating is used to protect against corrosion of ferrous metals. Cadmium is chemically more stable than zinc. However, if the zinc coating is almost always anodic, then cadmium can change its character. Under certain conditions, it can be anodic, while for others it can be cathodic. The cadmium coating is rather plastic, which has determined its application to protect parts of threaded joints from corrosion. One of the main drawbacks of cadmium coating is that, when it meets various lubricant and fuel materials containing sulfur compounds, as well as some plastics that release gaseous products, cadmium breaks down quite quickly. That is why the cadmium parts in the aircraft industry are not used in fuel systems.

The aluminum coating is applied by hot aluminizing in melts, by cladding steel sheets and by spraying in a vacuum. For steel parts with an aluminum coating, a combination of high strength and corrosion resistance is characteristic. Corrosion resistance of steel parts with the aluminum coating is due to the high protective properties of the surface, which a thickness less than 0.1 μm . This oxide layer has a high density and, if damaged, quickly re-forms. The protective action of an aluminum oxide film on an aluminum coating is particularly pronounced in high-temperature heating. Aluminum coatings are stable in aqueous solutions of aggressive food media and organic acids. Non-toxicity, inertness to many media, good priming properties for the subsequent application of polymer and glass-enamel coatings cause a wide application of aluminum coatings in different branches of engineering.

2. EXPERIMENTAL PART

2.1 MATERIALS AND METHODS

According to ASTM standards, materials used in the industry should pass different mechanical qualifying test in order to be allowed to be used in industry. These tests determine the properties of the material and check if these properties are according to standards specifications. For testing, standard test methods should be used for the result obtained to be comparable.

2.1.1 Preparation of samples

The samples were too big to start the corrosion testing. Thus, it was decided to make them suitable for testing by cutting into some pieces. The material was cut to the desired size (diameter = 40 mm, thickness = 5mm) by using the lathe machine in the workshop.

The surface was very rough after cutting process. Thus, the surface smoothed by using a grinding machine. This process was necessary to avoid the rough surface for getting accurate results.

After the testing process, ZEISS Axio metallographic microscope was used to analyze all the samples, which exposed to corrosion testing. According to the types of detected corrosion, three modes of magnification were used, including 5x, 20x and 50x during the experiment.



Fig. 2.1. ZEISS Axio Metallographic Microscope

2.1.2 Properties and application of structural steel

Structural steel is a standard building equipment, made of a certain grades of steel and formed in a number of industry standard. Structural steels are designed with special chemical structures and mechanical characteristics prepared for application.

There are lots of patterns of structural steel, such as; S195, S235, S275, S355, S420, S460 and so on. According to the European Standard classifications, structural steels must be made using the standard symbol, such as S235, J2, K2, C, Z, W, JR, JO. [6]

Where:

S – shows that it is Structural Steel

235 – related to the minimum yield strength of the steel

J2 / K2 / JR / JO – steel hardness

W – Weathering Steel

Z – steel with advanced power

C – Cold-formed

Table 1. US Equivalent Grades [6]

EU	US
S235	A283C
S275	A570Gr40
S355	A572Gr50

Mechanical properties of steel - S235, S275, S355

These types of structural steel have excellent mechanical properties, which makes it possible to widely use it for the production of construction and industrial steel structures, including those having welded joints. The metals can boast excellent weldability, so it can be used to create complex welded structures with almost no restrictions. Mechanical properties of structural steel consist of two parts: Yield Strength and Tensile Strength.

Yield strength

Yield limit is the mechanical characteristic of the material, characterizing the stress at which deformations continue to grow without increasing the load. The yield point sets the boundary between the elastic and elastic-plastic deformation zones. Even a slight increase in stress (load) above the yield point causes considerable deformation.

Table 2. Yield Strength of Structural Steel [6]

Structural Steel Grade at 16mm	Minimum Yield Strength at minimum thickness 16mm	
	ksi	N/mm ² (MPa)
S235	33 000 ksi	235 N/mm ²
S275	36 000 ksi	275 N/mm ²
S355	50 000 ksi	355 N/mm ²

Tensile strength

The tensile strength of structural steel is a voltage corresponding to the maximum load that the material can withstand to break. The tensile strength is a material characteristic that is not only important when loaded on a train. It states how strong a material is a maximum load. If the value of the tensile strength is exceeded, the material fails. It should be noted that the material deforms permanently even before the tensile strength is reached. For the mechanical design of components and constructions, the minimum value or the guaranteed value of the tensile strength is relevant. This value is used for the strength calculation.

Table 3. Tensile Strength of Structural Steel [6]

Structural Steel Grade	Tensile Strength MPa at Nom thickness between 3mm and 16mm
S235	360 – 510 MPa
S275	370 – 530 MPa
S355	470 – 630 MPa

Chemical properties of steel - S235, S275, and S355

The chemical composition of the structural steel is necessary for the construction process. It is the main element, that clarifies the mechanical characteristics of the material.

Table 4. Chemical Composition of Structural Steel [6]

Grade	C%	Mn%	P%	S%	Si%
S235	0.22 max	1.60 max	0.05 max	0.05 max	0.05 max
S275	0.25 max	1.60 max	0.04 max	0.05 max	0.05 max
S355	0.23 max	1.60 max	0.05 max	0.05 max	0.05 max

2.1.3 Applications of structural steel

The s235 alloy is actively used in general construction solutions. Produce parts and parts of freight cars, power line supports, excavators and forestry equipment, marine structures, automobile bridges, building structures, oil and gas platforms are mainly produced from the structural steel s235. It is irreplaceable material in the production of dump trucks, lifting equipment, bulldozers and railway wagons, pipelines, equipment and machinery in the energy and engineering industries, fans, pumps, lifting devices. Steel is produced with a thickness of 8 mm-300 mm, a width of 1500-4020 mm, a length of 3000-27000 mm. Finished products, brand s235, is supplied in the form of flat and long products and blanks intended for further processing in sorted or figured rolled products. The mechanical properties of steel, chemical composition, types of treatment and uses are regulated by the European standard EN 10025-2: 2004.

These are the main application areas of general structural steel: railways, appliances, factories, warehouses, stadiums, bridges and airports.

2.2 SALT SPRAY TEST

Salt is the most common type of compounds in the world. It can be found in the ocean, in the atmosphere, on the surface of the earth, as well as in rivers and lakes. The salt has an enormous impact on all the things around us. Therefore, carrying out the corrosion test for many fields of manufacturing is preferable, and for some fields are a necessity.

Salt spray test is one of the most widespread and long-established corrosion test methods. The salt spray test is the standard and an accelerated way for testing the corrosion resistance and surface coating of metals. The test is very helpful in deciding whether there is a requirement for a preventative measure or anti-corrosive prevention on steel parts. The testing specimens are exposed to an abrasive atmosphere to determine suitability for use. The salt spray test was carried out according to the ASTM B117 standard which was the first internationally recognized salt spray standard.

Stuff required

- Testing sample (four pieces)
- Testing cup (four pieces)
- Distilled water
- Sea salt
- Penta color (epoxy based protective coating)
- Hammerite (zinc-based protective coating)
- Ferox convertiruggine (metal surface protective material)
- Sandpaper
- Paint brushes (two pieces)
- Acetone

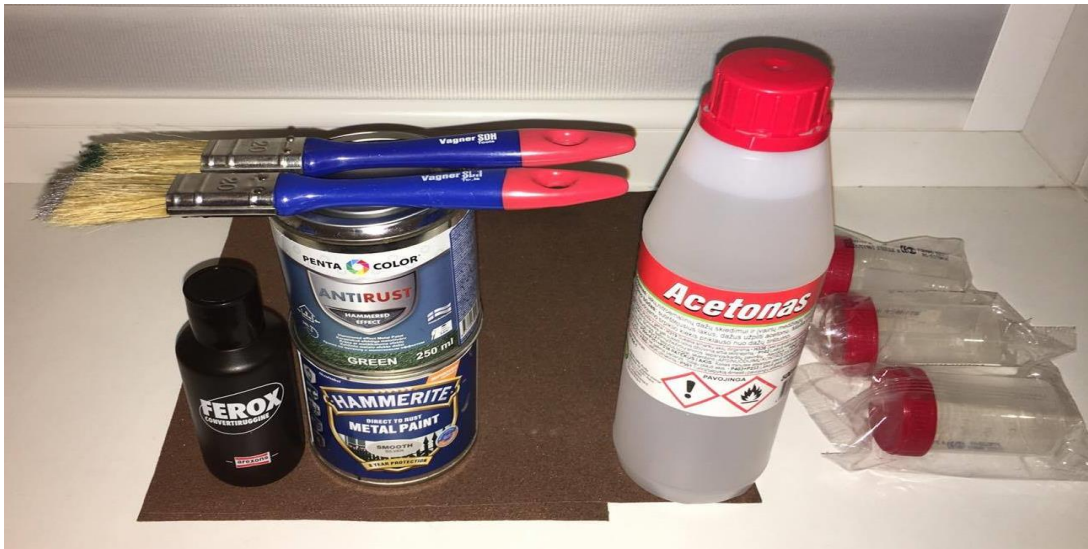


Fig. 2.2. Required stuff for salt spray test

Procedure

At the first step, the surfaces of testing samples were polished with sandpaper. Afterwards, all the samples were kept in acetone for 24 hours for cleaning the remaining small particles from the surface.

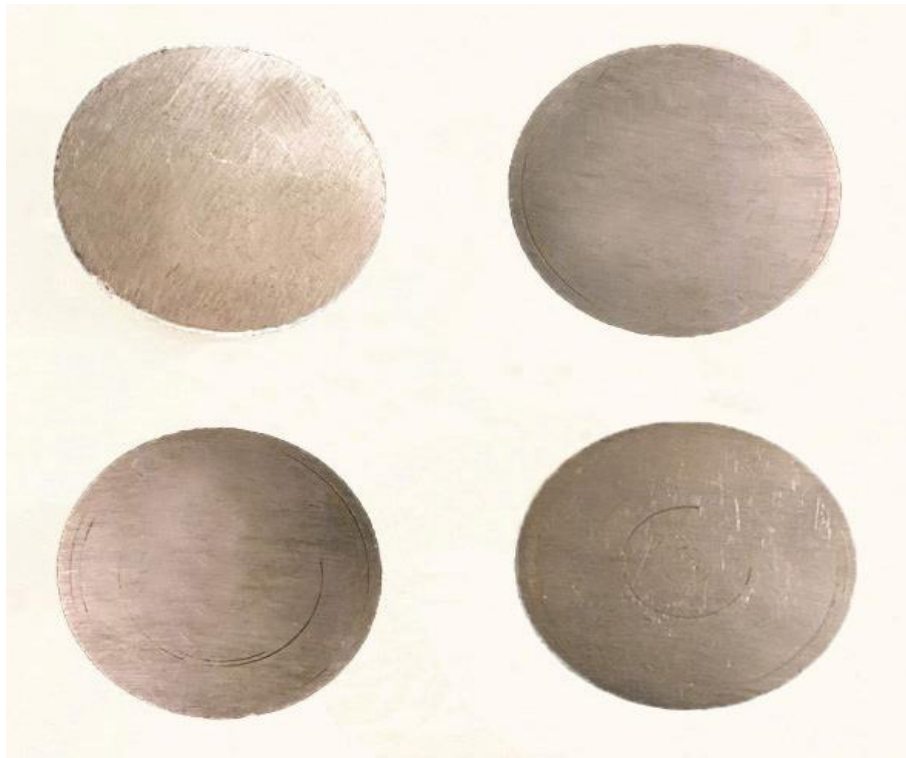


Fig. 2.3. Samples are ready for salt spray experiment

After 24 hours, the samples were dried by using a rag and then the anti-corrosive paints and surface protection liquid were applied to three different testing samples and left for drying.



Fig. 2.4. Application of Ferox and anti-corrosive paints

After the drying process, 5 mg natural sea salt was dissolved in 40ml distilled water. In each testing cup, one testing sample was placed to get more accurate results. After placing the samples in the cups, the plastic covers were used to cover cups to prevent the evaporation process of water.



Fig. 2.5. Initial step of salt spray test

After the test time was over, all the testing samples were washed with water and left for drying at room temperature for one day. Dried samples were first visually examined and then the metallographic microscope and photoshop software were used to analyze the testing samples.

2.3 PASSIVATION TEST

The passivation testing assesses the surface of steel by examining the surface passivity. The test intended to find out the best preventative method and environment, which the steel can withstand corrosion process. The test is a crucial step in assessing whether the product is suitable for outdoor use, as well as in a cold and humid environment. Stainless steel that undergoes this process may require a variety of treatments, including precleaning, chemical exposure which can be accomplished different ways. The test was carried out considering the ASTM A380 standard.

Stuff required

- Testing sample (eight pieces)
- Testing cup (five pieces)
- Distilled water
- Paint brushes (two pieces)
- Sandpaper
- Tosol (ethylene-based antifreeze)
- Autoserio (acid-based antifreeze)
- Defender (engine oil)
- Acetone
- Penta color (epoxy-based protective coating)
- Hammerite (zinc-based protective coating)



Fig. 2.6. Required stuff for passivation test

Procedure

In passivation testing, four chemicals were used for checking anti-rust properties of metals in a highly corrosive environment. Firstly, all the samples were polished by sandpaper to remove corrosion products appropriately from the metal surface and kept in acetone to remove remaining corrosion particles for 24 hours.

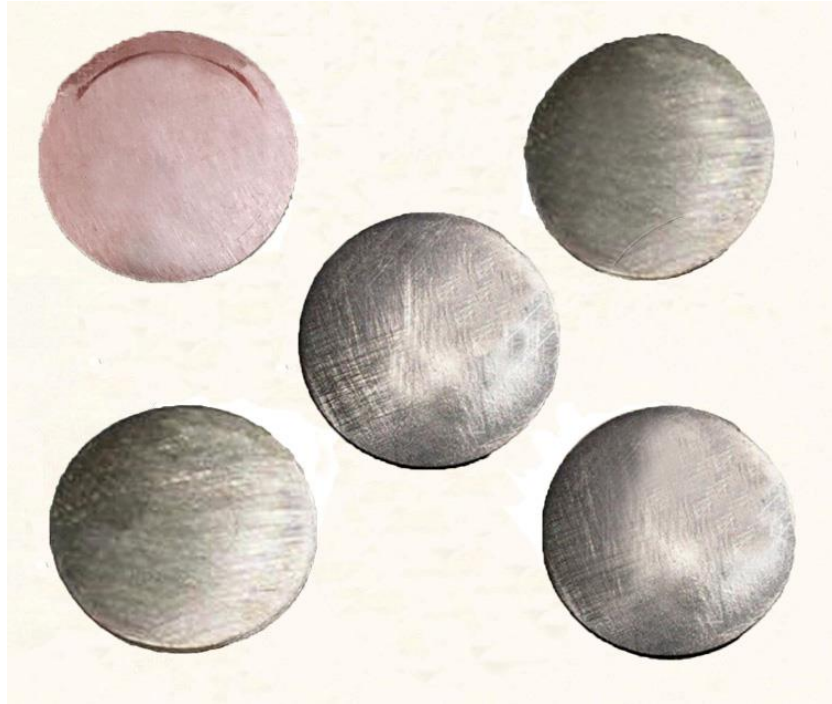


Fig. 2.7. Ready samples for passivation test

After 24 hours, all the samples were lifted from acetone, washed with water and dried by using rags. The testing cups were filled with the several types of chemicals after drying process, which are described in **Figure 2.8**.



Fig. 2.8. Chemicals in testing cups

Firstly, five testing samples were placed in the testing cups. Afterwards, epoxy-based and zinc-based protective coatings (Penta color, Hammerite) and surface protection liquid (Ferox Convertiruggine) were applied to another three samples and left in outside temperature till the end of passivation test. The plastic covers were used to cover the cups to avoid any evaporation or accidents.



Fig. 2.9. Samples in outside temperature

3. RESULTS

In this project, the results of the given testing methods divided into two parts. The first part shows the results of salt spray test with the images, which present initial, current, damaged part and metallographic microscope analysis respectively. The testing results are presented with images and in tabulated form. The second part deals with the result obtained from passivation test where results are presented with images. In this part, five testing tools, including acetone, tosol, autoserio, engine oil, distilled water were used in order to implement the test both at outside and room temperature.

All the testing specimens were exposed 180 and 360 hours of corrosion environment respectively. After all testing methods were completed, the samples were analyzed by Zeiss Axio Metallographic Microscope and Adobe Photoshop CS5 for deeper investigation. The figures consist of four parts, including initial appearance (A), current appearance (B), photoshop analysis (C) and metallographic microscope analysis (D).

3.1 SALT SPRAY TEST

In the salt spray test, the corrosion testing was performed by using several testing procedures. As a result of this test, different types of corrosion were discovered on the surface of samples. The test results were first examined visually to measure the integrity of the steel and its coating. Afterwards, testing photos were taken in order to compare the samples with each other using photoshop software and metallographic microscope.

3.1.1 Penta color test results

The image shows the initial and final appearance of the Penta color test piece after 360 hours salt-spray exposure respectively. After the accelerated corrosion exposure, the sample changed its color and contained some areas covered with grey-black corrosion particles. The epoxy-based protective coating presented a set of corrosion process on the surface. The sample demonstrates some parts of the protective coating that were completely broken down, causing the surface to rust. In addition to this, it was possible to see the characteristics of pitting which was like a growth ring formation. The coating continues to save the underlying steel in some parts, but if the testing sample would have exposed to corrosion environment more than 360 hours, it would be probably affected by corrosion process. The area calculation shows that 22% of the surface was subjected to corrosion displayed in **Figure 3.1C**.

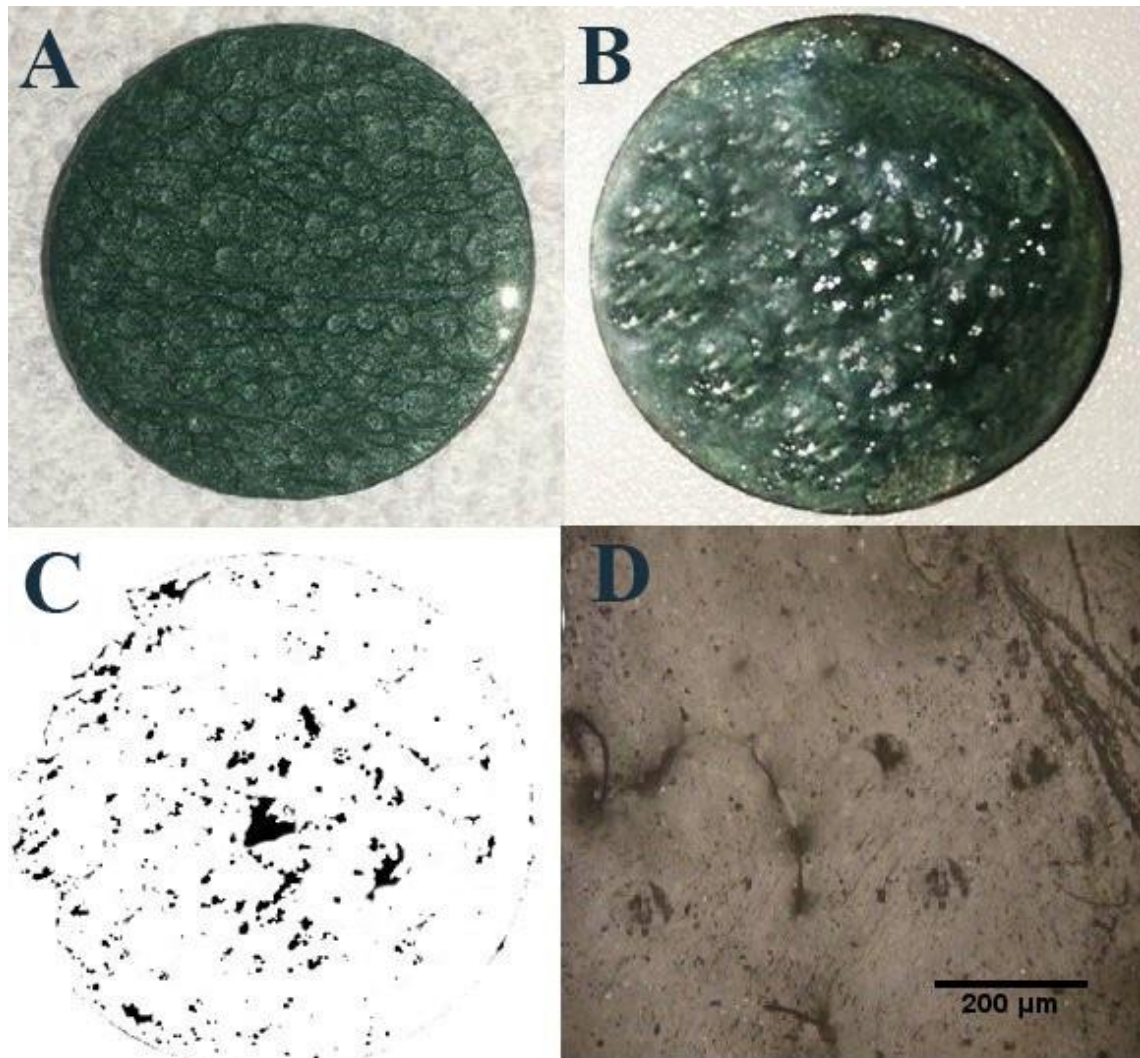


Fig. 3.1. Penta color after salt-spray test and microscope image

3.1.2 Hammerite test results

The Hammerite testing sample was also exposed to the highly corrosive environment for 360 hours. **Figure. 3.2C** shows the damaged areas of steel after salt spray exposure. The Hammerite part contains some areas of red rust, mostly near to edges and the middle of the sample. The zinc-based coated part remained quite well protected, although it has apparently broken down at edges, which allows steel to corrode. Even the corners of steel had some cracks, the surface coating was not completely damaged. This process shows that the zinc-based coating does not protect corners well. Compared to the epoxy-based coating (Penta color), the zinc-based coating (Hammerite) has less area which contains corrosion products. The area calculation indicates that 7% surface has exposed to both pitting and crevice corrosion.

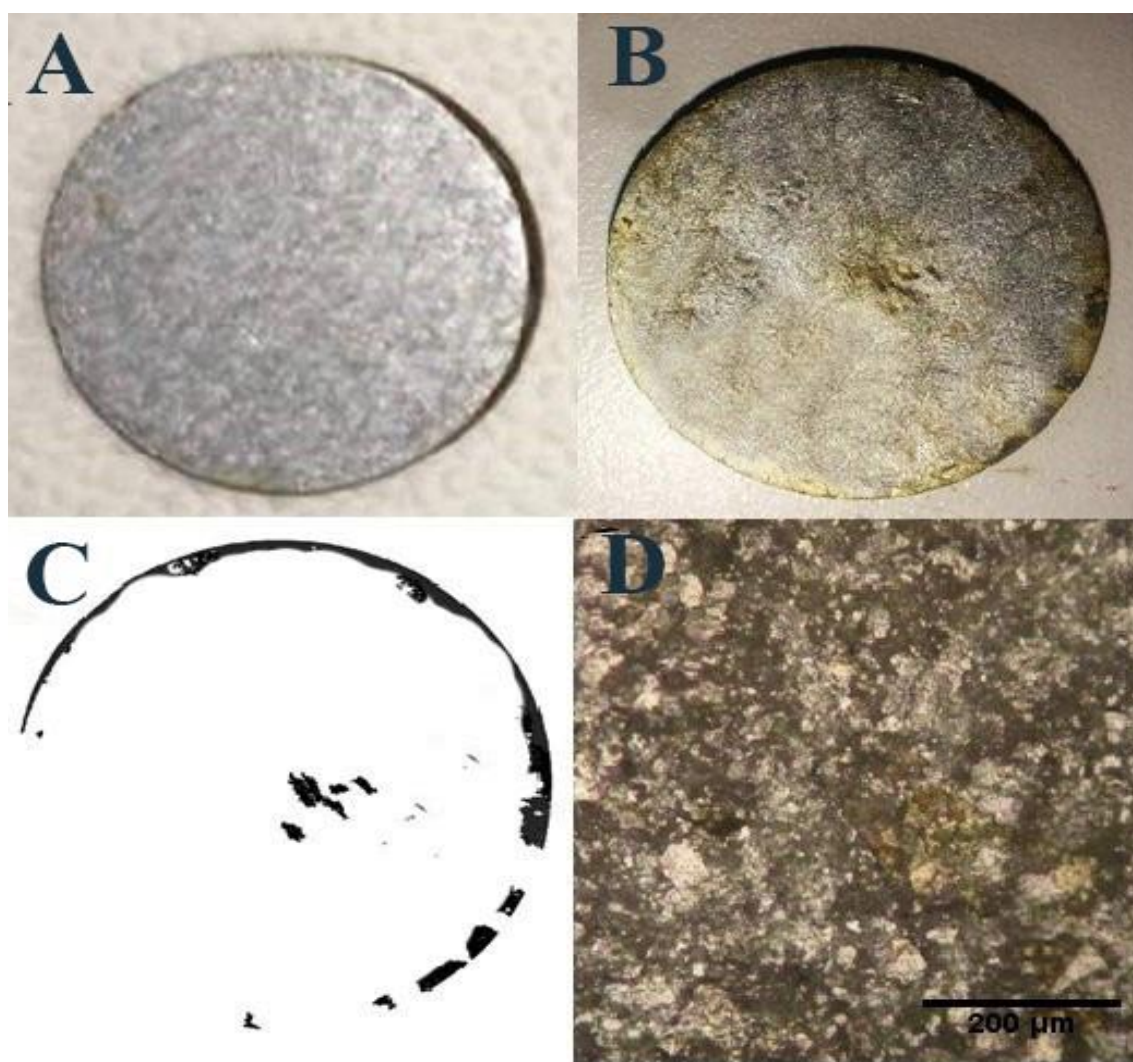


Fig. 3.2. Hammerite after salt-spray and microscope image

3.1.3 Ferox test results

Although the Ferox part changed its color to black, it presents a set of powerful response to salt-spray exposure. The Ferox sample contains only small spots on the surface, which can only be seen under the photoshop and microscopic analysis, but it has not affected the steel significantly. There was only one major area in the center of the specimen, which shows the beginning period of crevice corrosion. The area calculation under photoshop software presents that only 3% of the surface was damaged by corrosion products shown in **Figure 3.3C**.

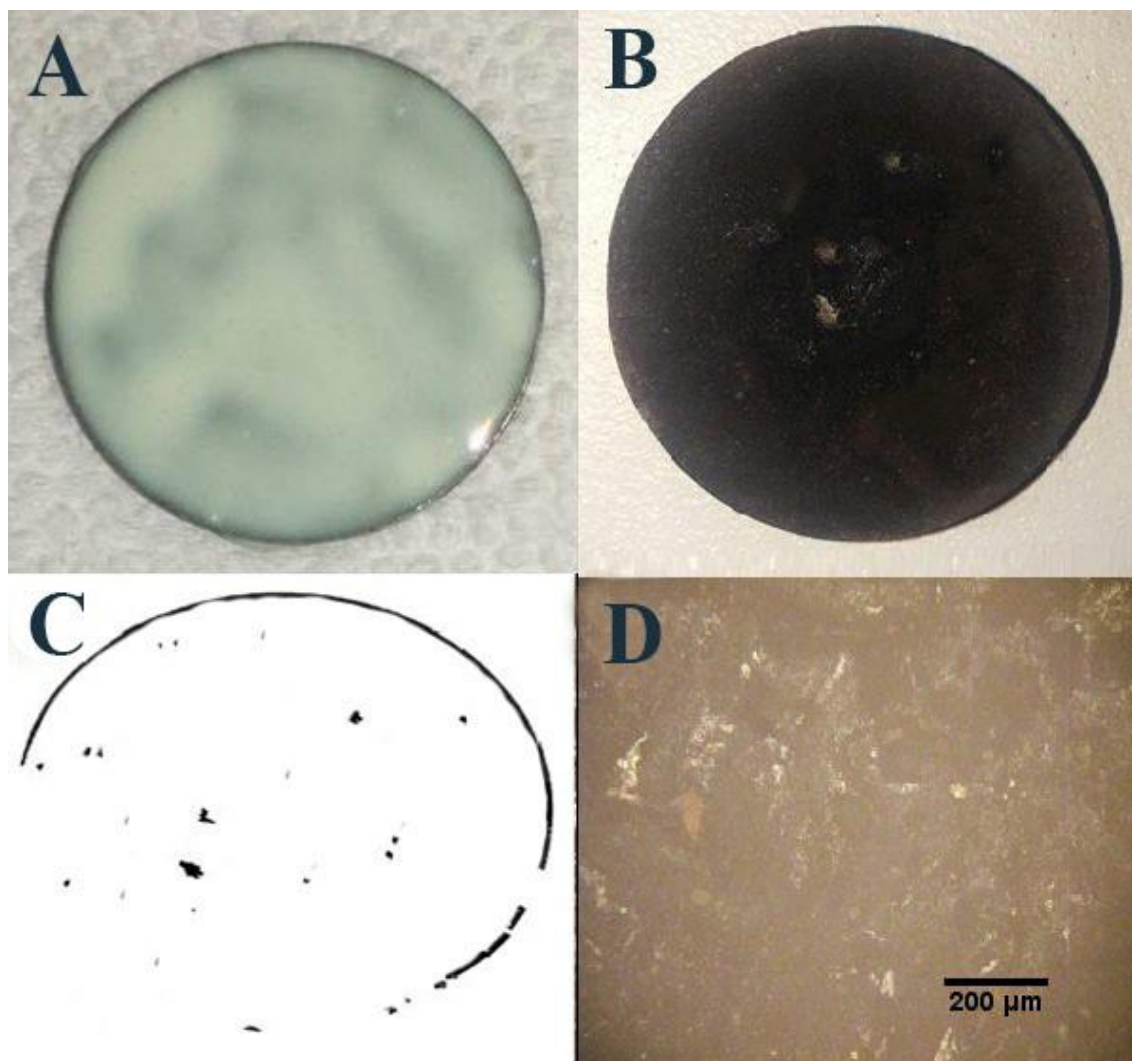


Fig. 3.3. Ferox after salt-spray test and microscope image

3.1.4 Normal sample test result

After 2 weeks of accumulated immersion, the uncoated surface of the sample changed significantly. The bare steel plate was strictly worn and there were large areas of red rust, which were visible clearly. Although all the surface of the sample was covered with crevice and pitting corrosion

particles, there were only some tiny areas, which were not covered by rusts and cracks. The area calculation shows that 96% of the surface area was damaged because of the corrosion process.

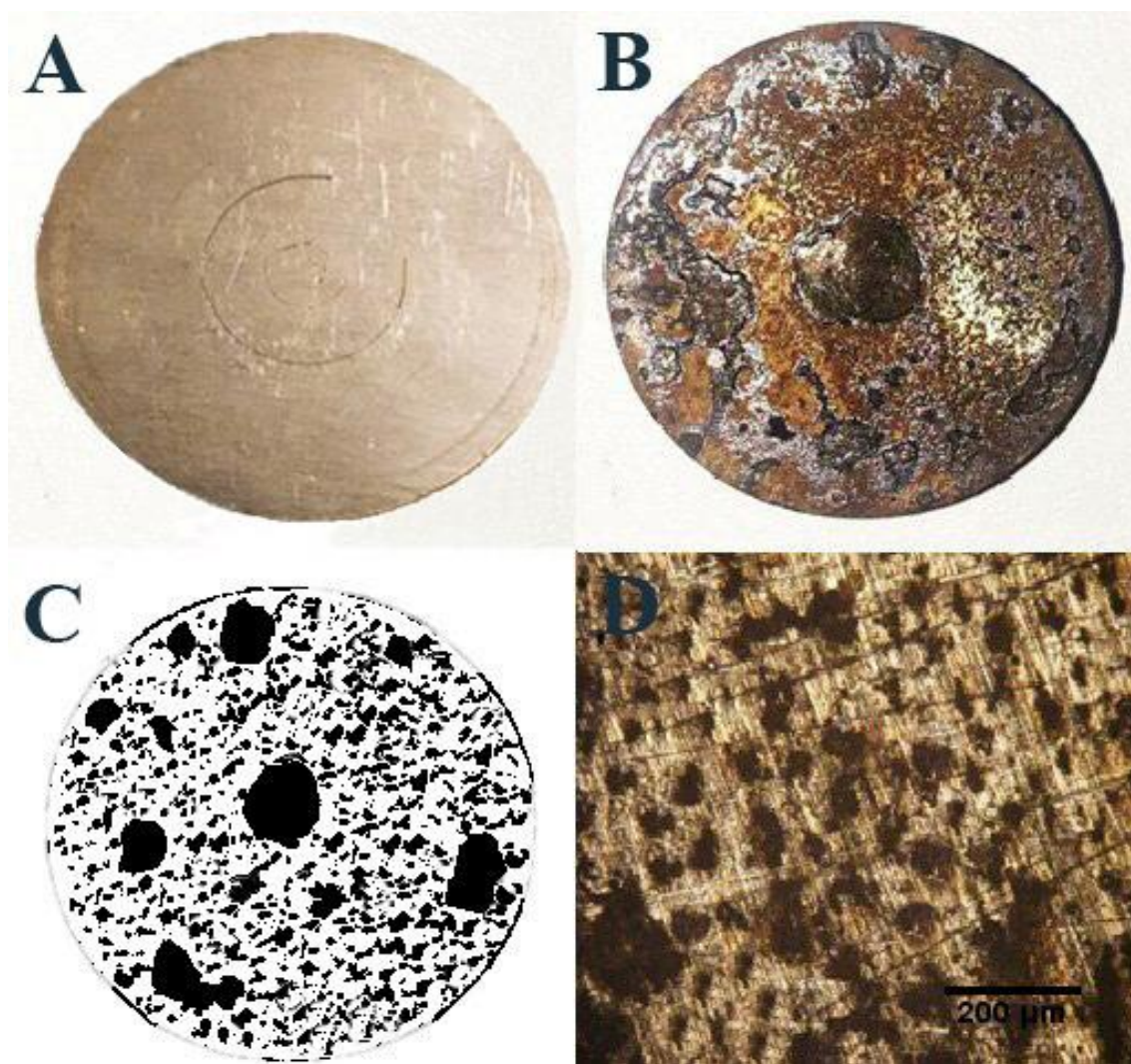


Fig. 3.4. Normal Sample after salt-spray test and microscope image

General overview of salt spray test

Table 5. Salt spray test results in tabulated form

Testing sample	Corrosion types	Oxidation level	Type of rust
Penta color	General corrosion	Moderate oxidation	Black rust
Hammerite	Pitting corrosion	Moderate oxidation	Red rust
Ferox	Pitting corrosion	Minimal oxidation	Tiny black rust
Normal Sample	Crevice corrosion	Severe oxidation	Red and black rust

3.2 PASSIVATION TEST

In this section, the results obtained from the passivation test are presented. The testing samples were observed in the two-time period, including 180 hours and 360 hours of exposure. All the results were analyzed carefully, and the images of each sample included in the report to present precise results.

3.2.1 Acetone test results

The sample was tested at room temperature and the steel was found to be lightly corroded. The samples presented slight corrosion rate after rate 360 hours exposure. There was observed only increased crevice corrosion which existed before the testing. Aside from edges, the rust particles did not appear on the other parts especially in the center of the sample. The 5% of the area was damaged by crevice corrosion.

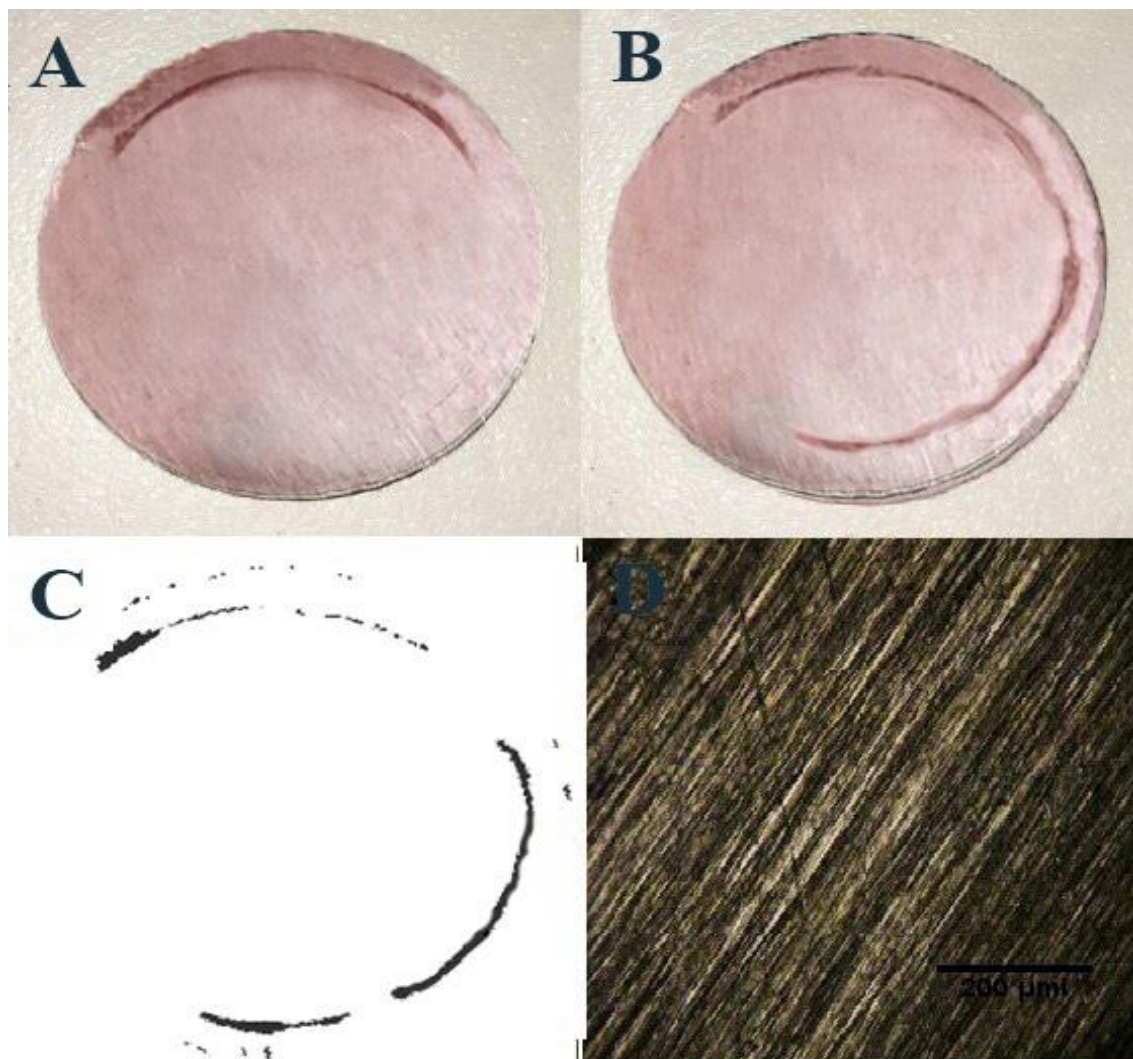


Fig. 3.5. Acetone after passivation test and microscope image

3.2.2 Tosol test results

It appears that there was not any significant corrosion effect on the steel surface. The image shows that the steel has not been exposed corrosion completely. There were only minor effects of crevice corrosion, which were visible in the center of the testing sample. In general, the sample exposed to the pitting corrosion but it was not so deep as indicated in **Figure 3.6C**. There was only 10% of corrosion rate on the surface.

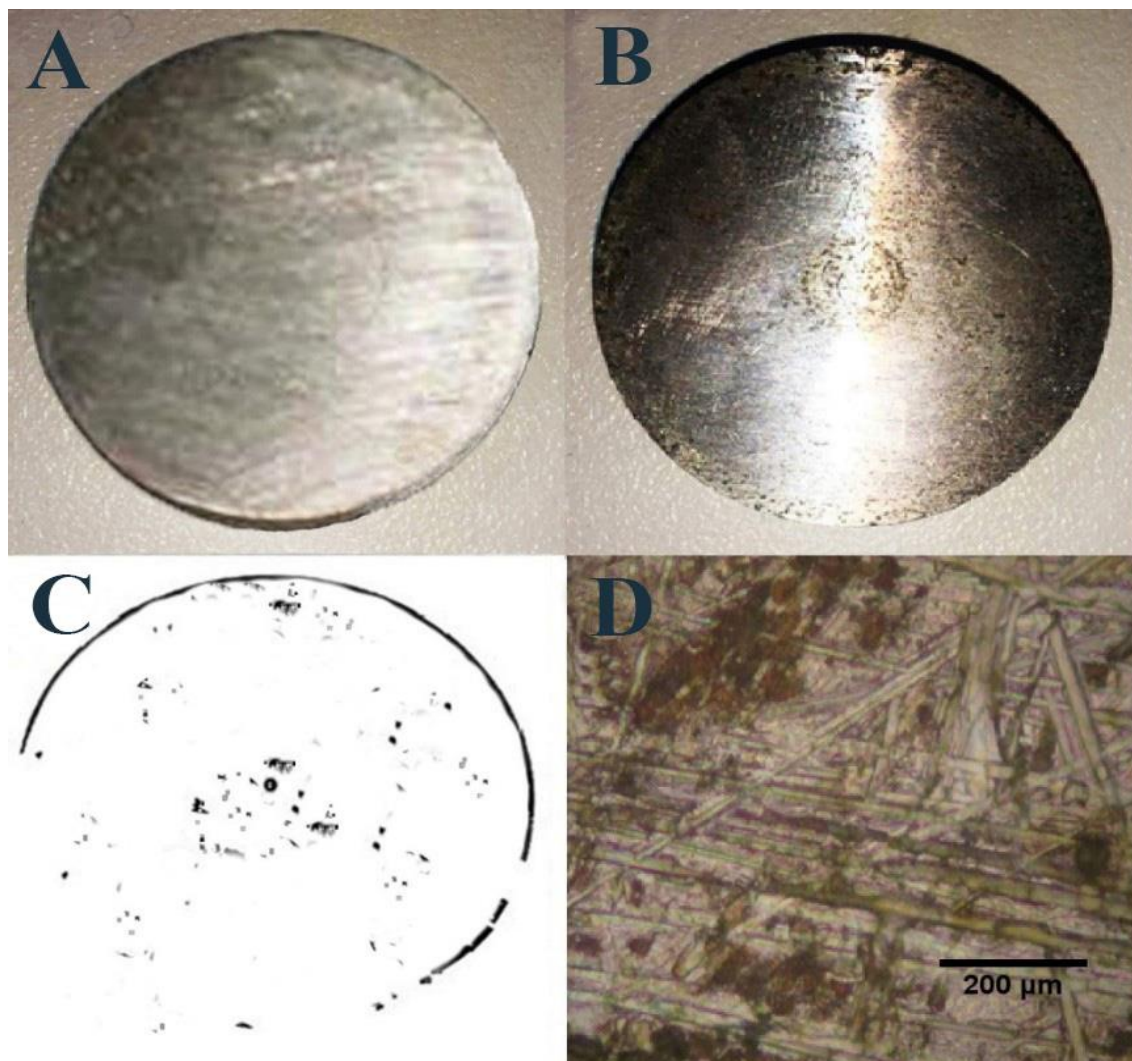


Fig. 3.6. Tosol after passivation test and microscope image

3.2.3 Autoserio test results

Figure 3.7 indicates the condition of the steel after passivation testing process. Mostly the edges of the sample presented the small red pitting corrosion product. Additionally, there was a big evidence of crevice corrosion product on the surface of the sample. It can be clearly seen that starting from the bottom part more and more micro-cracks occur on the surface. Furthermore, significant

crevice rust particles were observed on the center of the sample which formed like a ring. Compared to the ethilen-based antifreeze (tosol), the acid-based antifreeze (autoserio) had more areas, which were exposed to corrosion process. The acid-based antifreeze had about three times more area which covered with corrosion products. The photoshop area calculation shows that 35% of the surface was damaged.

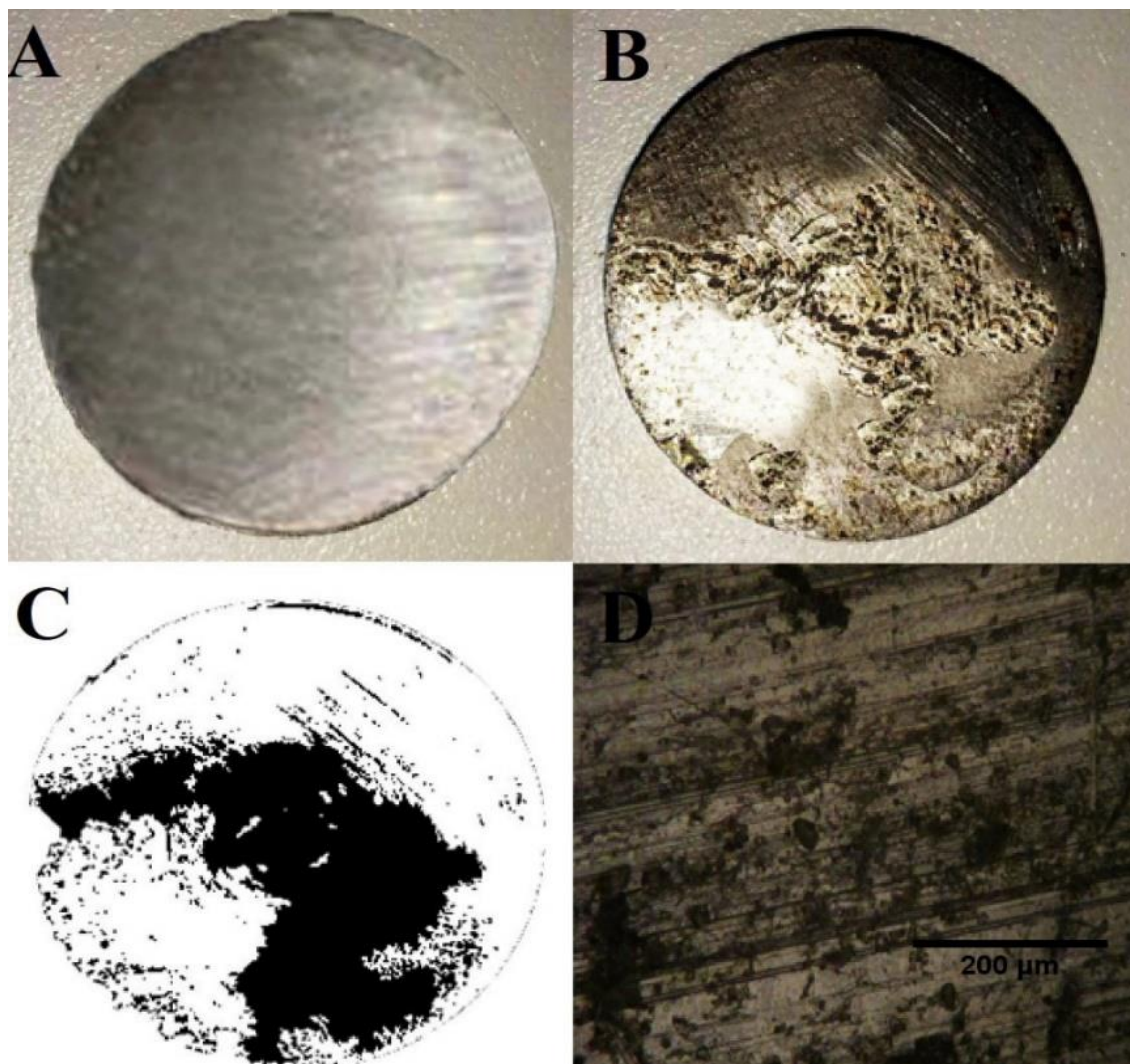


Fig. 3.7. Autoserio after passivation test and microscope image

3.2.4 Defender (engine oil) test results

Figures 3.8 show the appearance of the steel test piece after 360 hours passivation test exposure. After 360 hours exposure, significant corrosion rate was observed on the surface of the testing sample. The defender test piece was clearly tarnished and contained numerous areas covered by gray-black corrosion products. Most of the area was covered with crevice corrosion products but there were also some damaged areas which contained pitting corrosion. These pitting particles were

completely different than others due to its diameter. The sample was first analyzed after 180 hours exposure and found not any corrosion particles on the surface. However, after the passivation test was over the rate of corrosion increased markedly and reached 31% of the total surface area.

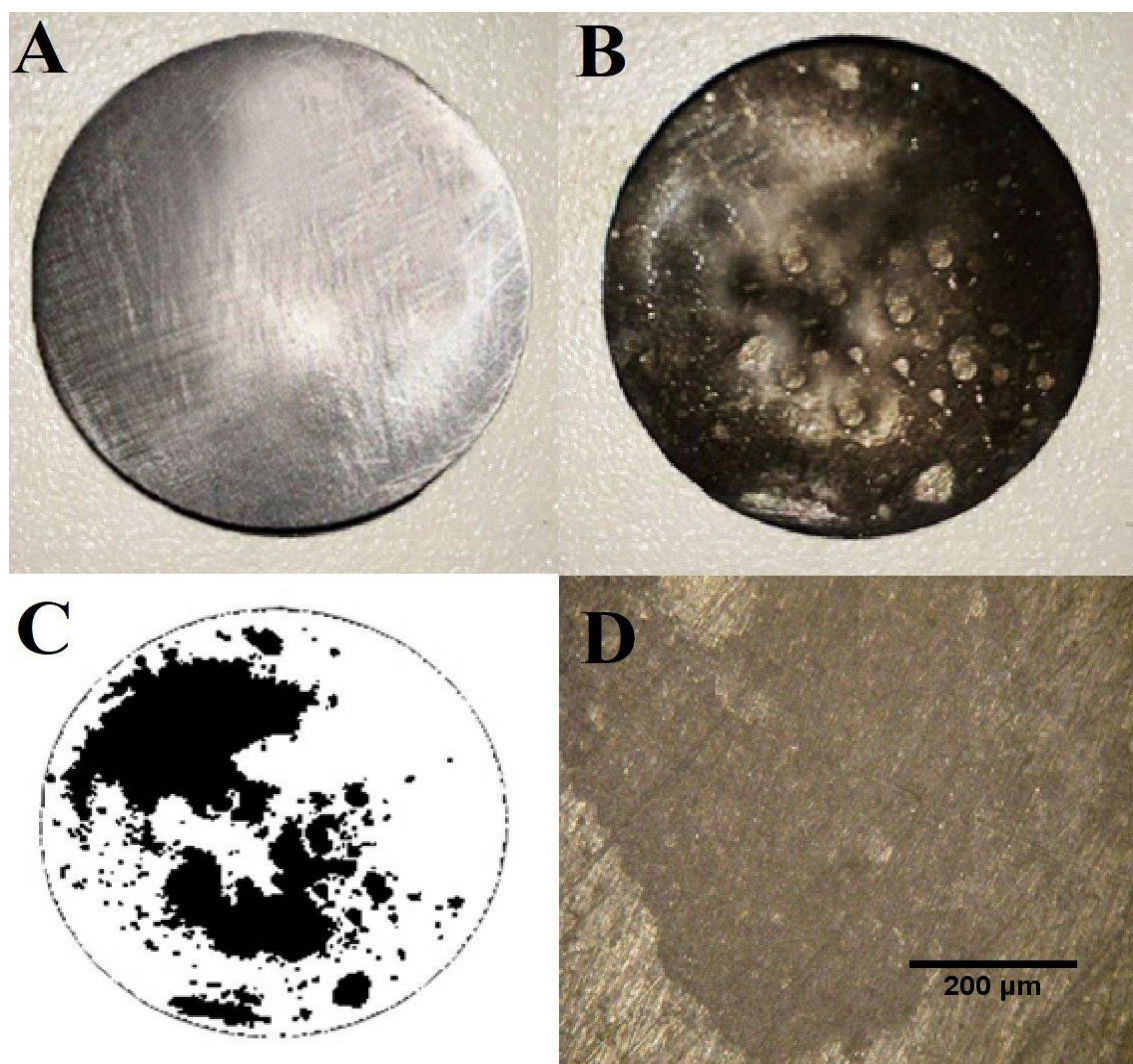


Fig. 3.8. Engine oil after passivation test and microscope image

3.2.5 Distilled water test results

Figure 3.9 demonstrates the states of the steel, which was exposed 360 hours of corrosion environment in outside temperature. Most of the surfaces of the steel presented red corrosion particles after the testing exposure. The red rust particles were observed during the 180 hours of investigation and increased to a greater space of the surface through the end of the test. Although the most part of the steel exposed to corrosion, there were some areas that were not incurred to corrosion process. The steel part, exhibit a range of corrosion behavior. The uncoated sample shown in **Figure 3.9B** shows several areas in which the metal surface has completely covered with rust, allowing the

underlying steel to destroy. The pitting corrosion particles were only visible under microscopic analysis. The diameters of pitting particles were extremely small compared to other testing samples. Additionally, some large black-rust spots occurred on the surface, which was the proof of crevice corrosion. After the photoshop calculation, 65% of corrosion rate was revealed on the surface area.

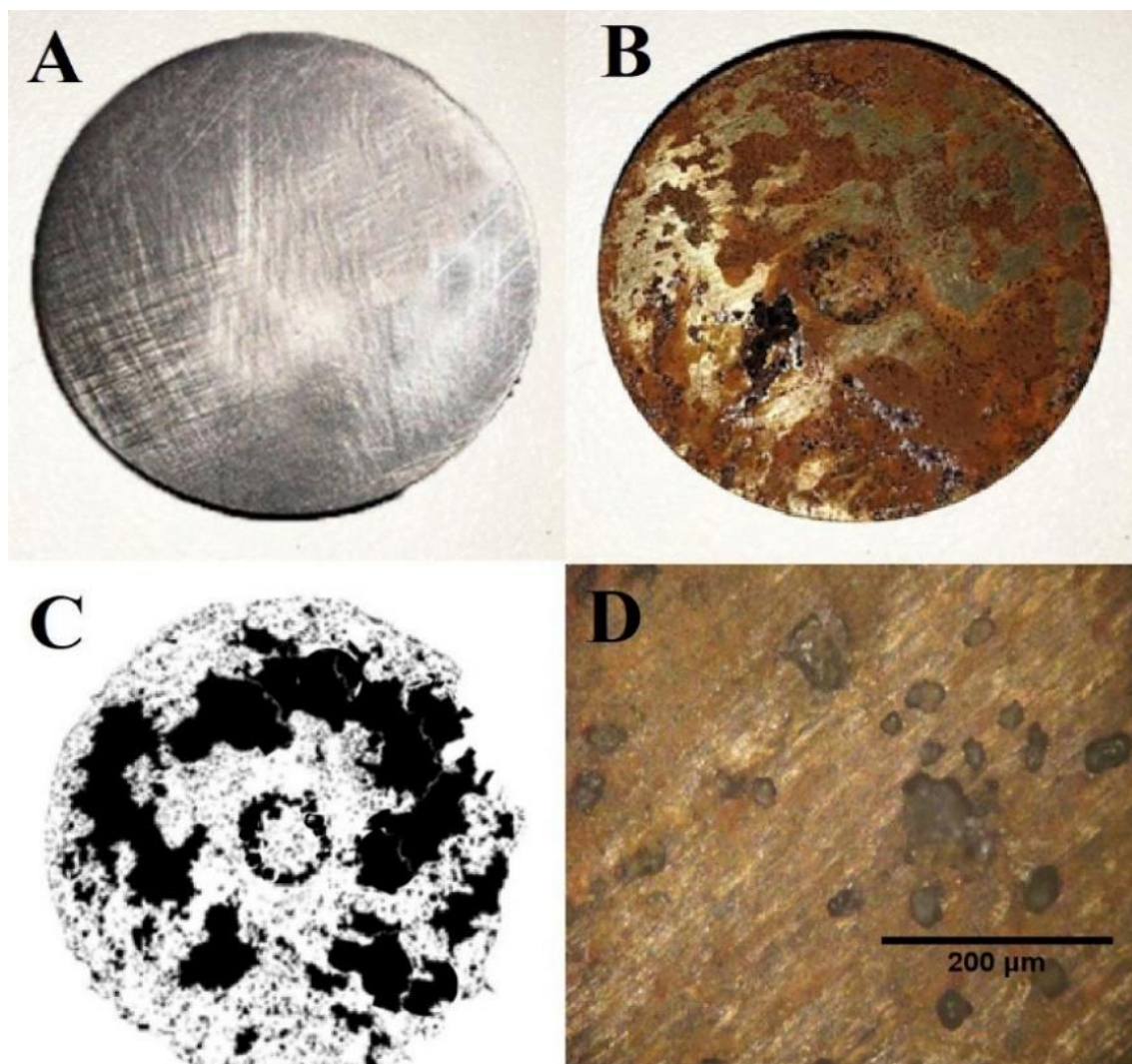


Fig. 3.9. Distilled water sample after passivation test and microscope image

3.2.6 Hammerite (outside) test results

Figure 3.10 represents the images from passivation test and metallographic microscope analysis for after 360 hours exposure at room temperature. The analysis of images indicates that there was almost no existence of pitting and crevice corrosion on the metal surface. The zinc-based coating was found to be highly resistant to corrosion process. The Hammerite part exhibits very light black pitting corrosion at the corners and shows the superior corrosion resistance gained with the use of the zinc-based coating. The damaged part was only 2% shown in **Figure 3.10C**.

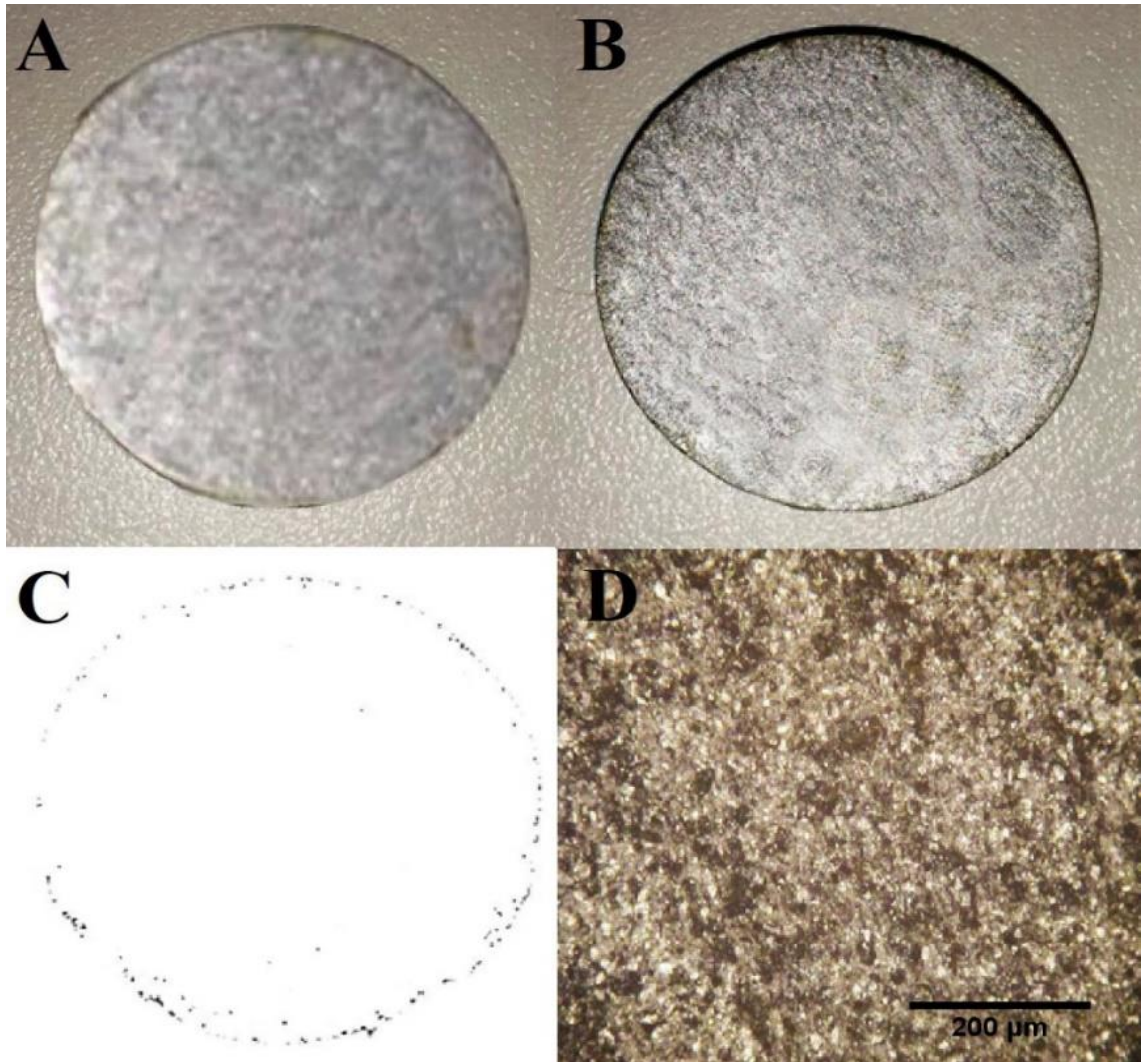


Fig. 3.10. Hammerite after passivation test and microscope image

3.2.7 Penta colour (outside) test results

The experiment was carried out at outside temperature and the results are presented in **Figure 3.11**. The testing results present that epoxy-based coating (Penta color) was less resistant to corrosion process comparing to zinc-based coating (Hammerite). There was some evident of crevice corrosion, which is shown in **Figure 3.11B**. After 180 hours of exposure, the sample remained in the same condition but after the test time was finished the steel changed color. Furthermore, there were not any big effects of corrosion damage in this sample. The photoshop analysis shows that 9% of steel surface has damaged by corrosion which is almost four times more than a zinc-based protective coating.

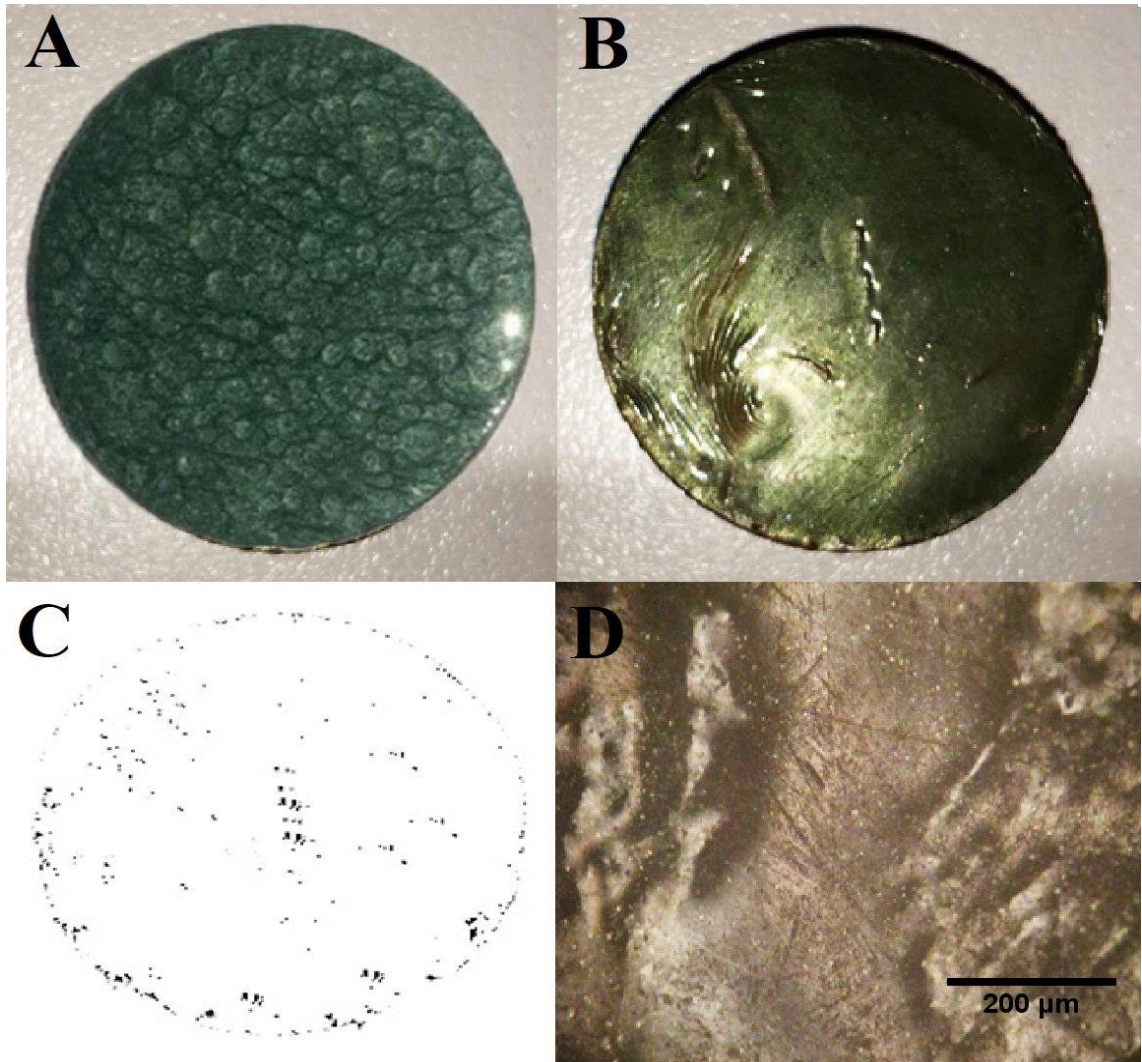


Fig. 3.11. Penta color after passivation test and microscope image

3.2.8 Normal sample (outside) test results

It can be seen the material was found to be heavily corroded after the passivation testing. There were lots of small pits on the surface, even there was not bare space because of the accelerated corrosion process. The pits were penetrating the surface of material making a depth which is shown in **Figure 3.12D**. This sample is the proof of general corrosion and it shows that the uncoated material is less resistant to pitting corrosion. **Figure 3.12** shows examples of metal loss due to the corrosion process. The area calculation indicates that 83% of the total surface area has damaged by the oxidation process.

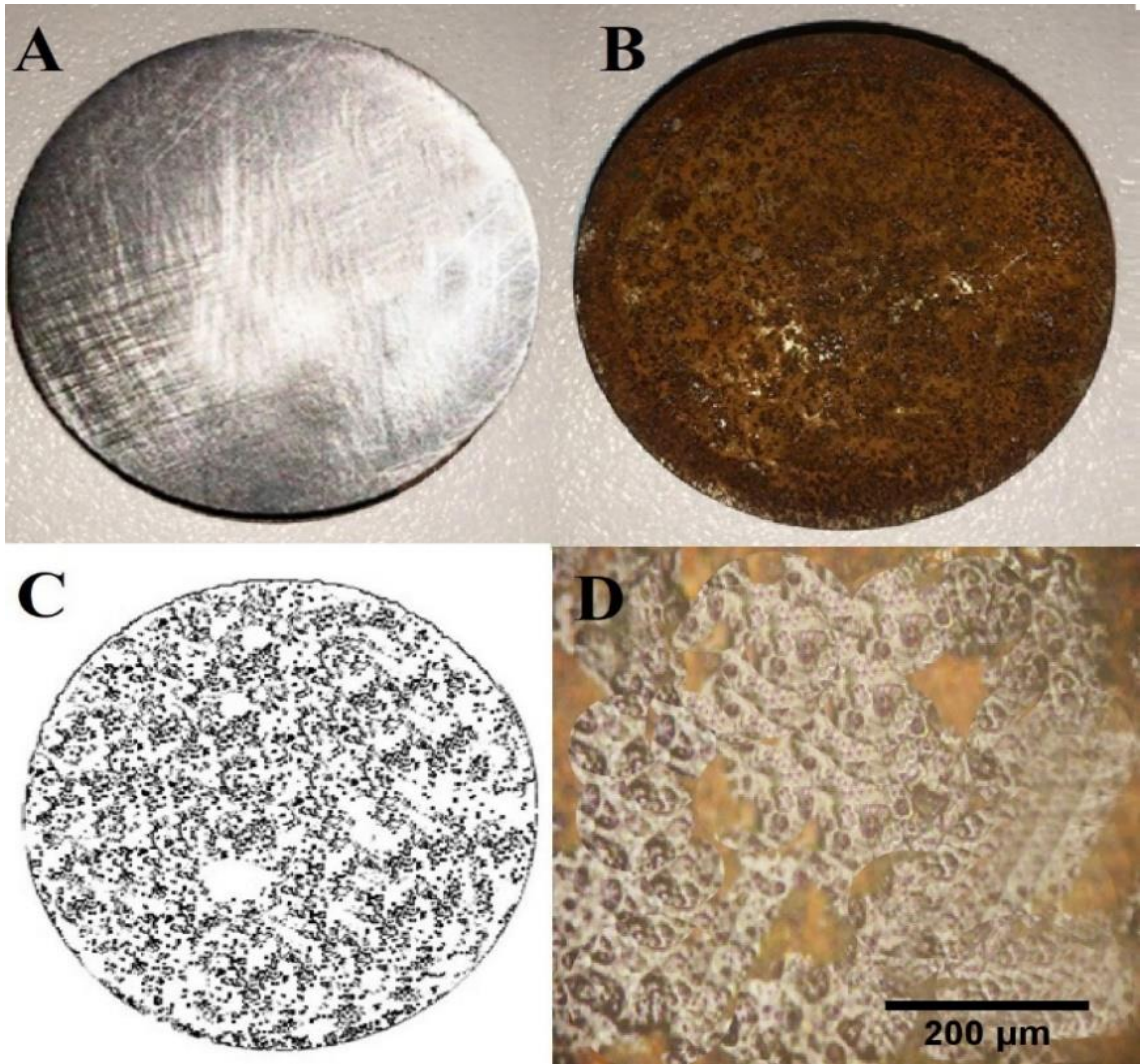


Fig. 3.12. Normal sample after passivation test and microscope image

CONCLUSIONS AND RECOMMENDATIONS

To sum up, the main aim of the project has been accomplished and the conducted tasks have been reached its goals. Based upon the scientific investigations and corrosion tests, the following conclusions were presented:

1. The factors which affect the rate of corrosion were analyzed during the experimental part of the project. The salt spray and passivation test results revealed that the chemical salts, humidity, and temperature were the main core of corrosion process. However, the chemical salts play the most crucial role among these three factors. In order to obtain this result, two uncoated samples were analyzed and compared. The salt spray test was applied to the first sample while the other was subjected to the passivation test at outside temperature. The results show that the uncoated sample exposed to the salt spray test contained more corroded area than the second sample (96% and 83% respectively).
2. After the salt spray test, three coated samples and one uncoated sample were compared for corrosion rate. There was a severe corrosion rate on the uncoated sample after 360 hours exposure (96%). It was found that the condition of two protective coatings (Penta color, Hammerite) were better than uncoated sample and the damaged area were 22% and 7% respectively. Although there was some evidence of corrosion products on the surface, the general appearances of protective coatings were satisfactory. However, the protective material (Ferox) presented more strong resistance to corrosion comparing to others. The sample had changed its color to black, but the steel was not affected by corrosion. There was only 3% damaged area in Ferox part.
3. Passivation testing was implemented to analyze the corrosion resistant properties of steel and determine the suitability of the product for use in different corrosive environments. Due to differences in temperature and humidity levels, the samples kept in outside corroded more compared to the samples kept in inside. The results presented that the engine oil, acid-based antifreeze (Autoserio) and uncured samples were exposed corrosion more than others in both outside and inside temperature indicated 31%, 35%, 83% respectively and it was found that these products were not suitable for use due to the high corrosion rate. However, ethilen-based antifreeze (Tosol), epoxy-based paint (Penta color) and zinc-based paint (Hammerite) presented a strong response to corrosion environment. The Tosol and Penat color parts were partly suitable but the Hammerite part was completely suitable for use which contained only 2 % of the damaged area.

4. As a result of corrosion testing, the different types of corrosion occurred in different environments. The most effective way of protecting the metals was to apply anti-corrosive paints and protective materials on metals. The second useful method was to avoid a place which was closer to the sea due to the chemical salt exposure. The last method was to prefer less humidity environment, which leads metals to corrode slowly.

To protect the metals from corrosion, some experimental investigations must be carried out before construction process. Firstly, the appropriate materials should be selected according to the type of environments. Secondly, the suitable design parameters should be selected according to the material. Then, the correct protective or preventative methods should be applied to the metals. Finally, the maintenance and inspection procedures must be carried out to prevent the degradation process of steels.

REFERENCES

1. Corrosion Technology Laboratory, "*Forms of Corrosion.*" [accessed 25.09.2017];
Internet link: <https://goo.gl/LDCzPj>
2. The Corrosion Society, NACE International (National Association of Corrosion Engineers. (2014). "*Coating Inspector Program Level 1.*" Version 1.03. ISBN: 1575901099
3. S.A. KHODIR and H. ALEEM. (2016) "*Localized Corrosion.*" [accessed 17.10.2017];
Internet link: <https://goo.gl/1Gi7sm>
4. Recognition, Mechanisms & Prevention. "*Types of Pitting.*" [accessed 08.10.2017];
Internet link: <https://goo.gl/7vU9Tp>
5. Coating Services Information, "*Coating Application methods.*" [accessed 30.10.2017];
Internet link: <https://goo.gl/FJcFMv>
6. Structural Steel, "*Chemical Composition, Mechanical Properties and Common Applications.*" [accessed 30.10.2017] Internet link: <https://goo.gl/AcHRT5>
7. STREITBERGER, J. (2003). "*Basics of coating technology.*" ISBN: 9783866309036.
Internet link: <https://goo.gl/qnXFja>
8. TRACTON, A. A. (Ed.). (2006). "*Fundamentals, testing, and processing techniques.*" ISBN: 9781420044089. Internet link: <https://goo.gl/My6MLs>
9. TIWARI, A. (2015). "*Intelligent coatings for corrosion control.*" ISBN: 9780124114678.
Internet link: <https://goo.gl/bMf1BZ>
10. CHANDLER, H. (Ed.). (1995). "*Practices and procedures for irons and steels.*" ISBN: 9780871705204. Internet link: <https://goo.gl/MdeUeU>
11. MCGUIRE, M. F. (2008). "*Stainless steels for design engineers.*" p.304.
ISBN 9781615030590. Internet link: <https://goo.gl/sZXf7L>
12. AHMAD, Z., DIGBY, M. (2006). "*Principles of corrosion engineering and control.*" p.704.
ISBN: 9780080971346. Internet link: <https://goo.gl/coeoMU>
13. BAZANT, Z. P. (1979). "*Physical model for steel corrosion in sea structures.*" p.585.
ISBN: 9780727735171. Internet link: <https://goo.gl/NEZFWz>
14. BENTUR, A. (1997). "*Fundamentals and civil engineering practice.*" P.201.
ISBN 9780419225300. Internet link: <https://goo.gl/FsruWv>
15. CLEAR, K. C. (1989). "*Measuring rate of corrosion of steel in field concrete structures.*" ISBN: 9780309048087

16. SCHWEITZER, P. A. (1987). *"What every engineer should know about corrosion."*
ISBN: 9780824777555. Internet link: <https://goo.gl/ChU7FV>
17. ENEVOLDSEN, J. N. (1994). *"The influence of internal relative humidity on the rate of corrosion of steel embedded in concrete and mortar."* ISBN: 97800088846
18. GLASS, G. K. (1997). *"The presentation of the chloride threshold level for corrosion of steel in concrete."* ISBN 9780010978783
19. GONZALEZ, J. A. (1995). *"Comparison of rates of general corrosion and maximum pitting penetration on concrete embedded steel reinforcement."* Internet link: <https://goo.gl/iNQaQH>
20. KAHL, S. (2007). *"Corrosion Resistant Alloy Steel"*. p.31. [accessed 03.11.2017].
Internet link: <https://goo.gl/zxTV8Y>
21. TOMASHOV, N. D. (1958). *"Methods for Increasing Corrosion Resistance of Metal."*
ISBN: 9784433303710. Internet link: <https://goo.gl/hKfV6U>
22. RAMACHANDRAN, V. S., (2000). *"Analytical techniques in concrete and technology."*
ISBN: 9780815517382. Internet link: <https://goo.gl/6gtcnN>
23. ANDREW, C. P. (2008). *"Subsea pipeline engineering."* ISBN: 9781593701338.
Internet link: <https://goo.gl/uYTEbY>
24. HERRMAN, K., *"Hardness Testing Principle and Applications."* ISBN: 9781 732566822.
Internet link: <https://goo.gl/kooSfu>
25. SMIALOWSKA, M.J. (1971) *"The Analysis of Methods for the Determination of Characteristic Potential."* [accessed 03.11.2017]. Internet link: <https://goo.gl/2ZesFU>
26. CICEK, V., & AL-NUMAN, B. (2011). *"Corrosion chemistry."* ISBN: 9780470943076.
Internet link: <https://goo.gl/j7Qvy2>
27. ROBERT G. KELLY, J. (2003). *"Electrochemical Techniques in Corrosion Engineering."*
ISBN: 9781420028331. Internet link: <https://goo.gl/ZZ8NFj>
28. SCHWEITZER, P. A. (2006). *"Fundamentals of metallic corrosion: atmospheric and media corrosion of metals"*. ISBN: 9780849382444. Internet link: <https://goo.gl/32K7H7>
29. WESSEL, J.K. (2004). *"Handbook of Advanced Materials: Enabling Modern Designs."*
p.656. ISBN: 9780471454755.
30. HERBERT, H. U. (2011). *"Uhlig's corrosion handbook."* ISBN: 9781591244615.
Internet link: <https://goo.gl/Za9T3R>
31. LOTO, R. T. (2015). *"Pitting corrosion evaluation and inhibition of stainless steels"* Article,
[accessed 25.11.2017]; Internet link: <https://goo.gl/HdrnC9>
32. CHAN H. L. (2012). *"An Introduction and Their Recent Developments."* (Vol. 437).
ISBN: 9781608055630. Internet link: <https://goo.gl/kGUXNJ>

33. BRUBAKER, G. R. (1979). *"Corrosion chemistry. American Chemical Society."*
ISBN: 0841204713 Internet link: <https://goo.gl/i26Wxe>
34. FARRAR, J.C.M. (2004). *"A guide to low-alloy steel, stainless steel, and nickel-base alloys."*
p189. ISBN: 9781280373091. Internet link: <https://goo.gl/66GhQ7>
35. SHREIR, L. L. (Ed.). (2013). *"Corrosion: corrosion control."* Newnes.
ISBN: 9781591245018
36. CARTER, V. E. (2013). *"Metallic Coating for Corrosion Control."* Newnes. p.283.
ISBN: 9780408002707.
37. CRAMER, S. D (2005). *"ASM international."* ISBN: 9780871707079.
Internet link: <https://goo.gl/9dYtHJ>
38. TALBOT, D. E., & TALBOT, J. D. (2007). *"Corrosion science and technology."* CRC press.
ISBN: 9780849392481. Internet link: <https://goo.gl/b6HYph>
39. PEREZ, N. (2004). *"Electrochemistry and corrosion science."* (Vol. 412).
ISBN: 9783319248479. Internet link: <https://goo.gl/hUru2d>
40. MCCAFFERTY, E. (2010). *"Introduction to corrosion science."* ISBN: 9783319282459.
Internet link: <https://goo.gl/7D7SjH>

APPENDICES

Images from ZEISS Axio metallographic microscope and list of equipment

1. Salt spray test (2 pages)
2. Passivation test (3 pages)
3. List of equipment used (2 pages)

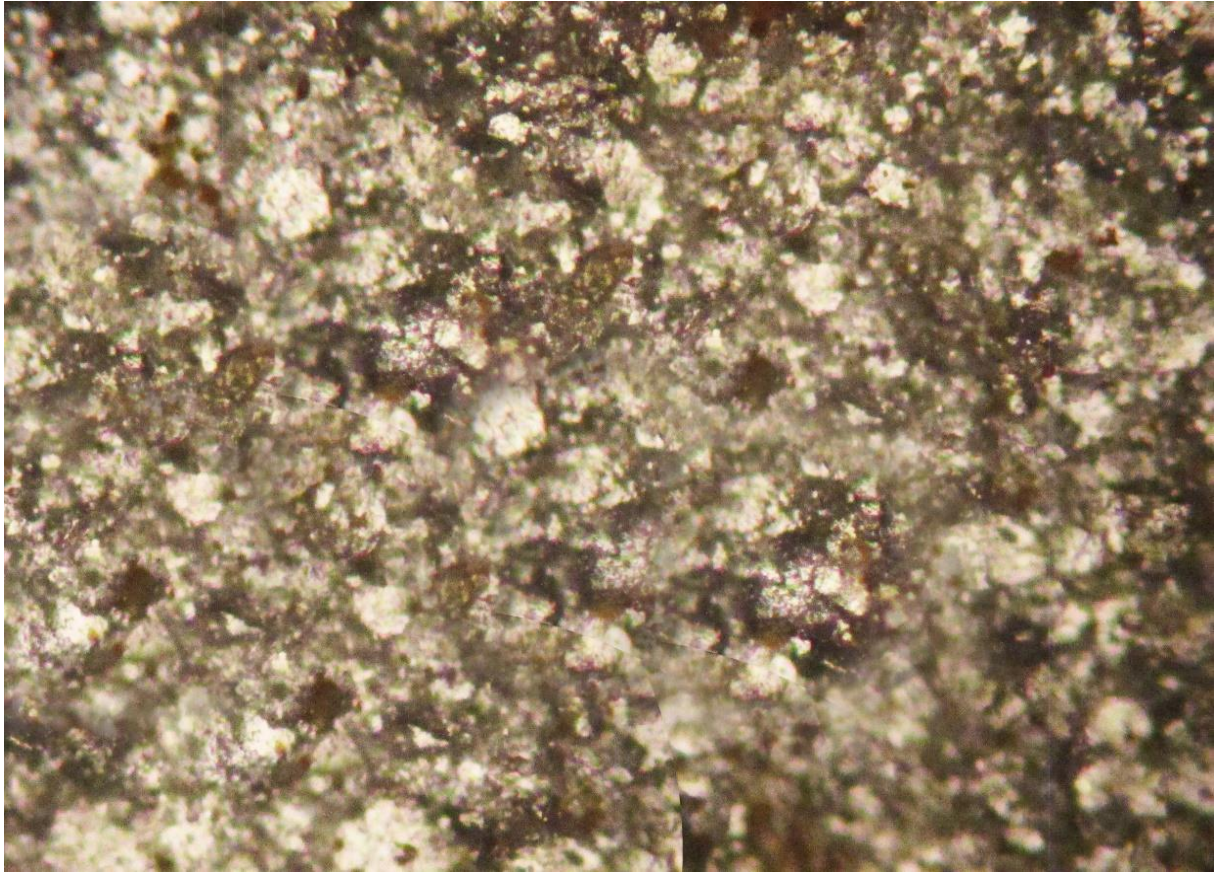


Image: 9193 Hammerite after salt spray test. Magnification = 20x

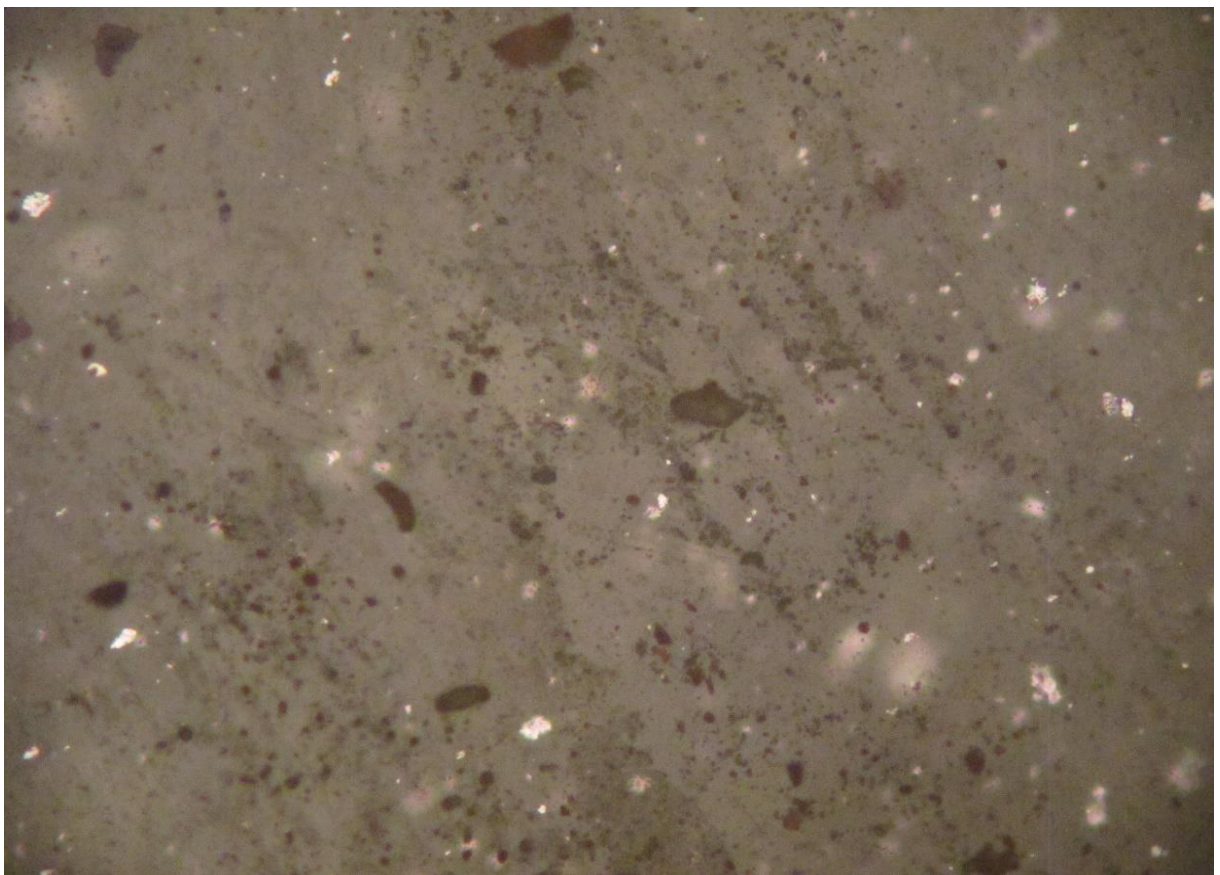


Image: 9199 Penta color after salt spray test. Magnification = 20x

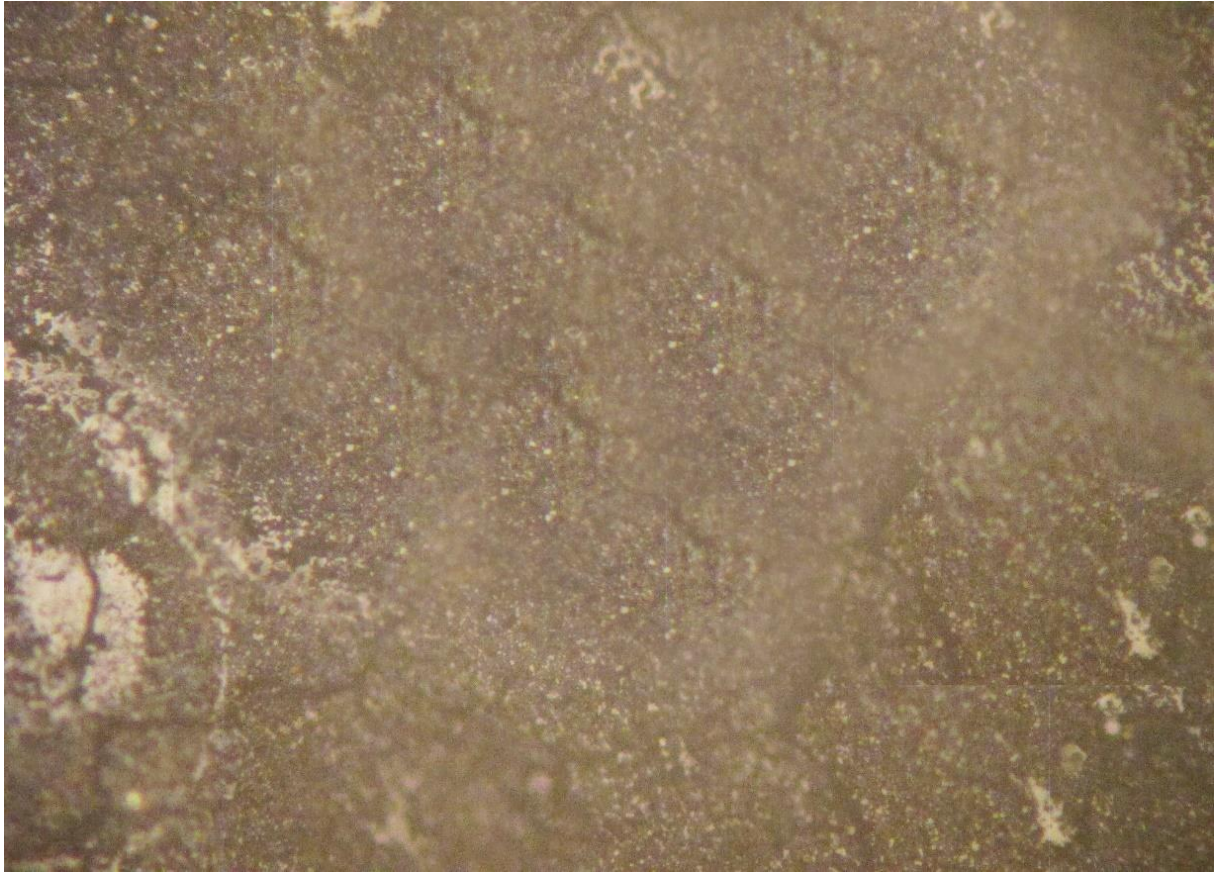


Image: 9215 Ferox sample after salt spray test. Magnification = 20x

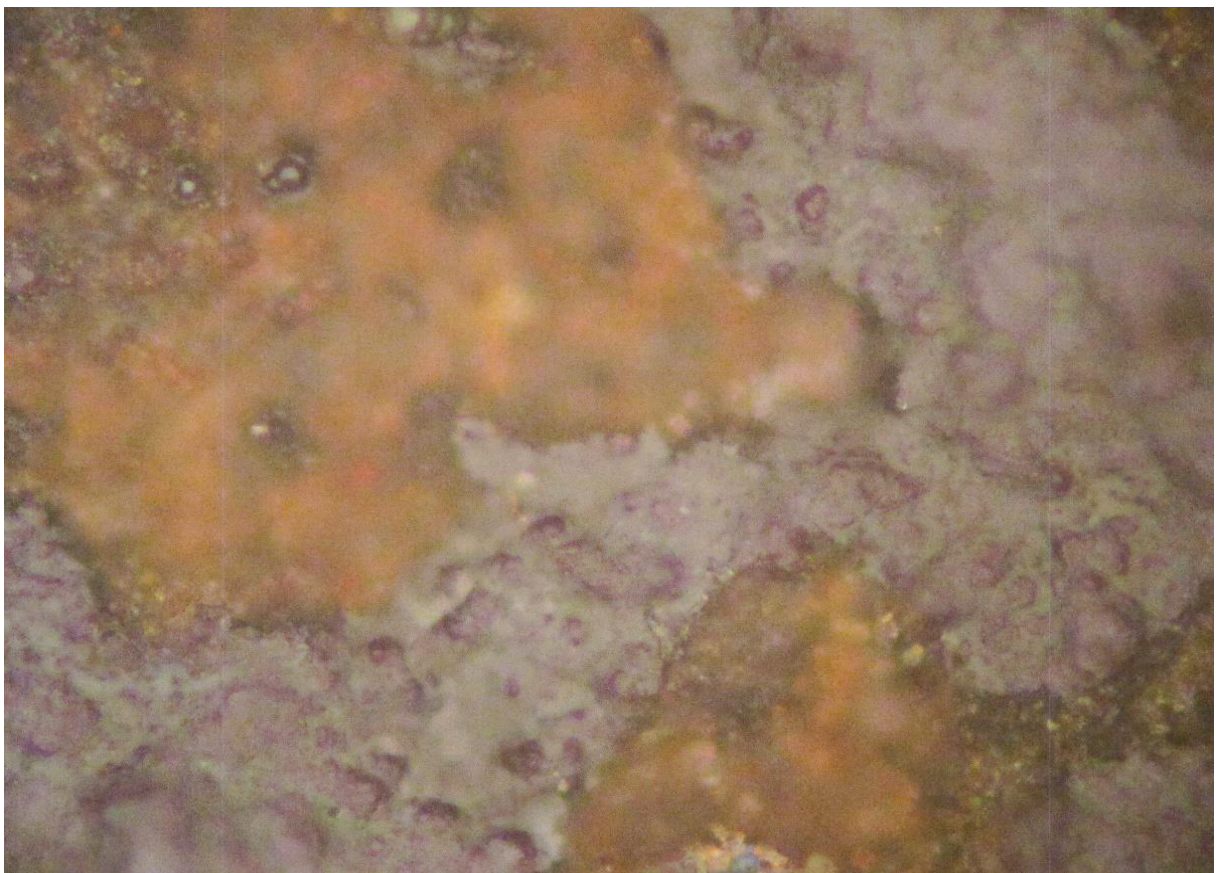


Image: 9204 Normal sample after salt spray test. Magnification = 50x

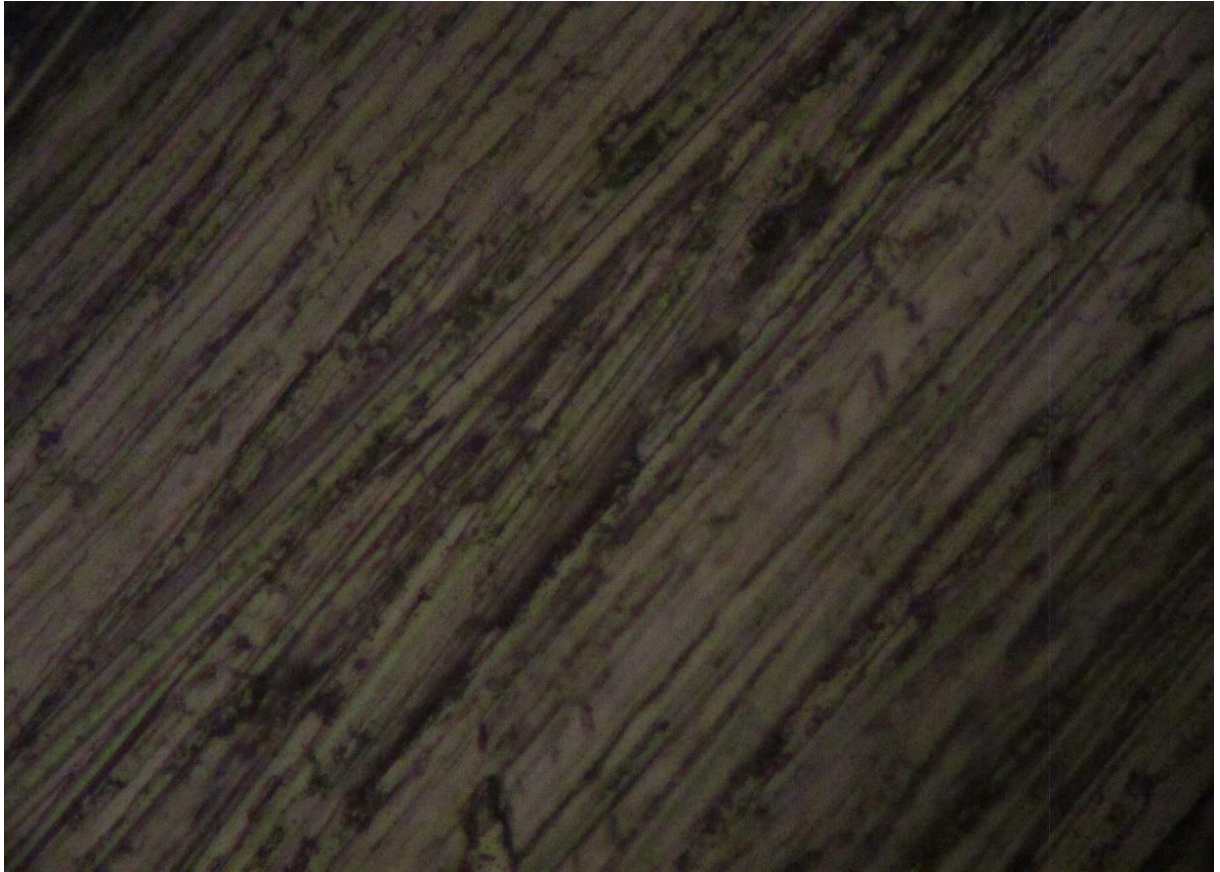


Image: 9224 Acetone after salt passivation test. Magnification = 50x

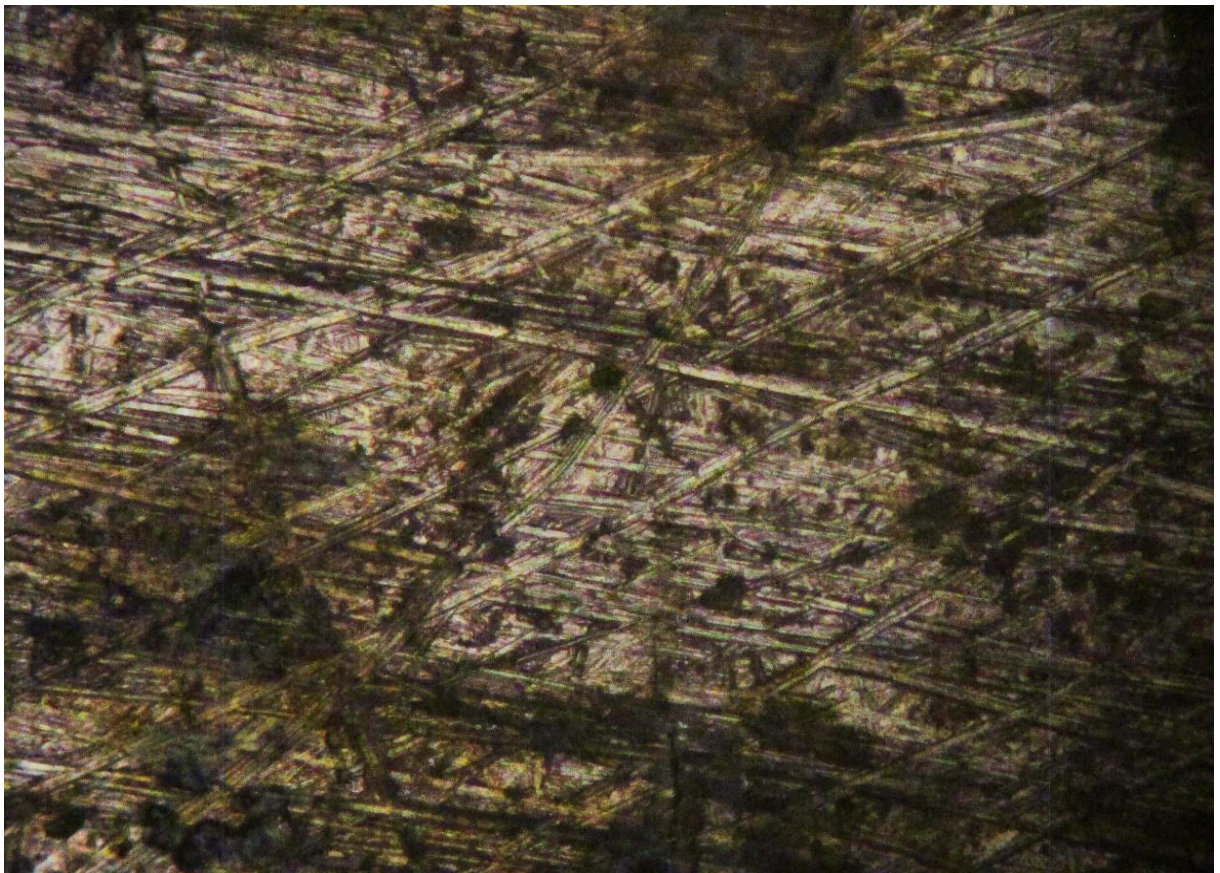


Image: 9228 Tosol after passivation test. Magnification = 20x

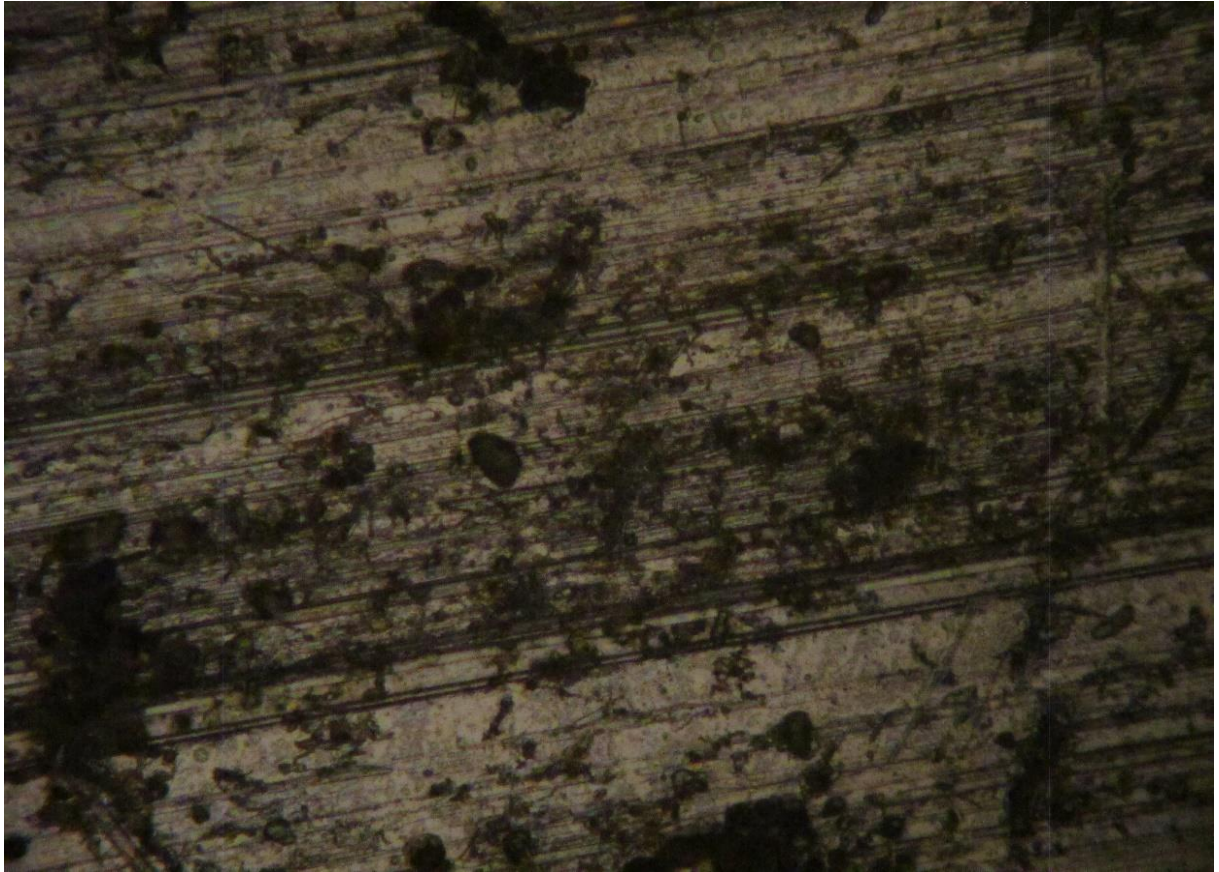


Image: 9231 Autoserio after passivation test. Magnification = 20x

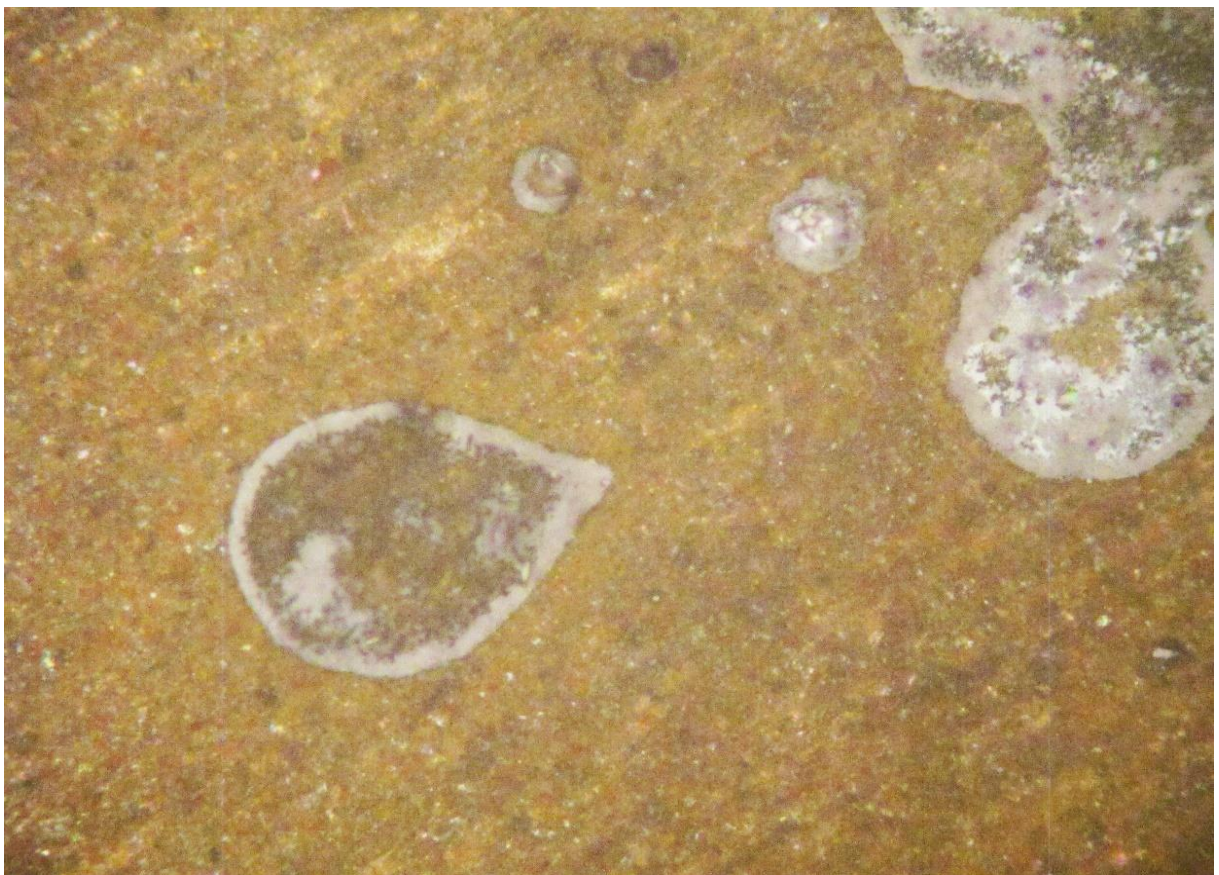


Image: 9234 Distilled water after passivation test. Magnification = 20x

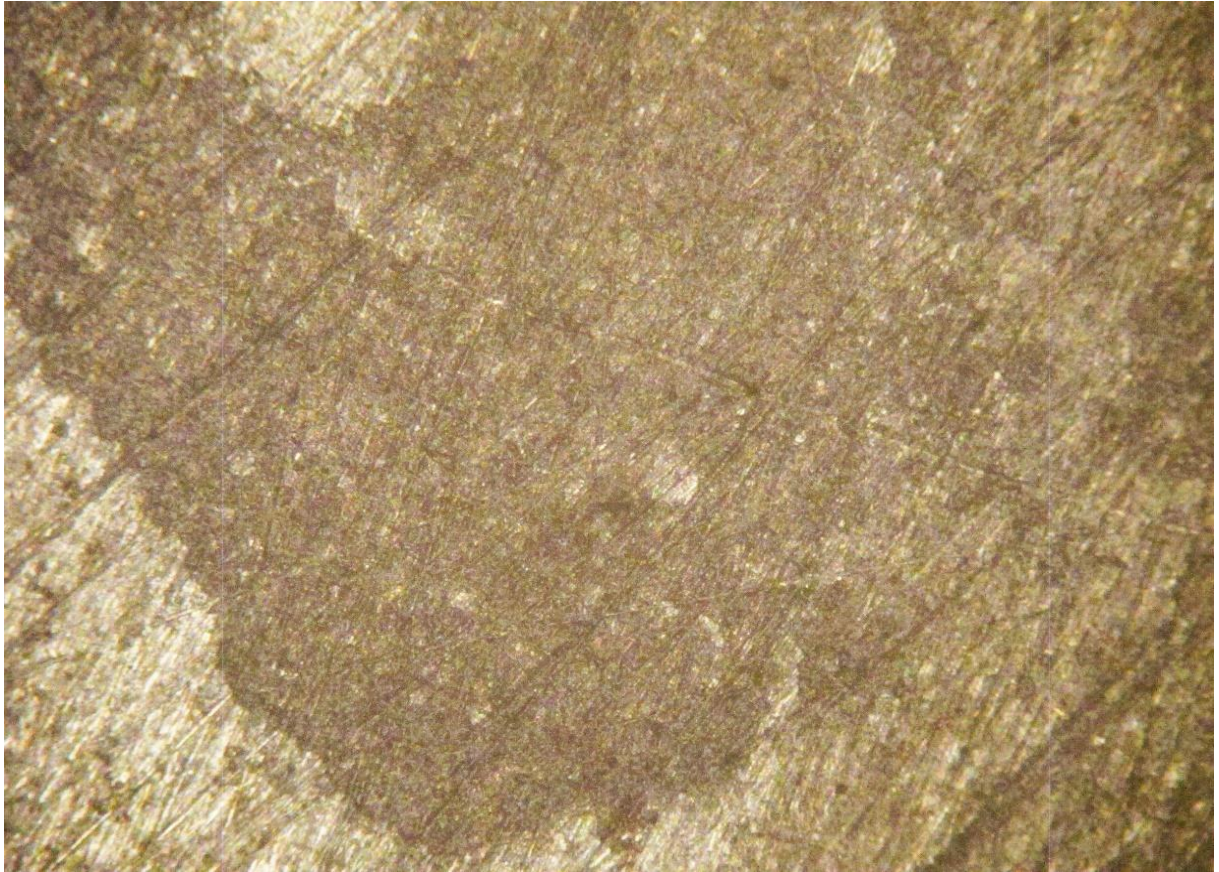


Image: 9240 Engine oil after passivation test. Magnification = 50x



Image: 9222 Penta color after passivation test. Magnification = 20x

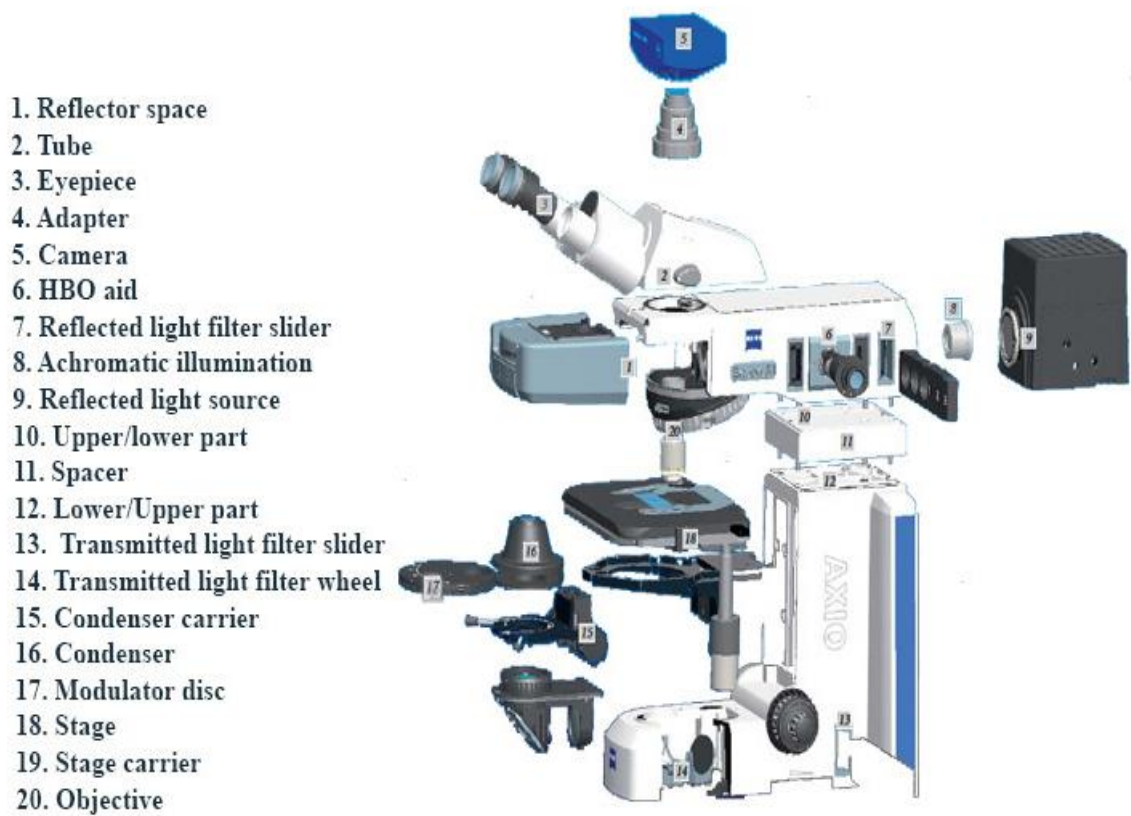


Image: Main parts of ZEISS Axio metallographic microscope



Image: Cutting process by Lathe machine



Image: Grinding machine