ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Evaluation of corrosion rate and illustrate mechanical properties of a given steel subjected to corrosive environment

A Thesis submitted to the graduate school of Addis Ababa University in partial fulfillment of the requirements for the degree of masters of Science

In

Mechanical Engineering (Mechanical Design)

By: Melaku Tefera

Advisor: Dr. Daniel Tilahun

December, 2015

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Evaluation of corrosion rate and illustrate mechanical properties of a given steel subjected to corrosive environment

By

Melaku Tefera

Approved by Board of Examiners

Daniel Tilahun (Dr.)	_____	_____
Advisor	Signature	Date
_____	_____	_____
Examiner-1	Signature	Date
_____	_____	_____
Examiner-2	Signature	Date
Daniel Tilahun (Dr.)	_____	_____
Chairman of the School	Signature	Date

Addis Ababa University

School of Graduate Studies

Declaration

This is to certify that the thesis prepared by **Melaku Tefera**, entitled: **Evaluating Mechanical Properties of a given Steel Subjected To Corrosive Environment.** I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university and that all sources of materials used in the thesis have been fully acknowledged.

Declared by:

Signature: _____

Date: 21/12/2015

Advisor: Daniel Tilahun (Dr.) Signature: _____ Date: _____

Head of the School: Daniel Tilahun (Dr.) Signature: _____ Date: _____

ACKNOWLEDGMENT

This work wouldn't have seen the light of day had there been the support of many persons who involved at different stages of the study for which I am highly indebted to. First and foremost, I would like to express my heartfelt thanks to my **God** and next my advisor **Dr. Daniel Tilahun**, for his unreserved professional guidance, critical comments, constructive advice, and fruitful suggestions which made the work take its present shape. Honestly, I don't have words that appropriately express my thanks to you, Dr. Even if I don't know whether it can really describes you, you were like a good father to me for which I extend special appreciation.

I am also grateful to many other people who assisted me during the experimental test for the study by providing me valuable support. These included Ato Tollosa D. and Ato Fasil G. from Addis Ababa University Institute of Technology, Ato Megerssa Urgessa and Mesfin Engidawork from Ethiopian pharmaceuticals Manufacturing Sh.co., Ato Derege Asfaw and Birtukan Yenealem from Metal Industry Development Institute, Ato Asfaw Alemu from Productivity Improvement Center, Ato Gezahagn Kebede, from Hibret machine building and tools manufacturing industry.

My special thanks go to my wife w/o Hilina Terefe for all the moral and material support she extended me during my studies. Honey, you have always been on my side; you are my source of hardworking, endurance and success.

ABSTRACT

Melaku Tefera
Addis Ababa University, 2015

Steel is one of the major materials used all over the world in the industries and steel constructions. So the steel to be effective on the application, it should have stable mechanical properties. This paper focuses on experimental study of the effect of corrosion on mechanical properties. A steel diameter 20mm and 3500mm long steel rod; 3.5% Nacl plus distilled water (Based on ASTM G 44, G 47) and tape water for corrosive environment is taken for this experiment and studied for a period of ten days interval for fifty days by measuring weight, hardness test, impact and tensile test before and after immersion; then the weight losses, tensile test, hardness and Impact test were tabulated and analyzed graphically. The corrosion rate for group one samples is 6.432%/year and the same thing for group two samples 6.894% /year is loss. Generally it is observed that steel corroded and loss its mechanical properties; as well the different environments with decreasing intensity in the order of tape water than 3.5% Nacl plus distilled water. Based on the result when design such material for corrosive environment should consider corrosion effect or use corrosion protection mechanism.

Key words: Steel AISI1050, Mechanical properties, Corrosion, Tensile test, weight loss, hardness test, Impact test, corrosion rate, PH and Conductivity

Table of Contents

TABLE OF CONTENTS……..….IV
LIST OF TABLE…….…….…..VI
LIST OF FIGURES VII
LIST OF ABBREVIATIONS , NOMENCLATURE AND ACRONYMS IX
CHAPTER 1: INTRODUCTION.....1
1.1. INTRODUCTION 1
1.2. BACKGROUND OF THE STUDY 2
1.3. STATEMENT OF THE PROBLEM.....5
1.4. ORGANIZATION OF THE THESIS.....5
1.5.PURPOSE …….……...……..... 6
1.6. SCOPE OF THE STUDY…… …….6
1.7. METHODOLOGY OF THE STUDY……...6
1.8. LIMITATION OF THE STUDY.....6
1.9. OBJECTIVE OF THE STUDY 7
CHAPTER 2: LITERATURE REVIEW 8
2.1. CORROSION AND STEEL MATERIAL 8
CHAPTER 3: EXPERIMENTAL METHODS AND CONDITIONS 11
3.1. MATERIAL……11
3. 2. METHOD AND PURPOSE 11
3. 2.1.METHOD 11
3. 2.1.1.WEIGHT MEASUREMENT WITH ELECTRONIC SCALES..... 11
3.2.1.2.SPECTROMETER TEST 12
3.2.1.3.ATOMIC ABSORPTION SPECTROSCOPY AND VOLUMETRIC TITRATION 13
3.2.1.4. VOLUMETRIC TITRATION 13
3.2.1.5. HARDNESS TEST 14
3.2.1.6. TENSILE TEST. 15
3.2.1.7. IZOID IMPACT TEST…..…….. 16
3.2.1.8.CONDUCTIVITY METER ….....……...17
3.2.1.9.PH METER…….…….....…….....……..…17
3.2.2.PROCEDURE OF THE EXPERIMENT…….……...……..…..18
3.3.TEST MATERIAL…….…….……...19

3.3.1. PREPARATION OF TEST PIECES 19
3.3.1.1. SAMPLE PREPARE FOR SPECTROMETER AND HARDNESS TEST 19
3.3.1.2. SAMPLE PREPARE FOR TENSILE TEST 20
3.3.1.3.PREPARED SAMPLES FOR IZOID TEST 21
3.3.2. DIMENSION OF TEST PIECES 21
3.4. EXPERIMENTAL CONDITIONS AND TESTING 22
3.4.1.DEVELOPMENT OF CORROSIVE ENVIRONMENT 23
3.4.2. EXPERIMENTAL SETUP AND PROCESS 24
3.5. EQUIPMENTS (TEST MACHINES) 26
CHAPTER 4: EXPERIMENTAL RESULT AND DISCUSSION 27
4.1. EXPERIMENTAL RESULTS 27
4.1.1. TENSILE TEST 27
4.1.2. IZOID IMPACT TEST 31
4.1.3. WEIGHT MEASUREMENT 32
4.1.3.1. WEIGHT LOSS TEST 32
4.1.4. PH MEASUREMENT OF THE CORROSIVE MEDIA 33
4.1.5 CONDUCTIVITY MEASUREMENT OF THE CORROSIVE MEDIA 34
4.1.6. HARDNESS TEST 36
4.1.7. SPECTROMETER TEST 37
4.1.8. ATOMIC ABSORPTION SPECTROSCOPY AND VOLUMETRIC TITRATION TEST 37
4.2. DISCUSSIONS 38
4.2.1. CORROSION RATE ANALYSIS 38
4.2.2. SPECTROMETER TEST RESULT ANALYSIS 41
4.2.3. TENSILE TEST RESULT ANALYSIS 42
4.2.4. IZOID IMPACT TEST RESULT ANALYSIS 43
4.2.5. HARDNESS TEST RESULT ANALYSIS 43
CHAPTER 5: CONCLUSION AND RECOMMENDATION 44
5.1. CONCLUSION 44
5.2. RECOMMENDATION 45
5.3. FUTURE WORK 46
REFERENCES 47
APPENDIX A: GRAPHS 49

List of Table

Table 4.1:G-1 samples tensile test result in stress VS strain…….……..……...27

Table 4.2:G-2 samples tensile test result in stress VS strain…….……...…..29

Table 4.3: Izoid impact test result……..…….……31

Table 4.4: measured Sample weight value and difference b/n before and after sample immerse (Weight loss)……..……..……32

Table 4.5: PH measurement value results……..…….……33

Table 4.6: Conductivity measurement of each group environment and respective samples……..….. 34

Table 4.7: Hardness test results……..36

Table 4.8: Spectrometer test result of sample steel material…….....37

Table 4.9: atomic absorption spectroscopy and volumetric titration test result..……...37

Table 4.10:G1 and G2 specimens surface wear results……..…….……...……...… 40

Table 4.11: Corrosion rate comparison table ….. …… ……...…….……..…….41

Table 4.12: Spectrometer based properties of the selected steel…….…….41

List of Figures

Figure 1.1:The corrosion cycle of steel…….…….....…..3

Figure 3.1: Analytical balance…….....11

Figure 3.2:Spectrometer test machine...……...…….…….....12

Figure 3.3: Atomic absorption spectroscopy…….…….……...13

Figure 3.4: Rockwell hardness test (indentation) machine…….....14

Figure 3.5: Computer-Electro-hydraulic Universal Test Machine …….....15

Figure 3.6: Izoid Impact test machine (A) and its clamping adjustment (B and C)….....16

Figure 3.7: Conductivity, PH and temperature measuring Instrument…….…...……...17

Figure 3.8: Chemicals used for intact sample and corroded sample cleaning…..……..18

Figure 3.9: Sample material and sample specimen ……..……...…20

Figure 3.10: Samples prepared for tensile test…….....20

Figure 3.11: For Izoid impact test samples manufacturing is based on the No s sequence....21

Figure 3.12:Test samples…...…….. 22

Figure 3.13: Group one Corrosive environment development and its sample containers…. 23

Figure 3.14: Group two sample containers…….….....24

Figure 3.15: Pictures from first to last are Impact test, tensile test and hardness test sample corrosive environment exposure progress respectively…….…….25

Figure 4.1: Tensile test results of samples immersion in group one corrosive environment…….…..28

Figure 4.2: Tensile test results of samples immersion in group two corrosive environment…….....….30

Figure 4.3: Izoid Impact test result of samples…….....…31

Figure 4.4: Weight loss measurement (g) VS Exposure time (hr)…….…….....33

Figure 4.5:PH value measurement result for all samples and each group……..….....33

Figure 4.6: graph A and graph B are with conductivity measurement result of group one and group two corrosive environment respectively…….....35

Figure 4.7:Corrosion rate of specimens….……..…….……..…….....40

Figure A.1: Print out of G1 sample result from Computer-Electro-hydraulic universal Test Machine……..…….....49

Figure A.2: Print out of G2 sample result from Computer-Electro-hydraulic universal Test Machine……...……..…….…….50

Figure A.3: Print out of G1and G2 sample result from Computer-Electro-hydraulic universal Test Machine…….….51

Figure A.4: Print out of sample A (5) and B (10) result from Computer-Electro-hydraulic universal Test Machine……...52

Figure A.5: Print out of sample C (4) and D (9) result from Computer-Electro-hydraulic universal Test Machine……...53

Figure A.6: Print out of sample E (3) and F (8) result from Computer-Electro-hydraulic universal Test Machine……...54

Figure A.7: Print out of sample G (2) and H (Original sample) result from computer-Electro-hydraulic Universal Test Machine…..……..55

Figure A.8: Print out of sample I (1) and J (7) result from computer-Electro-hydraulic Universal Test Machine……..….....56

Figure A.9: Print out of sample K (6) result from computer-Electro-hydraulic Universal Test Machine……...……57

List of Abbreviations Nomenclature and Acronyms

ASTM	America Society for Testing Materials
AISI	American Iron and Steel Institute
HRC	Rockwell hardness C
W_i	Initial weight (g)
W_f	Final weight (g)
W_L	Weight loss (g)
UTM	Universal Testing Machine
RH	Relative humidity
G1	Group one samples (No1-5)
G2	Group two samples (No 6-10)
Group one	Group one corrosion environment (3.5% Nacl plus distilled water)
Group two	Group two corrosion environment (Tap water)
K	Weight loss constant
D	Density
A	Surface Area
M	meter
cm	centimeter
mm	millimeter
ALWC	accelerated low water corrosion
µs	micro Siemens
ms	mile Siemens
µm	micro meter
X	times
min	minute
hr	hour
g	gram
yr	Year
SOP	Standard operational procedure

CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION

Metallic corrosion represents a loss of material that may be characterized by different techniques. The simplest is visual observation of the metal before and after being submitted to the corrosive environment and thus the number of pits or proportion of corroded areas is obtained from visual techniques. Gravimetric loss measured by weight difference referred to the surface exposed to corrosion, is also a simple, although time consuming, method to study metallic corrosion. It remains a reliable reference method [1].

For advanced socio-economic societies with much infrastructure investment in the coastal region the corrosion of steels may be a considerable problem. Even casual visual observation shows evidence of moderate to advanced corrosion, particularly for older infrastructure, despite considerable efforts to prevent it. Because of the cost of maintenance, cost of protective coatings and increasing concern about the environmental impacts of some corrosion prevention measures, there is increasing interest in the application of weathering steels. The design philosophy for weathering steels is that there is no protective coating (paint) applied and the steel is permitted to rust at an uncontrolled, but sufficiently low rate such that the corrosion loss does not exceed the corrosion allowance set at the design stage. Evidently a sacrificial amount of steel is required to provide the corrosion allowance. This may be a disadvantage for structures with significant self-weight, such as long-span bridges.

Evidently, it would be advantageous to use a steel composition that minimizes the rate of corrosion loss and thus reduces weight and cost penalties [2].

Rusting is an important phenomenon accompanied with the corrosion of carbon steel and the formation of corrosion products such as iron oxides is an a biotic process of chemical reactions. It was generally agreed by most of the researches that carbon steels are generally attacked by uniform corrosion or general corrosion. The term ‘uniform’ or ‘general’ corrosion is used to describe the corrosion damage that proceeds in a relatively uniform manner over the entire surface of an alloy. It is an even rate of metal loss over the exposed surface. It also characterized by a chemical or electrochemical reaction or metal loss due to chemical attack or dissolution that proceeds uniformly over the entire exposed surface or over a large area. During this process, the material becomes thinner as it corrodes until its thickness is reduced to the point at which failure occurs. Corrosion attack of metal in seawater is dependent mainly on the salt content (which increase the electrical conductivity) and its oxygen content [3].

1.2. BACKGROUND OF THE STUDY

Corrosion has a huge economic and environmental impact on virtually all facets of the world's infrastructure, from highways, bridges, and buildings to oil and gas, chemical processing, water and wastewater systems. In addition to causing severe damage and threats to public safety, corrosion disrupts operations and requires extensive repair and replacement of failed assets. The annual cost of corrosion worldwide is estimated to exceed $U. 8.1.8 trillion, which translates 3 to 4% of the Gross Domestic Product (GDP) of industrialized countries as presented by some groups of scientist [4].

In terms of their effect on structural integrity, marine corrosion problems range from localized issues affecting individual ship or marine fittings, for example shackles, bolts and chains, to much more severe issues associated with phenomena such as accelerated low water corrosion (ALWC) of port structures [5].

Corrosion involves the interaction (reaction) between a metal or alloy and its environment. Corrosive environments include the atmosphere, aqueous solutions, soils, acids, bases, inorganic solvents, molten salts and liquid metals. On a tonnage basis, atmospheric corrosion accounts for the greatest losses. Marine atmosphere are highly corrosive because of the presence of sodium chloride. Seawater contains predominantly sodium chloride, as well as some minerals and organic matters. Seawater is generally more corrosive than freshwater, frequently producing pitting and crevice corrosion. Soils have a wide range of compositions and susceptibilities to corrosion. Compositional variables include moisture, oxygen, salt content, alkalinity and acidity as well as the presence of various forms of bacteria [6].

Deterioration of steel bridge infrastructures constitutes a major worldwide problem in transportation engineering and maintenance management industry. Corrosion and fatigue cracking may be the two most important types of damage in aging structures. Various kinds of failures and the need of expensive replacements may occur even though the amount of metal destroyed is quite small. One of the major harmful effects of corrosion is the reduction of metal thickness leading to loss of mechanical strength and structural failure, causing severe disastrous and hazardous injuries to people [7].

Just like water flows to the lowest level, all natural processes tend toward the lowest possible energy states. Thus, for example, iron and steel have a natural tendency to combine with other chemical elements to return to their lowest energy states. In order to return to lower energy states, iron and steel frequently combine with oxygen and water, both of which are present in most natural environments, to form hydrated iron oxides (rust), similar in chemical composition to the original iron ore. Figure 1 illustrates the corrosion life cycle of a steel product [8].

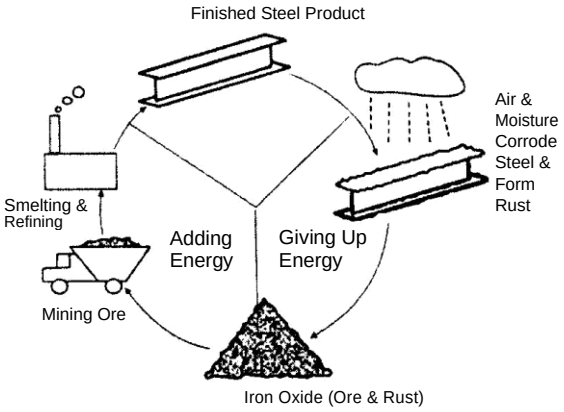


Figure 1.1: The corrosion cycle of steel

The corrosion reactions for carbon steel are:

$Fe \rightarrow Fe_2+ + 2e^-$

$Fe_2+ \rightarrow Fe_3+ + e^-$

$O_2 + 2H2O + e- \rightarrow 4OH^-$

$2Fe + 2H2O + O_2 \rightarrow 2Fe_2+ + 2OH- \rightarrow 2Fe(OH)_2$

$2Fe(OH)_2 + H2O + 1/2\ O_2 \rightarrow 2Fe(OH)_3$ (rust)

The effects of corrosion in our daily lives are both direct, in that corrosion affects the useful service lives of our possessions, and indirect, in that producers and suppliers of goods and services incur corrosion costs, which they pass on to consumers. At home, corrosion is readily recognized on automobile body panels, charcoal grills, outdoor furniture, and metal tools. Preventative maintenance such as painting protects such items from corrosion.

A principal reason to replace automobile radiator coolant every 12 to 18 months is to replenish the corrosion inhibitor that controls corrosion of the cooling system. Corrosion protection is built into all major household appliances such as water heaters, furnaces, ranges, washers, and dryers.

Of far more serious consequence is how corrosion affects our lives during travel from home to work or school. The corrosion of steel rein-forcing bar (rebar) in concrete can proceed out of sight and suddenly (or seemingly so) result in failure of a section of highway, the collapse of electrical towers, and damage to buildings, parking structures, and bridges, etc., resulting in significant repair costs and endangering public safety. For example, the sudden collapse because of corrosion fatigue of the Silver Bridge over the Ohio River at Point Pleasant, OH in 1967 resulted in the loss of 46 lives and cost millions of dollars.

Perhaps most dangerous of all is corrosion that occurs in major industrial plants, such as electrical power plants or chemical processing plants. Plant shutdowns can and do occur as a result of corrosion. This is just one of its many direct and indirect consequences.

Some consequences are economic, and cause the following:

- Replacement of corroded equipment
- Overdesign to allow for corrosion
- Preventive maintenance, for example, painting
- Shutdown of equipment due to corrosion failure Contamination of a product
- Loss of efficiency such as when overdesign and corrosion products decrease the heat-transfer rate in heat exchangers
- Loss of valuable product, for example, from a container that has corroded through
- Inability to use otherwise desirable materials
- Damage of equipment adjacent to that in which corrosion failure occurs
- Still other consequences are social. These can involve the following is-sues:
- Safety, for example, sudden failure can cause fire, explosion, release of toxic product, and construction collapse
- Health, for example, pollution due to escaping product from corroded equipment or due to a corrosion product itself
- Depletion of natural resources, including metals and the fuels used to manufacture them
- Appearance as when corroded material is unpleasing to the eye [8].

1.3. STATEMENT OF THE PROBLEM

Statement of the problem is based on the corrosion effect on steel that subjected to the corrosive environment. In most material corrosion has great side effect by reducing the weight and the strength of the materials. So this research has great response for the following two main points:-

1. To ensure the mechanical properties of a steel are stable or not in corrosive environment.
2. To decide how can use steel in corrosive environment.

1.4 ORGANIZATION OF THE THESIS

A brief outline of the work organization is classified in five chapters. The first chapter is devoted on a brief description using background of different researches and journals that are done in area of steel and corrosion environment; the thesis background; problem of the statement; general and specific objectives.

The second chapter presents literature review on corrosion effect. The third, fourth and fifth chapters are based on experiment and result to accomplish the research objective. This is done based on the following procedure:-

1. A steel specimen is prepared.
2. Corrosive environment in two different group environments is developed; which helps to accelerate the test and compare effect due to concentration.
3. Spectrometer test of the specimen is performed, weight measurement, hardness test, tensile test and Impact test on intact specimens to quantify proper mechanical properties and for analysis of corrosion effect of the specimens.
4. Corrode specimens in solutions that imitate a corrosive environment.
5. Cleaned the corroded samples and make ready for tests.
6. Perform weight measurement, hardness, tensile and Impact tests on the corroded specimens.
7. Record the results of each test.
8. Then compare the corroded specimens and the intact specimens recorded values.
9. Based on the result conclusion will be set.
10. Finally recommendation on how to use steel in corrosive environment.

1.5. PURPOSE

Based on the real world and different literature that written on the back ground part of the thesis. A steel has been exhaustively used in various industrial application, swimming pool, ships and marine machine using all over the world, so that steel to be effective in the application area, it should have stable mechanical properties. This may affecte by corrosion, since corrosion has effects on metals. From this the main purpose of this thesis to evaluate the corrosion effect on the mechanical properties of steel and to recommend in what ways steel will be used in corrosion environment.

1.6. SCOPE OF THE STUDY

The study is limited to short-term corrosion tests; which is basically concerned with evaluating mechanical properties of given steel subjected to corrosive environment. The study discussed broadly the corrosive effect on the mechanical properties based on corrosion rate using weight loss, hardness, tensile and impact testing of selected steel subjected to corrosive environments.

1.7. METHODOLOGY OF THE STUDY

In this study the methodology is based on experiment, which contains selecting steel, preparing samples, developing corrosive environment, the samples emersion to the corrosive environment based on the labeled number and exposure time measuring the weight loss, hardness, tensile and impact testing of the intent samples and the corroded to evaluate and analyze the result value. Finally the conclusion is based on how can use steel in those environments without affecting the mechanical properties especially with respect to corrosion effect.

1.8. LIMITATION OF THE STUDY

This work, as mentioned in section 1.4 above, is basically study on mechanical properties of a given steel with respect to corrosion environment exposure; but to get better result the exposure time shall be extend more than one year. This is not to say that the study duration has not enough exposure time, but:-

1. Laboratory instruments like hardness test and sample preparation machine (lath machine, milling machine and surface grinder) precision is not enough to show the right significant change before and after emersion tests with respect to the weight loss, tensile test, impact test and hardness test result.

2. Steel is used for different application in different corrosive chemical industry and environments. But to consider on those environment it is difficult according to the time and availability to develop that environment.
3. Hardness testing machine precision is not enough for these types of research change measurement.

1.9. OBJECTIVE OF THE STUDY

1, General:-

To evaluate and study the mechanical properties of a given steel subjected to different two corrosive environments.

2, Specific:-

2.1 To study and develop the corrosive environment.
2.2 To select and identify a steel.
2.3 To test and measure the mechanical properties of steel before and after subjected to the corrosive environment with different time interval and sample level number.
2.4 To evaluate the mechanical property based on the results that found from the experiment.
2.5 To study the corrosion rate of a given steel.
2.6 Based on the result to determine how to use steel in corrosion environment.

CHAPTER 2: LITERATURE REVIEW

2.1. CORROSION AND STEEL MATERIAL

Corrosion is the degradation of materials (mostly metals and their alloys) as a result of their interactions or chemical reactions with the environment. A coupon immersion test was carried out in the laboratory to determine the rate of corrosion of stainless steel in both fresh water and salt water samples. The result is proved that corrosion rate of stainless steel in salt water is relatively higher than the rate in fresh water. This was as a result of the difference in the physiochemical properties of both water samples, the salt water sample was observed to have more aggressive elements that would initiate the formation of pits on stainless steels. The followings were recommended to reduce or prevent corrosion on stainless steels; selection of materials should be based on their ability to offer resistance to the aggressive nature of the service environment, application of protective coatings and effective control of the aggressive materials of the medium and application of cathode or anodic protection on the materials [4].

The marine atmospheres are usually highly corrosive, due to the presence of chlorides, and the corrosion tends to be significantly dependent on wind direction, wind speed and distance from the coast. One of the most frequently corrosion type is the atmospheric corrosion. This has been reported to account for more failures in terms of cost and tonnage than any other type. About 80% from all degradations produced by corrosion in the metallic constructions are due to the atmospheric corrosion. The atmospheric conditions for corrosion are very complex and the corrosion rates vary in function of geographic zone, of season and daily time. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction, etc. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction, etc. These variables make meaningful results from laboratory experiments very difficult to obtain. The object of this work is to outline the principles that govern atmospheric corrosion of the carbon steel the construction material with the largest application how is influenced his corrosion rate by the atmospheric variables and that are the corresponding corrosion products [19].

Corrosion fatigue behavior of a medium strength structural material was studied in air and in 3.5% NaCl solution. Emphasis was placed on the study of corrosion pit formation and the development of cracks from pits.

Pitting and crack propagation were quantified throughout the fatigue loading thereby allowing a model to be developed that included the stages of pitting and the pit-to-crack transition in order to predict the fatigue life.

The results showed that a large number of corrosion pits with small size form at a very early stage in the fatigue lifetime. The number of pits and subsequent cracks was found to be higher at higher stress levels leading to multiple crack development and coalescence.

When compared to air, fatigue life in a corrosive environment was significantly reduced at low stress levels due to pitting damage, indicating a dominant role of corrosion over that of mechanical effects. An important aspect of the corrosion fatigue mechanism is that of time-dependent mechanisms. In this respect, conducting the tests at different frequencies is seen as an obvious follow on study.

From analysis of these observations, a corrosion fatigue model has been developed taking into account: pit growth, pit-to-crack transition and crack growth [9].

Due to aggressive environment prevailing in and around Gulf seacoast, the materials of construction are subjected to corrosion of varying degree. There are many factors influencing the initiation of one or several corrosion processes. These factors include nature of material, surface finish, temperature, humidity, wind directions, rainfall, etc.

Steels are the predominant constructional materials in seashore structures including desalination plants which are subjected to general or localized corrosion of varying degree. Complete systematic information regarding corrosively of materials in Gulf seawater is lacking. Keeping in view the importance of the corrosion data of materials particularly steels in Gulf seawater, a systematic study on this subject had been initiated in 1990 and was completed in 1996. This paper provides the results of this study concerning with the corrosion behavior of steels, in Gulf seawater. The steels include carbon steels, stainless steels and super stainless steels (austenitic, ferritic and duplex). The study encompasses the factors influencing general, pitting and crevice corrosion of materials.

The effects of TDS in general and chloride concentration in particular and degree of chlorination have been discussed in detail. The role of dominant alloy addition on the corrosion behavior of steels has been emphasized. Weight loss and electrochemical techniques have been employed in determining the corrosion rates of materials. Effect of surface finish on crevice attack has been investigated in detail. Rank orders of corrosion rates of steels under different conditions have been presented and their importance vis-à-vis materials selection in desalination plants is discussed [10].

This paper aims to investigate the corrosion effect of mild steel in orange juice using a weight loss technique. Test specimens with known weights were immersed in the test media (orange juice with preservatives, natural orange juice and water) for a total exposure time of 10 days. Weight loss was measured at two day intervals for the determination of corrosion rate effect. Corrosion aggressive substance was discovered to have significant impact on the degradation of equipment and the maintenance or replacement of products lost or contaminated as a result of corrosion reactions.

Results revealed that the corrosiveness of sweet orange juice on mild steel was mainly a function of its acidity. Packed orange juice with preservative was most corrosive followed by natural orange juice and water, respectively [20].

Corrosive wear is one of the most destructive processes encountered in industry. However, how the mechanical and electrochemical actions contribute to the material removal during corrosive wear is still not well understood. In this work, an electrochemical scratch method was applied to study the synergic attack of wear and corrosion to high-Cr cast iron, cast iron and mild steel in a 3.5% NaCl solution and tap water, respectively. Contributions of corrosion, wear and corrosion-wear synergism to the total material loss were evaluated using the technique in combination with other experiments, including polarization test, scratch profile measurement, scratch test under cathodic protection. The emphasis of the research was to evaluate how corrosion and wear mutually affected each other, which helped to understand the synergism of corrosion and wear for the materials. The contributions of mechanical and corrosion actions to corrosive wear of the materials were correlated to their mechanical and electrochemical properties. It was determined that the electrochemical scratch method was effective for investigating the synergism of wear and corrosion. Wear and corrosion to high-Cr cast iron, cast iron and mild steel in a 3.5% NaCl solution and tap water, respectively. Contributions of corrosion, wear and corrosion-wear synergism to the total material loss were evaluated using the technique in combination with other experiments, including polarization test, scratch profile measurement, scratch test under cathodic protection. It was observed that mechanical wear dominated the total material loss caused by corrosive wear for all the materials under study. Effects of wear on corrosion depended on the material properties and also the corrosively of the environment [14].

From the above literature review it can be conclude that; life of steel material can be predict using corrosion rate with respect to the exposed environments. It is an appreciable input to this study to evaluate the mechanical properties of AISI1050 steel and its corrosion rate.

3. EXPERIMENTAL METHODS AND CONDITIONS

3.1 MATERIAL

In this study the material; which are used for samples; are carbon steel C50 (AISI-1050, ASTM A684) in addition to this [15].

Chemicals: analytical grade NaCl, 500ml Ethanol alcohol(100%),500ml Acetone(100%), 600ml toluene, silver nitrate (titrant), potassium dichromate (as indicator), distilled water.

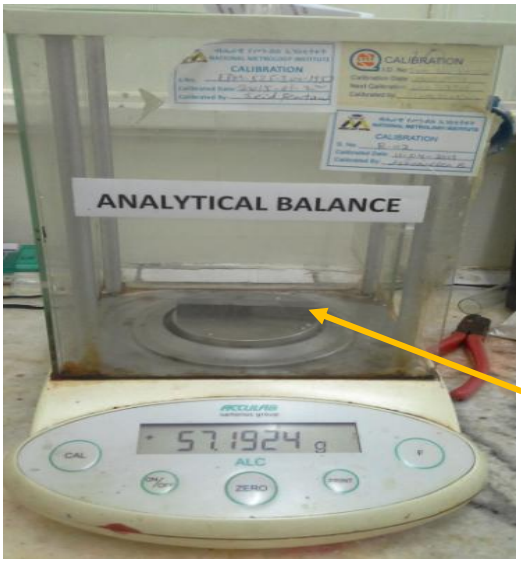
3.2 METHOD AND PROCEDURE

3.2.1 METHOD

-Weight measuring, Spectrometer testing, atomic absorption spectroscopy, hardness test, tensile test, izoid impact test and volumetric titration.

3.2.1.1 WEIGHT MEASUREMENT WITH ELECTRONIC SCALES

Electronic scales are a precision instrument with measuring scale 0.1mg and minimum weighting range is 0.01g and maximum range 80g [16]. It uses for weight measurement method, which is one of the method helps to evaluate the corrosion rate and weight loss by measuring the weights of samples based on order number and time of waiting in corrosion environment. The measured value is the main input for corrosion rate analysis to predict the future effect. The test instrument name: Analytical balance model: MS 2045, Sir.No: 8519903613, made in Switzerland by Mettler Toledo.



. *Figure 3.1: Analytical balance*

3.2.1.2 SPECTROMETER TEST

Spectrometer test machine is used to identify the material chemical composition by putting the sample material on the nozzle of argon gas burner then the result will display on the computerized operating panel. The spectrometer model-PP 902 00041;
Sir No: Specrotest TX25 and Made in Germany.

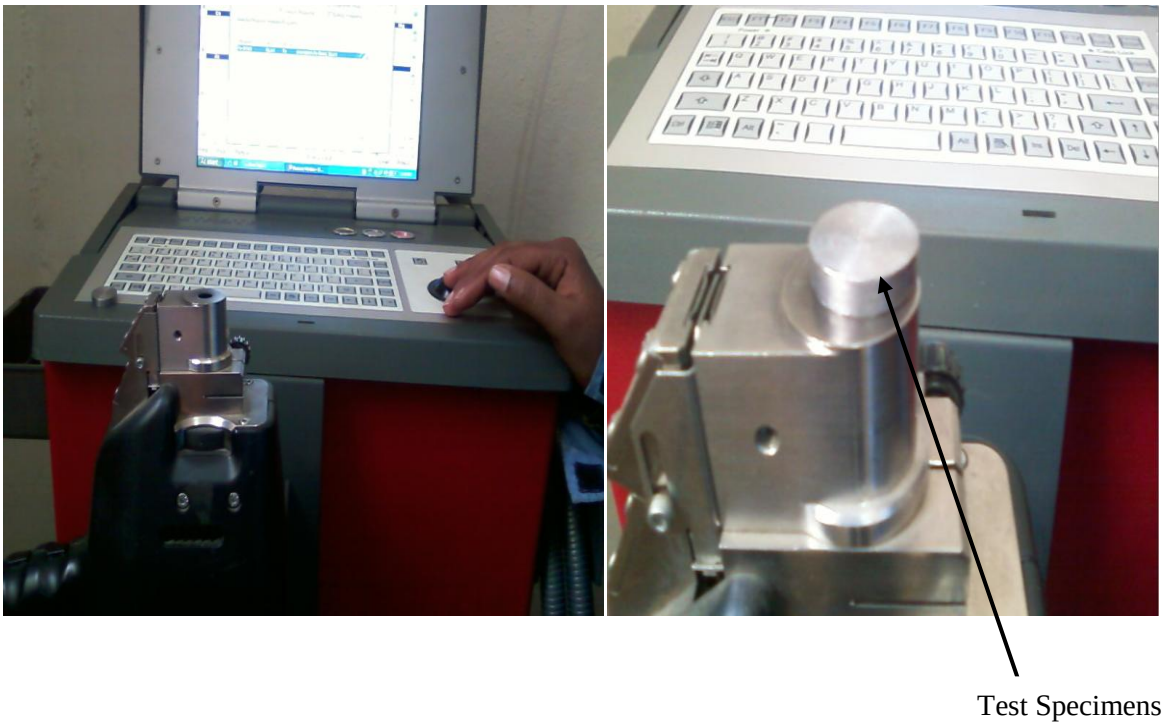


Figure 3.2: Spectrometer test machine

Spectrometer test procedure and test process:

-First the gas pressure (amount) of the Argon cylinder was checked.

- The power supply socket was plugged on

- The spectroscopic test- machine power was switched on

-First heating up for 15min up to 35^{O}C; till polish the surface of the sample material

-After the temperature reached put the sample on the burner nozzle

- The test continued by pressing the nozzle burner switch and with pressing the sample on the nozzle till the test result will come.

- The test was repeated at least three times to take the average.

3.2.1.3 ATOMIC ABSORPTION SPECTROSCOPY AND VOLUMETRIC TITRATION

This technique helps for determining the concentration of a particular metal element in a sample corrosive environment. Atomic absorption spectroscopy can be used to analyze the concentration of over 72 different metals in a solution. The technique typically makes use of a flame to atomize the sample with the help of flame and hallow cathode lamp. Then the amount of energy is specific to a particular electron transition in a particular element. As the quantity of energy put into the flame is known, and the quantity remaining at the other side (at the detector) can be measured, it is possible to calculate how many of these transitions took place, and thus get a signal that is proportional to the concentration of the element being measured. The test instrument name is Atomic Absorption Spectroscopy with Model: B3130126, Sir No: 851S1110106, Made in USA by Perkin Elmer. Instruments.

Figure 3.3: Atomic absorption spectroscopy

3.2.1.4 VOLUMETRIC TITRATION:

It is one of the three categories of titrimetric methods. Titrimetric methods are analytical procedures in which the amount of an analyte is determined from the amount of a standard reagent required to react completely with the analyte. Volumetric methods - measuring the volume of a solution (of known concentration) required to react completely with an analyte.

3.2.1.5 HARDNESS TEST

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell (AS1815) is the one most frequently used. The basic principle used in the Rockwell tests that a hard material can penetrate a softer one. We then measure the amount of penetration and compare it to a scale. For ferrous metals, which are usually harder than nonferrous metals, a diamond tip is used and the hardness is indicated by a Rockwell "C" number. Hardness, however, is not a fundamental property, because the resistance to indentation depends on the shape of the indenter and on the load applied. This method is helps to measure the hardness of the samples before and after exposure based on the duration of exposure to corrosive environment. This measured value is one of the mechanical properties of steel material; so it is one of the in-put to evaluate and decide the effect of corrosion. The machine name is O.M.A.G Hardness tester machine model: 206 RT and Sr.No: 363602 made in ITALY with indenter type diamond tip in 120^0.

Figure 3.4: Rockwell hardness test (indentation) machine

3.2.1.6 TENSILE TEST

The tension test is the most common method for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus, and strain hardening capability. Tension test is widely used to provide basic design information on the strength of materials and an acceptance test for the specification of materials. The major parameters that describe the stress-strain curve obtained during the tension test are the tensile strength (UTS), yield strength, elastic modulus (E), percent elongation (Δ L%) and the reduction in area (RA%). Toughness, Resilience, Poisson's ratio (ν) can also be found by the use of this testing technique [17].

In this test, a specimen is prepared suitable for gripping into the jaws of the testing machine type that will be used. The specimen used is approximately uniform over a gage length (the length within which elongation measurements are done).

The type of tensile testing machine is Computer-Electro-hydraulic Universal Testing Machine with model: WAW-600 and serial No: 16259.

Figure 3.5: Computer-Electro-hydraulic Universal Test Machine

3.2.1.7 IZOID IMPACT TEST

Impact tests determine the energy required to completely break a specimen. This energy is called the impact toughness of the material. Impact tests are also useful for determining the transition temperatures of materials.

Izod impact test procedures described in ASTM Standard D 256, we have seen a growing interest in ISO Standard DIS 13802, and decided to follow its procedural requirements [18].

The Izod impact test, the test piece is a cantilever, clamped upright in an anvil, with a V-notch at the level of the top of the clamp. The test piece is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed height, to give a blow of 120ft lb (162.7 Nm) energy. After fracturing the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount is read. The testing machine model: HLX30DG; Serial No: 2013/H6 is made in INDIA by ENKAY. Enterprise.

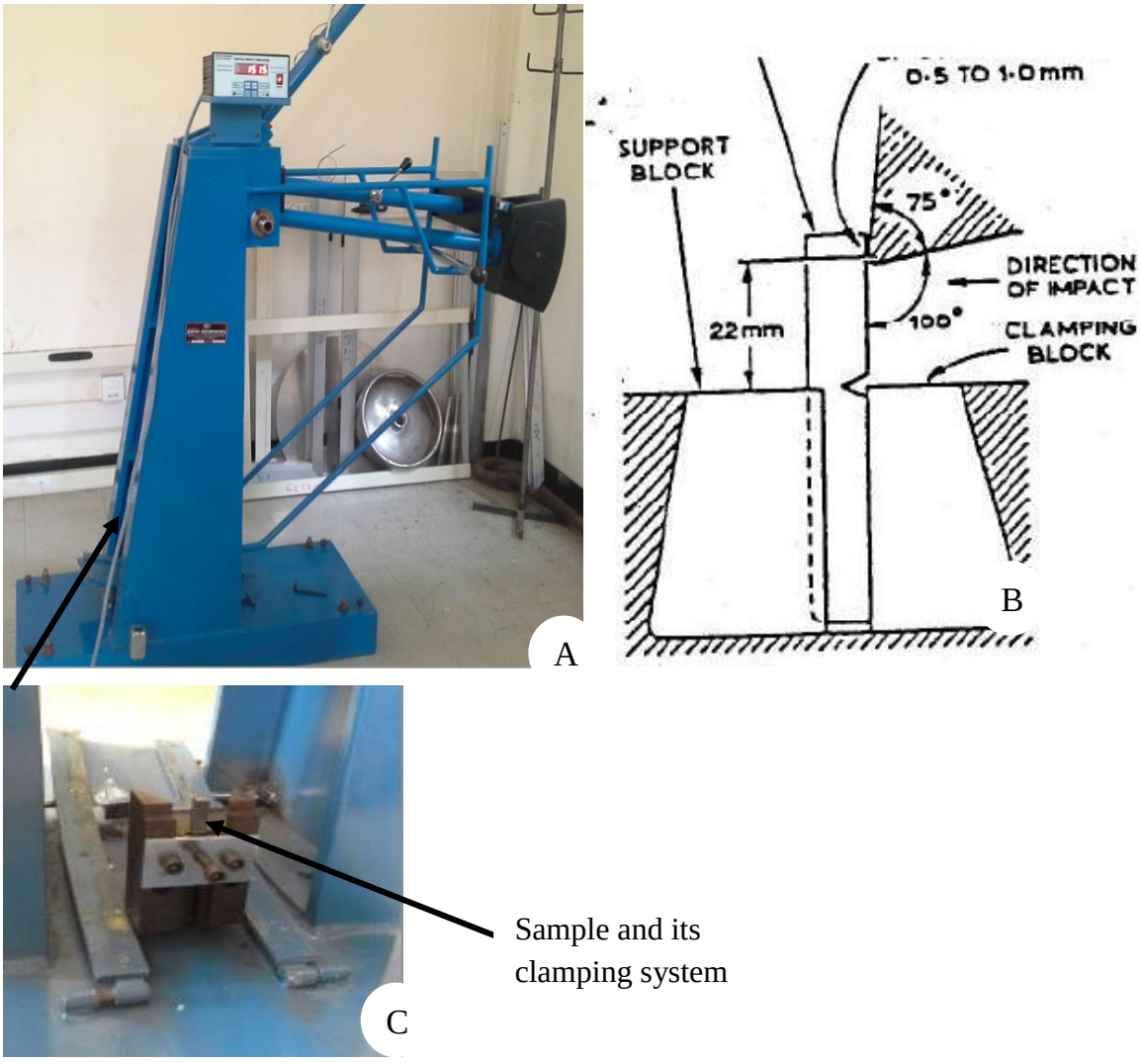


Figure 3.6: Izoid Impact test machine (A) and its clamping adjustment (B and C)

3.2.1.8 CONDUCTIVITY METER

Conductivity meter used to measure conductivity of sample water (the amount of ions anion and cathion). It measures how much electricity is being conducted through a centimeter of water. Specific conductivity is expressed as mhos per centimeter (M/cm), sometimes called Siemens per centimeter (S/cm). Because a mho (or Siemen) is a very large unit, the micromho (micro siemen) or millimho (milli siemen) typically is used (ms or µs).For this study the machine used for conductivity test is model: AD8000, Made in Romania Europe.

3.2.1.9 PH METER

PH meter is an important to measure the water acidic or basic, the H+ or OH^{-}. PH is expressed in a scale with ranges from 1 to 14. A solution with a pH less than 7 has more H+ activity than OH-, and is considered acidic. A solution with a pH value greater than 7 has more OH- activity than H+, and is considered basic. The pH scale is logarithmic, meaning that as you go up and down the scale, the values change in factors of ten. A one-point pH change indicates the strength of the acid or base has increased or decreased in the solution; for this condition the corrosive environment acid or base condition. The PH test machine model: Seven easy PH 8603, Sir. No: 1230255748, Made in Switzerland by Mettler Toledo group.

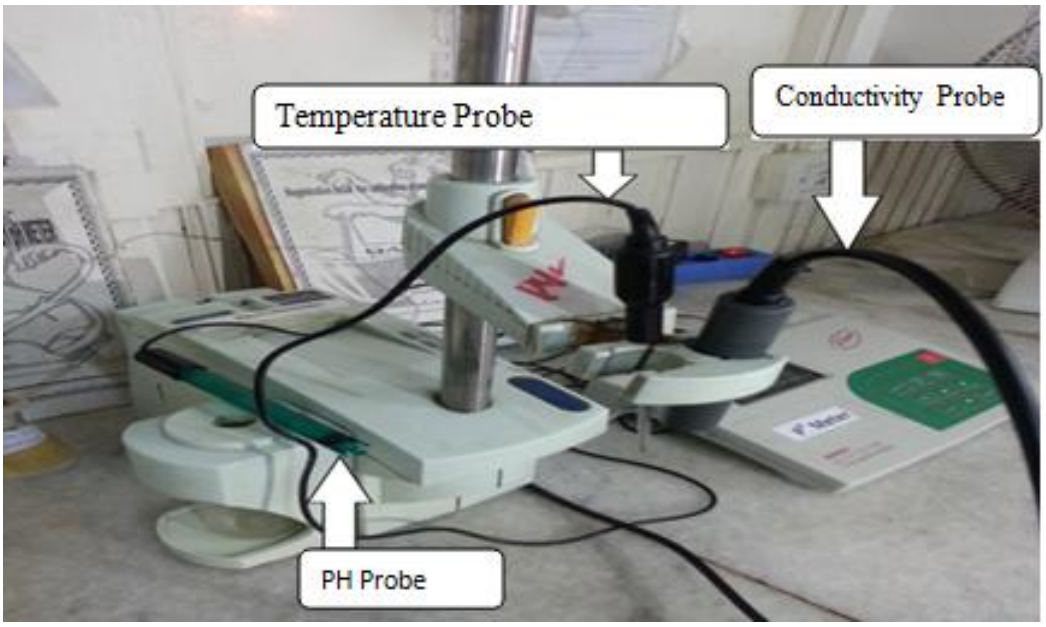


Figure 3.7: Conductivity, PH and temperature measuring Instrument

3.2.2 PROCEDURE OF THE EXPERIMENT

1. Steel is selected; which are used for industry machinery for gear, blades and shaft construction.

2. Preparing sample materials

3. Measured the mechanical properties of the selected sample materials.

4. Sample containers were prepared.

5. Corrosive environment was developed then labeled as group one (3.5% NaCl with distilled water based on ASTM G 44, G 47) and group two (tap water) [22].

6. Immerse the samples in developed corrosive environment.

7. With drawn samples in ten days intervals for mechanical testing; then based on the following cleaning procedure is taken for each samples.

7.1. Samples withdrawn first dipped samples in distilled water for 5 minutes.

7.2. Followed by washing all the samples in ordinary fresh water with a soft brush.

7.3. Then the samples immerse in ethanol alcohol for 5 minutes

7. 4. After which, the samples were soaked in Acetone for 5 min.

7.5. Finally cleaned with distilled water till the acetone completely remove from the surface then soaked in Toluene for 5 minutes then till the toluene completely removed rinse the samples with distilled water.

Ethanol alcohol (100%) Acetone (100%) Toluene (100%)

Figure 3.8: Chemicals used for intact sample and corroded sample cleaning

8. Finally allow to dry in sun, followed by measuring the initial weight (W_i) of the individual samples using a digital weighing (Analytical) balance.
9. The hardness measured in Rockwell hardness testing machine.
10. Then put the weighed and tested samples inside the solutions.
11. After every 10days (240 hours) of immersion, each of the samples were brought out and thoroughly cleaned by the same procedure as discussed before then weighed.
12. The weight loss (W_L) or ($W_L=W_i-W_f$) in milligram and the corrosion rate was calculated using the ASTM standard formula.
13. Plotting the results of corrosion rat and mechanical properties with time graph; which obtained before and after the corrosion effect.
14. Other mechanical tests (tensile and Impact) is also done based on the above procedure.

3.3 TEST MATERIAL

The test material is taken AISI 1050 [C 50] or ASTM 684 diameter 20mm and length 3500mm was taken.

3.3.1 PREPARATION OF TEST PIECES

Test pieces are manufacture from the test material for different mechanical properties test based on the test machine required sample dimension. In this work four different testes are taken: weight loss, Hardness, Tensile and Izoid Impact Test.

3.3.1.1 SAMPLE PREPARE FOR SPECTROMETER AND HARDNESS TEST

Rockwell hardness tests are measured by a steel ball or diamond cone indenter. RHN is given in various scales (B, C, R, etc.) depending on indenter and scales used. ASTM E-18 details a standard method for determining RHN for metals and gives a table of scale symbols [11]. Based on the test machine requirement test piece is prepared using lath machine based on the following procedure:

1. The test material is hacked with the help of Hack Saw in the length of 150mm.
2. Machined the piece with lath machine first by facing, turning and parting with the required dimension diameter 19mm and thickness 5mm depend on the test instrument suitability.

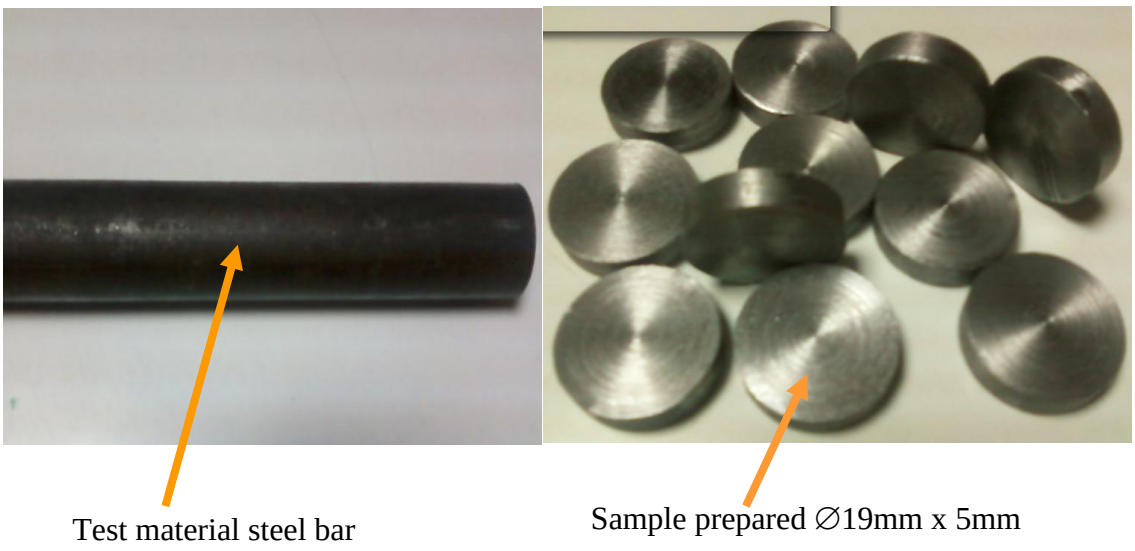


Figure 3.9: Sample material and sample specimen

3.3.1.2 SAMPLE PREPARE FOR TENSILE TEST

Computer Controlled Electro-Hydraulic Servo Universal Test Machine is the testing machine that used in tensile test. It requires sample dimension diameter ≤ 30mm and length more than 150mm based on this using manufacturing machines (hack saw and lath machine) the required samples are machined in the operation of cutting in the length of 200mm then by facing, turning and parting the test material. Finally the test pieces are made based on the dimension as shown in the following picture:-

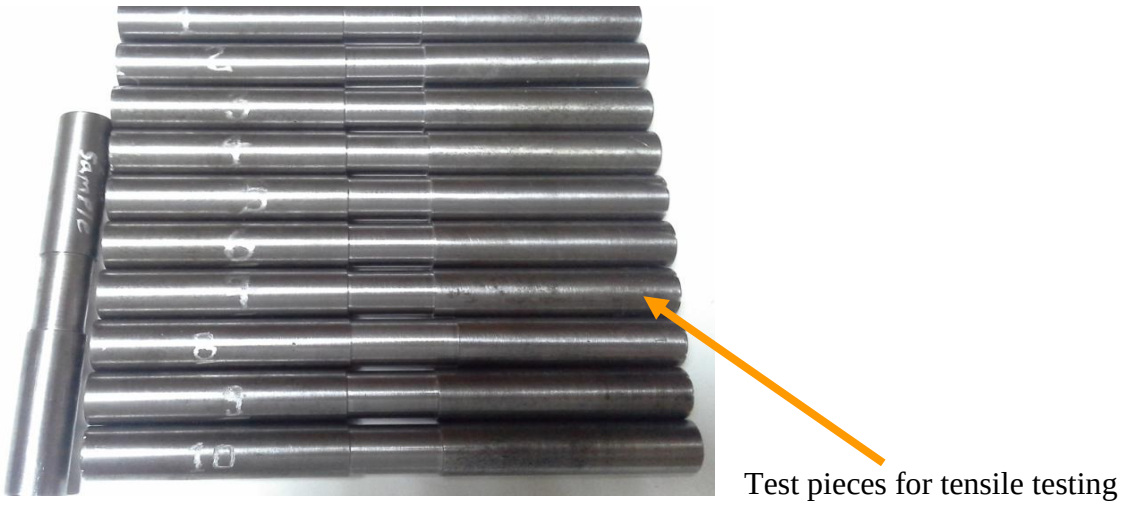


Figure 3.10: Samples prepared for tensile test

3.3.1.3 PREPARED SAMPLES FOR IZOID TEST

Izoid test method is used to determining the behavior of materials subjected to shock loading. Specimen supported as a cantilever beam is struck by a weight at the end of a pendulum. Impact strength is determined from the amount of energy required to fracture specimen. ASTM E-23 describes a standard test procedure, specimens (including notch shapes) and apparatus for Izod impact testing of metals [12]. Based on this standard procedure the test samples are prepared; using hack saw for cutting then lath machine for turning into 14mm diameter and parting with length 75mm after finished the lath machine activity using milling machine and end mill cutter the test pieces shape is changed into square with dimension 10mm*10mm then finally using high speed surface grinder the square surfaces are made into smooth and shine surface with batter precision. Some of the process and result picture as follows:-

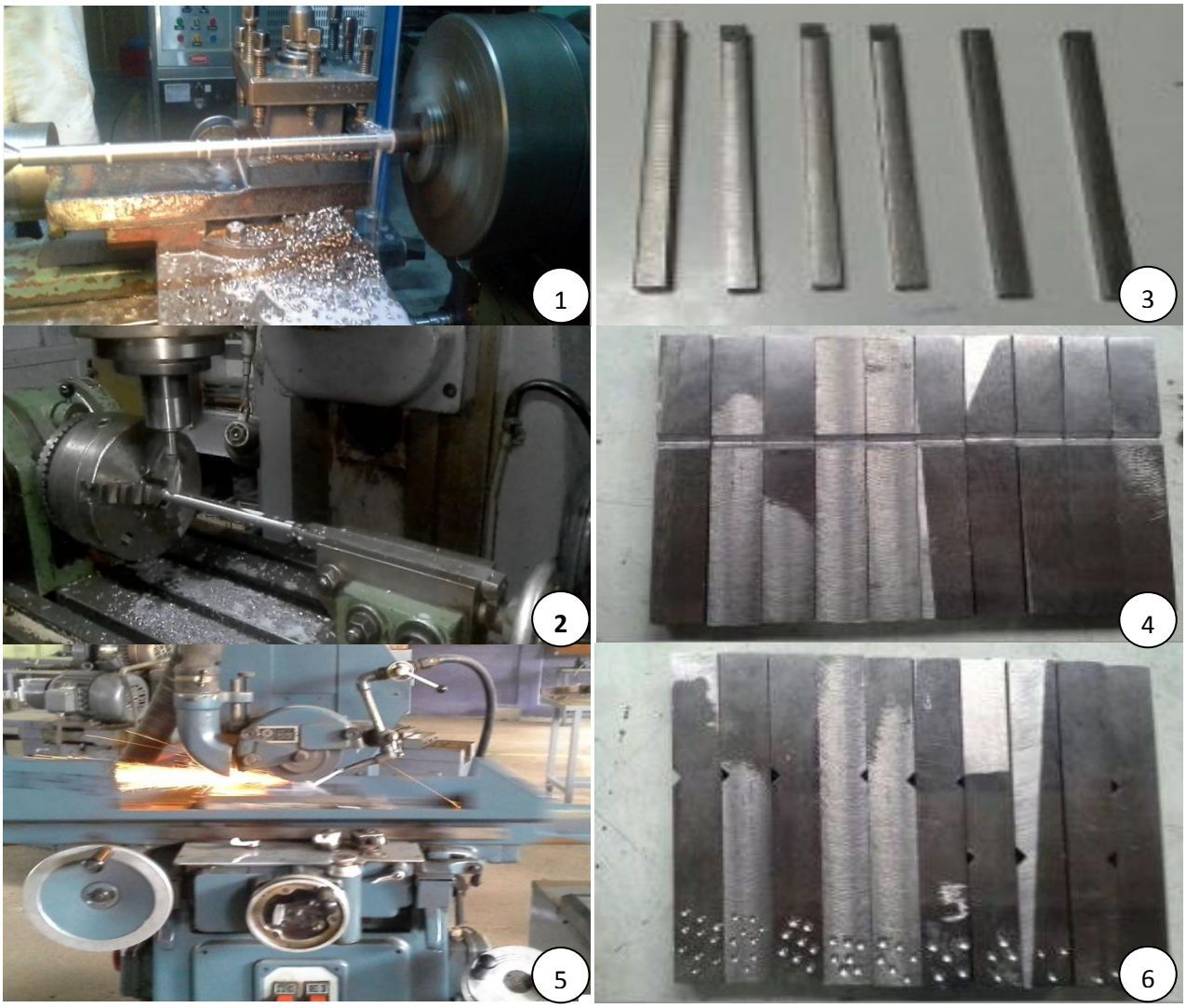


Figure 3.11: For Izoid impact test samples manufacturing was based on the No s sequence

The test sample specimens are prepared based on American Society of Testing Materials (ASTM) standard and test machines required dimensions. This dimension is illustrated as shown below.

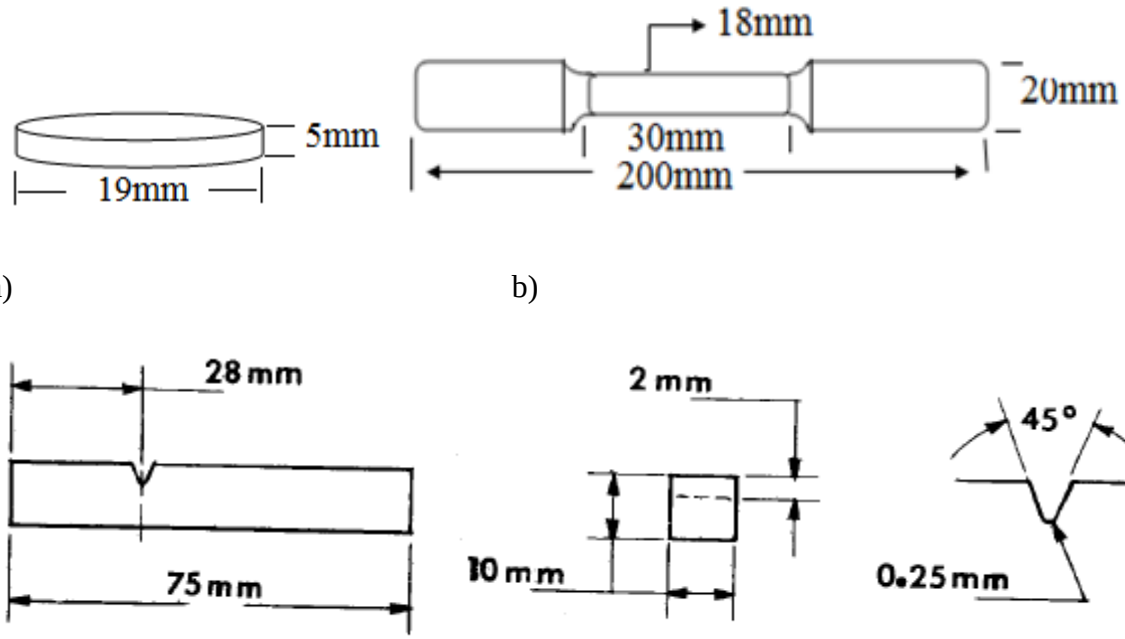


Figure 3.12: Test samples

a) Specimen dimensions for Spectrometer and Hardness Testes
b) Specimen dimensions for Tensile Test
c) Specimen dimensions for Izoid Impact Tests

3.4 EXPERIMENTAL, CONDITIONS AND TESTS

The main objective of this work is to evaluate mechanical properties of steel in corrosive environment, As explain in 3.3.1 the specimens are prepared for each test methods after this the two corrosive environments are developed, The first is by taking 3.5% NaCl in distilled water and the second is with tape water [14] . The test specimens are ten in number for two environments are divided in to two groups. For each group five specimens are prepared and each specimens stay in the environment for ten days (240hr) based on accelerated lab testing procedure of American society of testing materials (ASTM) standard then the specimens are tested with ten, twenty, thirty, forty and fifty days interval with respect to specimen one, two, three, four and five. The time interval for the second group is also the same with the first one.

3.4.1 DEVELOPMENT OF CORROSIVE ENVIRONMENT

Group one corrosive environment 3.5%NaCl plus distilled water is prepared based on the following procedure:

1. Analytical grade salt (NaCl) 87.5g is taken by measuring in analytical balance.
2. Distilled water 2.5 lit with conductivity 0.3µs and PH-7 is prepared.
3. Five container cups is prepared with labeled No 1up to 5 respectively.
4. Five litter bucket for mixing the salt with distilled water together.
5. After completely dissolved the analytical salt with distilled water the conductivity and PH of the solution was measured.
6. Pour 0.5 lit solutions in to each prepared sample containers.

Figure 3.13: Group one Corrosive environment development and its sample containers

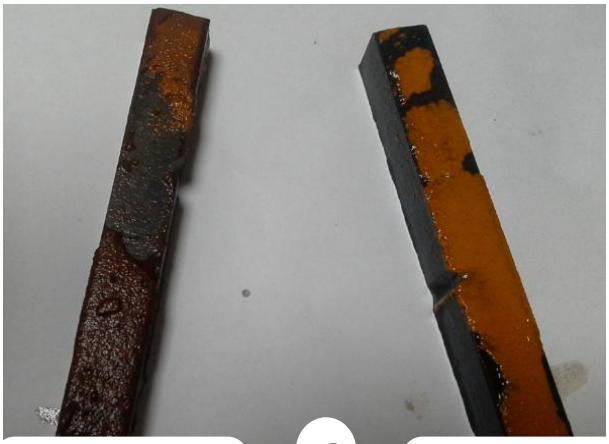
For development of group two corrosive environments using 2.5lit tap water then measured the conductivity and PH of the water. Finally pour 0.5 lit for each five sample containers. These group two environments ware labeled from No 6 up to 10 on the sample containers.

Figure 3.14: Group two sample containers

3.4.2 EXPERIMENTAL SETUP AND PROCESS

After development of corrosive environment and samples preparation, the sample weight is measured in gram; conductivity and PH of the solution is also measured then spectroscopy test, hardness test, impact test and tensile test measurement was taken. After this measurement all the samples washed fist with distilled water then immerse in 100ml ethanol alcohol (100%) for 5min then wash again with distilled water and immerse in 100ml acetone (100%) for 5min then again washed with distilled water finally immersed to the respective corrosive environment containers, then the sample containers are kept in a room of 25ºC temperature and 40-60% RH with the help of air conditioner (AC).

One samples is taken from each group (G1 and G2) in ten days interval then washed with distilled water after that immerse in 100ml toluene (100%) for 5 min next washed again with distilled water next dry with dry clothes and wait for 30min for better dry finally measure the hardness, tensile, Impact and weight for each sample based on the respective labeled numbers simultaneously the corrosive environment conductivity and PH measured and recorded.



G-2 Sample after corrosion

G-1 Sample after corrosion

Figure 3.15: Pictures from first to last are Impact test, tensile test and hardness test sample in corrosive environment exposure progress respectively.

The above figure 3.15 describe as follows:

A, Izoid Impact Test sample immersed in corrosive environment

B, Izoid Impact Test sample during corrosion effect

C, Tensile test sample immersed in corrosive environment

D, Tensile test sample during corrosion effect

E, Hardness and spectrometer test sample immersed in corrosive environment

F, Hardness and spectrometer test sample during corrosion effect

G, Samples after corrosion exposure; which are taken from group one and two.

3.5 EQUIPMENTS (TEST MACHINES)

The equipments and testing machines that are used for this research:-

-Sample container, and for titration (pippet, burette, magnetic stirrer, erleminier flask)

-Laboratory testing machine, i.e. Spectrometer, Analytical balance, Universal testing machine, Rockwell hardness testing machine, Impact testing, atomic absorption spectrometer, volumetric titration, Analytical digital electronics balance.

-For sample manufacturing: - Hack saw, digital caliper, Lath machine, vertical milling machine, Surface grinder.

CHAPTER 4: EXPERIMENTAL RESULT AND DISCUSSION

4.1 EXPERIMENTAL RESULTS

4.1.1. TENSILE TEST

In this test the sample is prepared based on the tensile test machine requirement then after the sample exposed to corrosive environment for the required time interval the test is performed; with respect to the sample number and day interval of the two group sample. Then after the result is printed and saved on the computer in force VS strain; this result is tabulated in stress (F/A) VS strain as shown below:

Sample-5		Sample-4		Sample-3		Sample-2		Sample-1		Original sample	
strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)
0	0	0	0	0	0	0	0	0	0	0	0
0.01	39.74	0.012	39.96	0.01	39.08	0.016	39.3	0.01	39.3	0.01	39.3
0.02	79.48	0.0158	79.92	0.0175	78.16	0.023	78.6	0.018	78.6	0.018	78.6
0.026	119.21	0.025	119.88	0.025	117.24	0.03	117.9	0.025	117.9	0.025	117.9
0.033	158.95	0.03	159.84	0.03	156.32	0.038	157.2	0.03	157.2	0.032	157.2
0.036	198.69	0.035	199.8	0.037	195.4	0.043	196.49	0.035	196.49	0.035	196.49
0.042	238.43	0.04	234.76	0.039	235.48	0.048	235.79	0.038	235.79	0.04	235.79
0.046	278.17	0.045	279.73	0.045	273.56	0.056	275.08	0.043	275.08	0.044	275.08
0.05	317.9	0.048	319.69	0.048	312.64	0.058	314.38	0.046	314.38	0.048	314.38
0.055	357.64	0.054	359.65	0.052	351.72	0.063	353.68	0.05	353.68	0.053	353.68
0.058	397.38	0.058	399.61	0.055	390.8	0.068	392.98	0.054	392.98	0.055	392.98
0.063	437.12	0.062	439.57	0.059	429.88	0.072	432.27	0.058	432.27	0.058	432.27
0.066	476.85	0.065	479.53	0.064	468.96	0.078	472.57	0.063	472.57	0.063	472.57
0.07	516.59	0.069	519.49	0.068	508.04	0.084	510.87	0.065	510.87	0.066	510.87
0.074	556.33	0.074	559.49	0.07	547.12	0.09	550.17	0.068	550.17	0.07	550.17
0.077	596.07	0.078	599.41	0.073	586.2	0.095	589.46	0.073	589.46	0.073	589.46
0.082	635.81	0.082	639.37	0.077	625.28	0.102	628.76	0.076	628.76	0.076	628.76
0.085	675.54	0.086	679.33	0.082	664.36	0.108	668.06	0.08	668.06	0.08	668.06
0.09	715.28	0.09	719.29	0.086	703.44	0.112	707.36	0.084	707.36	0.084	707.36
0.094	755.02	0.095	759.25	0.09	742.52	0.122	746.65	0.088	746.65	0.088	746.65
0.1	794.76	0.1	799.22	0.094	781.6	0.13	785.95	0.092	785.95	0.093	785.95
0.157	834.5	0.18	839.18	0.098	820.68	0.14	825.25	0.098	825.25	0.098	825.25
0.118	861.9	0.12	867.35	0.108	859.76	0.152	847.52	0.18	850.54	0.106	864.55
0.13	834.5	0.13	839.18	0.11	865.05	0.16	825.25	0.12	825.25	0.11	872.88
0.14	802.71	0.14	799.22	0.128	820.68	0.172	785.95	0.128	785.95	0.117	864.55
0.148	762.97	0.15	759.25	0.138	781.6	0.183	746.65	0.13	782.02	0.13	825.25
0.15	762.97	0.155	755.26	0.155	742.52	0.184	738.79	0.134	774.16	0.145	750.58

Table 4.1: G-1 samples tensile test result in stress VS strain

Finally for comparison all results of G1 plotted with excel on the same plane. The same thing is done for the second group. The plots are as follows:

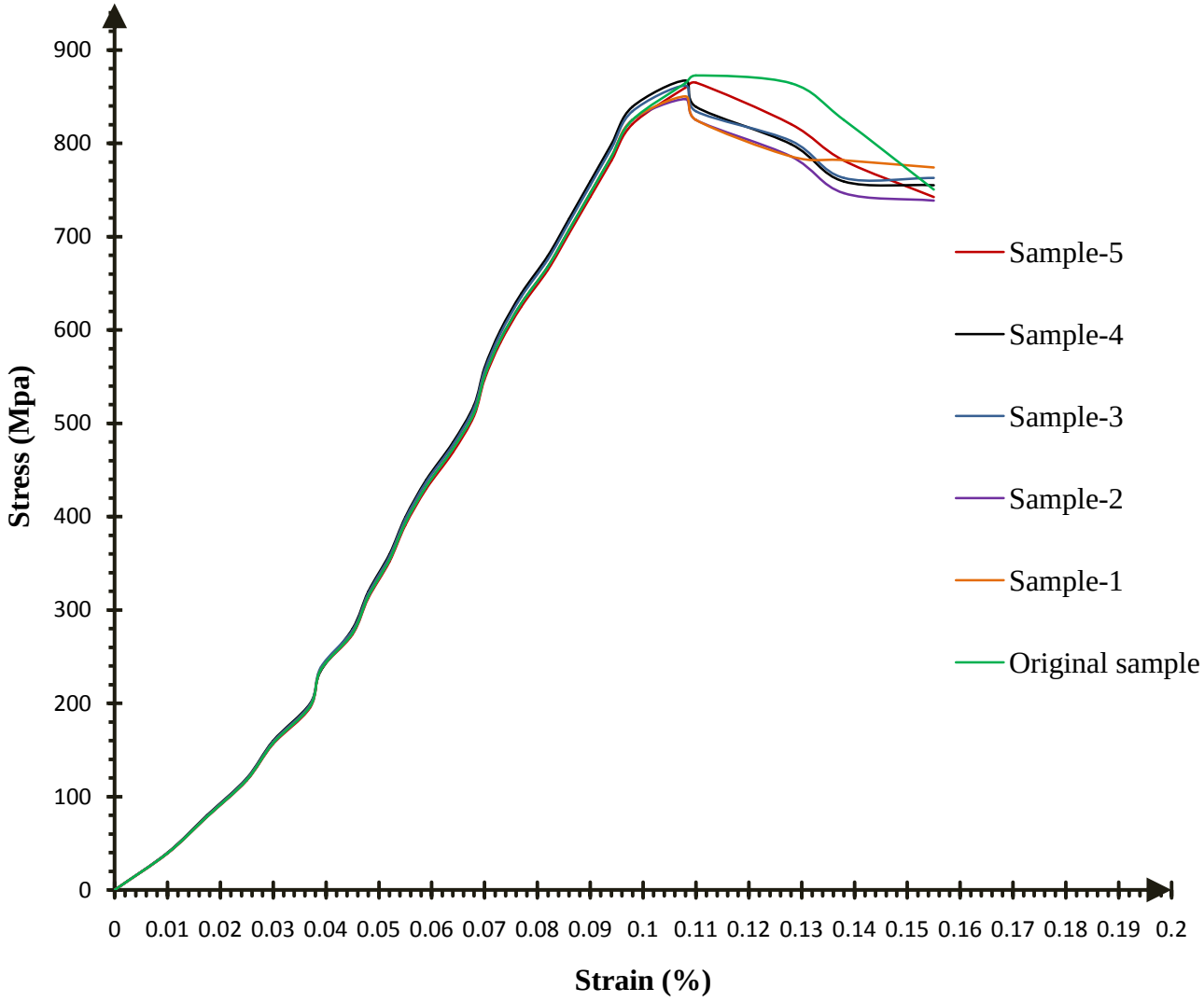


Figure 4.1: Tensile test results of samples immersion in group one corrosive environment

The tensile test result of the intact sample and G-2 corroded samples with the interval of ten days test was as shown below:

Sample-10		Sample-9		Sample-8		Sample-7		Sample-6		Original sample	
strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)	strain	Stress (MPa)
0	0	0	0	0	0	0	0	0	0	0	0
0.01	39.83	0.016	39.3	0.01	40.05	0.01	39.3	0.011	39.3	0.012	39.52
0.02	79.65	0.023	78.6	0.018	80.1	0.019	78.6	0.019	78.6	0.021	79.03
0.028	119.48	0.03	117.9	0.024	120.15	0.026	117.9	0.027	117.9	0.028	118.55
0.034	159.31	0.038	157.2	0.03	160.2	0.032	157.2	0.03	157.2	0.033	158.07
0.038	199.13	0.043	196.49	0.035	200.25	0.037	196.49	0.034	196.49	0.039	197.58
0.042	238.96	0.048	235.79	0.04	240.3	0.04	235.79	0.04	235.79	0.046	237.1
0.048	278.79	0.056	275.08	0.045	280.35	0.045	275.08	0.045	275.08	0.049	276.62
0.056	318.61	0.058	314.38	0.048	320.4	0.048	314.38	0.048	314.38	0.052	316.13
0.058	358.44	0.063	353.68	0.053	360.45	0.052	353.68	0.052	353.68	0.058	355.65
0.061	398.27	0.068	392.98	0.056	400.51	0.056	392.98	0.057	392.98	0.063	395.17
0.067	438.1	0.072	432.27	0.06	440.56	0.059	432.27	0.059	432.27	0.068	439.68
0.07	477.92	0.078	472.57	0.064	480.61	0.063	472.57	0.064	472.57	0.07	474.2
0.074	517.75	0.084	510.87	0.068	520.66	0.068	510.87	0.066	510.87	0.073	513.72
0.079	557.58	0.09	550.17	0.072	560.71	0.07	550.17	0.069	550.17	0.078	553.24
0.082	597.4	0.095	589.46	0.075	600.76	0.077	589.46	0.072	589.46	0.082	592.75
0.088	637.23	0.102	628.76	0.078	640.81	0.078	628.76	0.078	628.76	0.088	632.27
0.092	677.06	0.108	668.06	0.083	680.86	0.081	668.06	0.082	668.06	0.092	671.79
0.098	716.88	0.112	707.36	0.086	720.91	0.085	707.36	0.085	707.36	0.096	711.3
0.13	756.71	0.122	746.65	0.091	760.96	0.088	746.65	0.088	746.65	0.1	750.82
0.11	796.54	0.13	785.95	0.095	801.01	0.093	785.95	0.093	785.95	0.105	790.34
0.12	836.36	0.14	825.25	0.102	841.06	0.1	825.25	0.1	825.25	0.11	829.85
0.127	844.87	0.152	847.52	0.11	874.22	0.107	840.88	0.106	838.47	0.122	869.36
0.135	836.36	0.16	825.25	0.115	874.22	0.115	825.25	0.117	825.25	0.13	877.14
0.14	824.42	0.172	785.95	0.128	841.06	0.128	785.95	0.128	785.95	0.14	849.61
0.148	796.54	0.183	746.65	0.139	801.01	0.138	746.65	0.138	746.65	0.157	790.34
0.157	756.71	0.184	738.79	0.147	760.96	0.14	742.72	0.14	742.72	0.16	770.57

Table 4.2: G-2 samples tensile test result in stress VS strain

The above table 4.2 tensile test results was tabulated as shows below; which holds tensile test t result of intact result of and G-2 corroded samples, which are tested in the time interval of ten days.

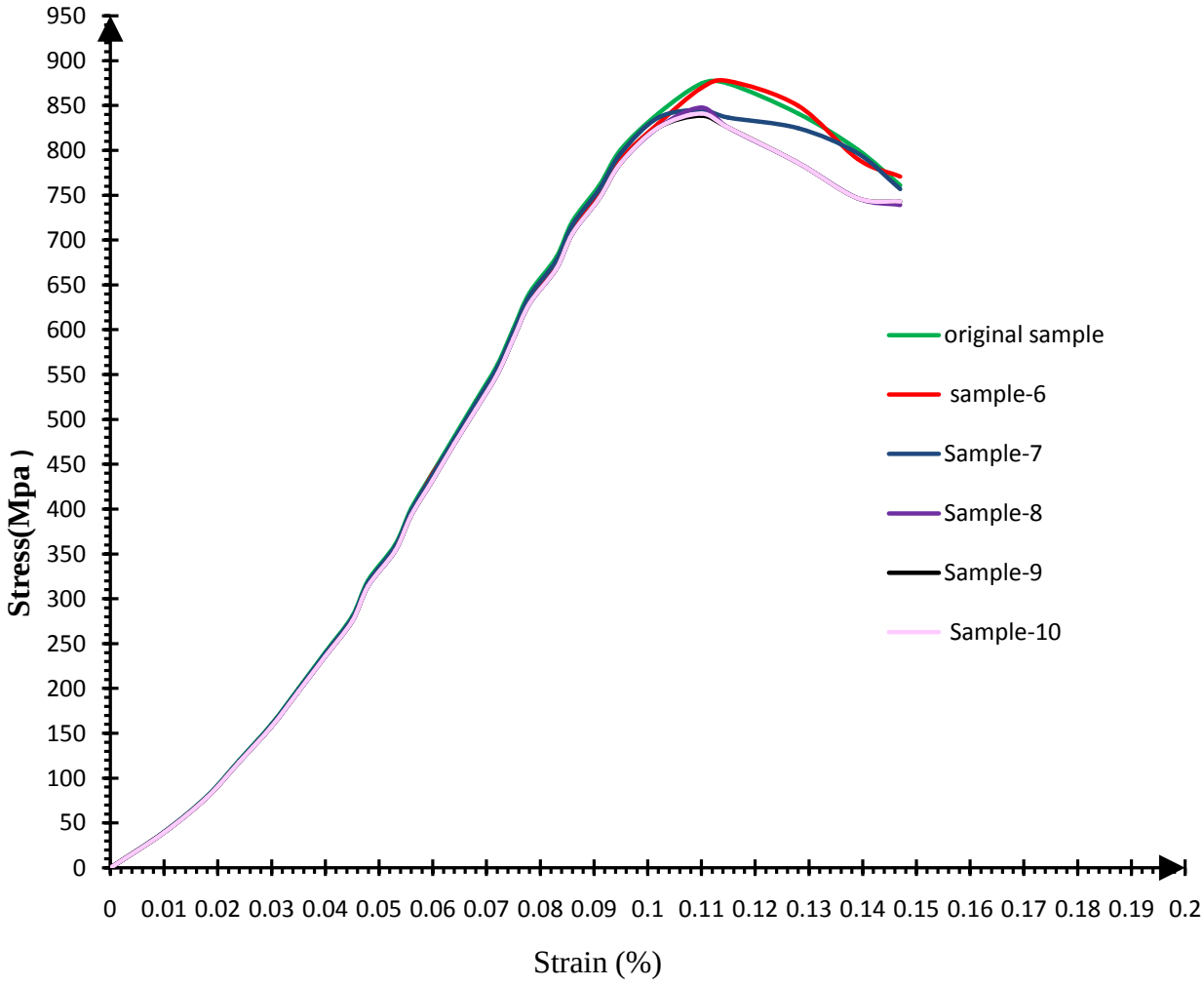


Figure 4.2: Tensile results of samples immersion in group two corrosive environment

4.1.2 IZOID IMPACT TEST

In Izoid Impact test each sample after brought out from the corrosive environment and based on the above section 3.2.2 described procedure after cleaned the sample the test was preceded based on the ASTM E-23 testing procedure the test was taken. The test result is tabulated and graphed as follows:

Sample exposure time (hr)	G-1 Test results (Joule)	G-2 Test results (Joule)	Test date after immerse
0	161.0	161.0	At start
240	160.7	158.3	After ten days/240hrs
480	158.4	158.0	After twenty days/480hrs
720	157.1	157.5	After thirty days/720hrs
960	157.0	156.6	After forty days/960hr
1200	156.2	149.8	After fifty days/1200hr

Table 4.3: Izoid impact test result

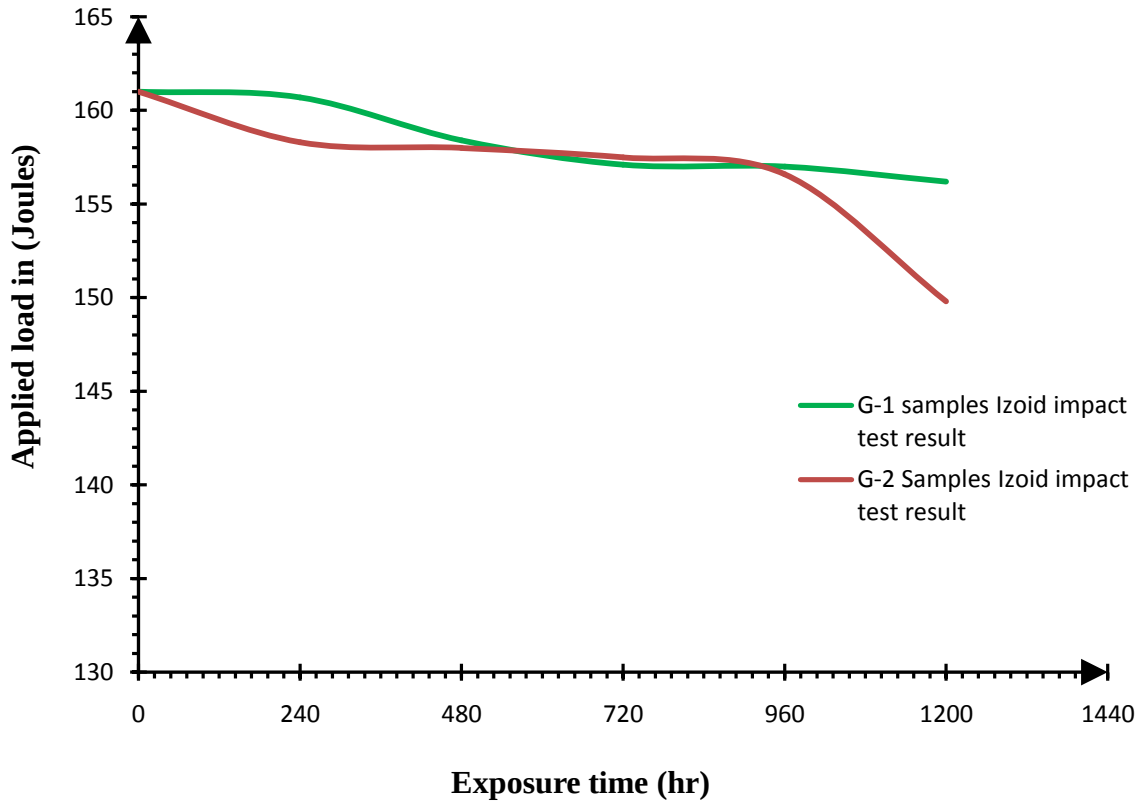


Figure 4.3: Izoid Impact test result of samples

4.1.3WEIGHT MEASUREMENT

4.1.3.1 WEIGHT LOSS TEST

The weight of each specimen is measured using analytical balance in their sequence before and after exposure of corrosive environment.

Each weight loss is recorded and plotted on the x-y plane to analyze the change. The results of each group are as follows:-

G-1 sample No	Sample Weight (g) before immerse (W_i)	Sample weight (g) after immerse (W_f)	Weight(g) loss (W_L) or (Wi - Wf)	G-2 sample No	Sample Weight(g) before immerse (W_i)	Sample weight (g) after immerse (W_f)	Weight(g) loss (W_L) or (Wi - Wf)	Test date after immerse
1.	57.8061	57.7562	0.0499	6.	57.2124	57.1458	0.0666	After ten days/240hrs
2.	57.2815	57.1922	0.0893	7.	56.9125	56.7956	0.1169	After twenty days/480hrs
3.	57.2587	57.1257	0.1357	8.	56.8553	56.6919	0.1634	After thirty days/720hrs
4.	56.7711	56.5839	0.1839	9.	56.6945	56.4925	0.202	After forty days/960hr
5.	56.6406	56.4178	0.2244	10.	56.2107	55.9702	0.2405	After fifty days/1200hr

Table 4.4: measured Sample weight value and difference b/n before and after sample immerse (Weight loss)

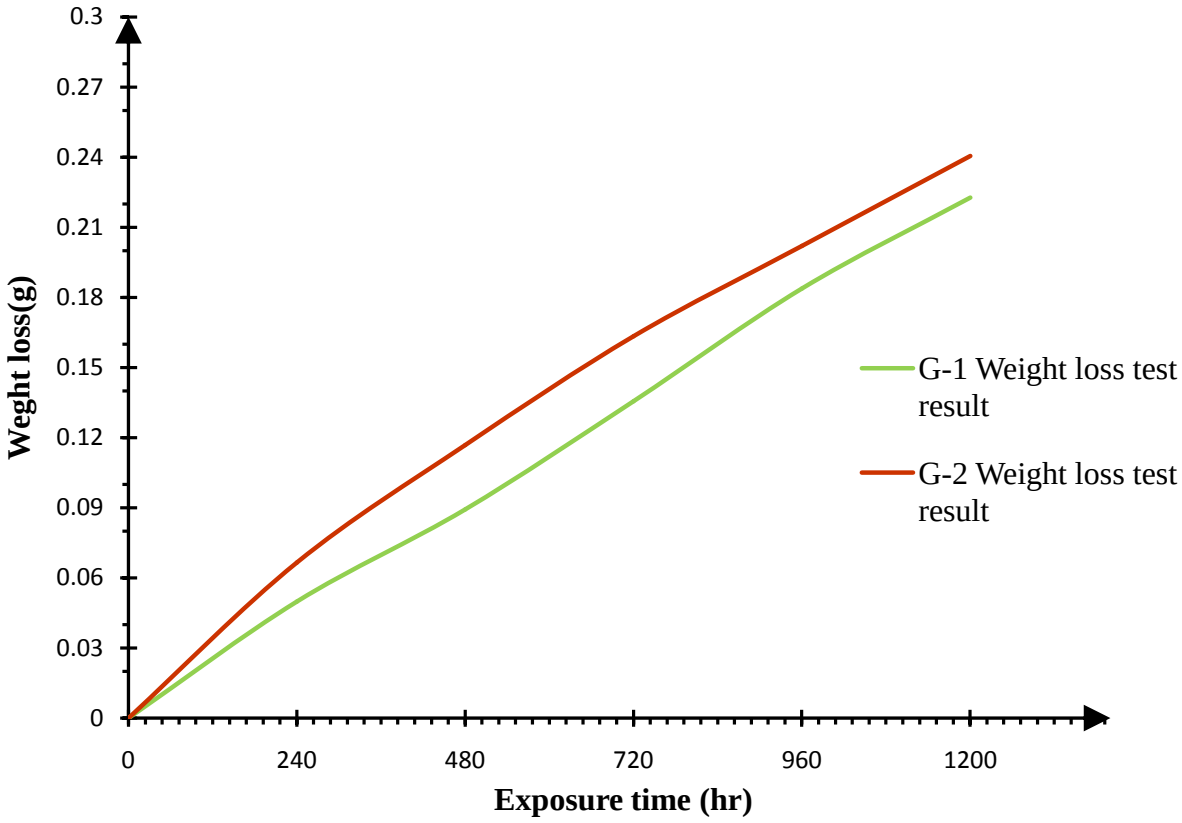


Figure 4.4: Weight loss measurement (g) VS Exposure time (hr)

4.1.4 PH MEASUREMENT OF THE CORROSIVE MEDIA

The developed corrosive environment PH- value is measured based o the sequence number for both groups during before and after corrosion effect. From this the measured result is shown as below in tabulation and graph:

Group one No	Sample PH-value before immerse	Sample PH-value after immerse	Group two No	Sample PH-value before immerse	Sample PH-value after immerse	Test date after immerse
1.	6.10	7.06	6.	7.21	8.25	After ten days/240hrs
2.	6.10	6.73	7.	7.21	8.21	After twenty days/480hrs
3.	6.10	6.76	8.	7.21	8.21	After thirty days/720hrs
4.	6.10	6.77	9.	7.21	8.17	After forty days/960hr
5.	6.10	6.84	10.	7.21	8.11	After fifty days/1200hr

Table 4.5: PH measurement value results

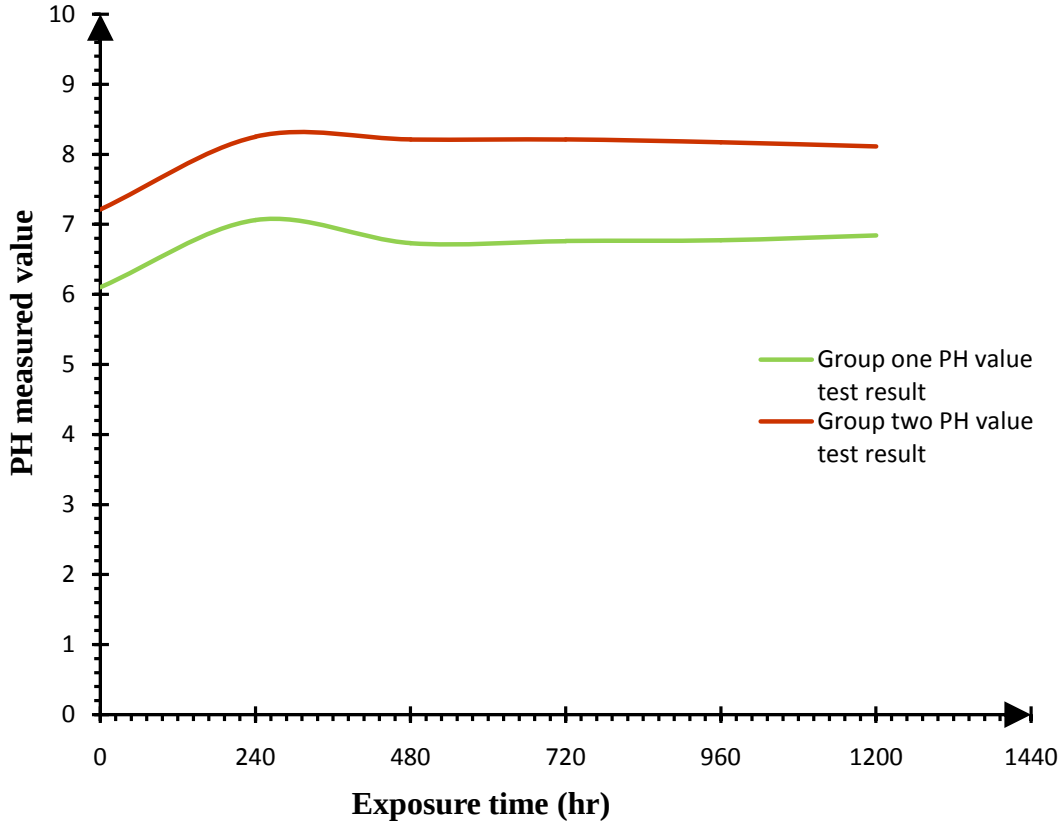


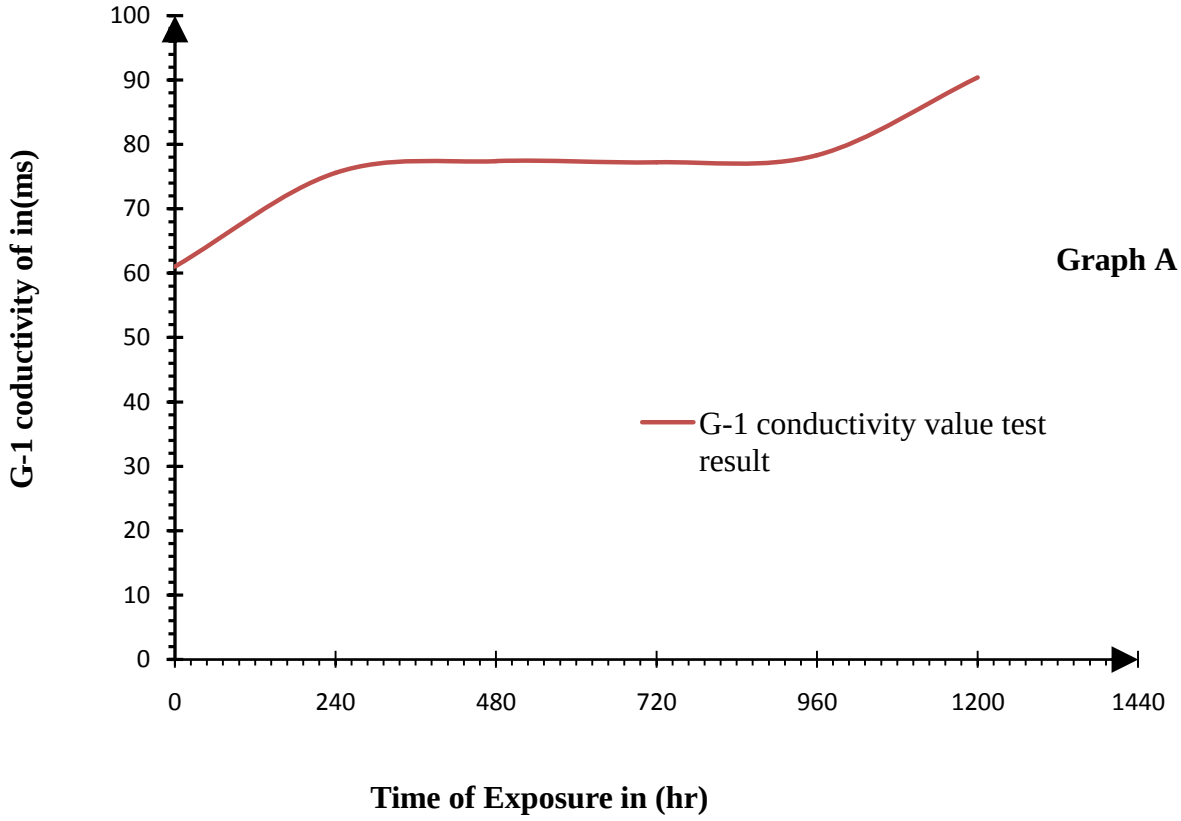
Figure 4.5: PH value measurement result for all samples and each group

4.1.5 CONDUCTIVITY MEASUREMENT OF THE CORROSIVE MEDIA

The developed corrosive environment conductivity- value is measured based o the sequence number for both groups during before and after corrosion effect. From this the measured result is shown as below in tabulation and graph:

Group one No	Sample conductivity value before immerse (ms)	Sample conductivity value after immerse (ms)	Group two No	Sample conductivity -value before immerse(µs)	Sample conductivity -value after immerse(µs)	Test date after immerse
1.	61	75.6	6.	252	490	After ten days/240hrs
2.	61	77.4	7.	252	391	After twenty days/480hrs
3.	61	77.2	8.	252	277	After thirty days/720hrs
4.	61	78.3	9.	252	300	After forty days/960hr
5.	61	90.4	10.	252	447	After fifty days/1200hr

Table 4.6: Conductivity measurement of each group environment and respective samples



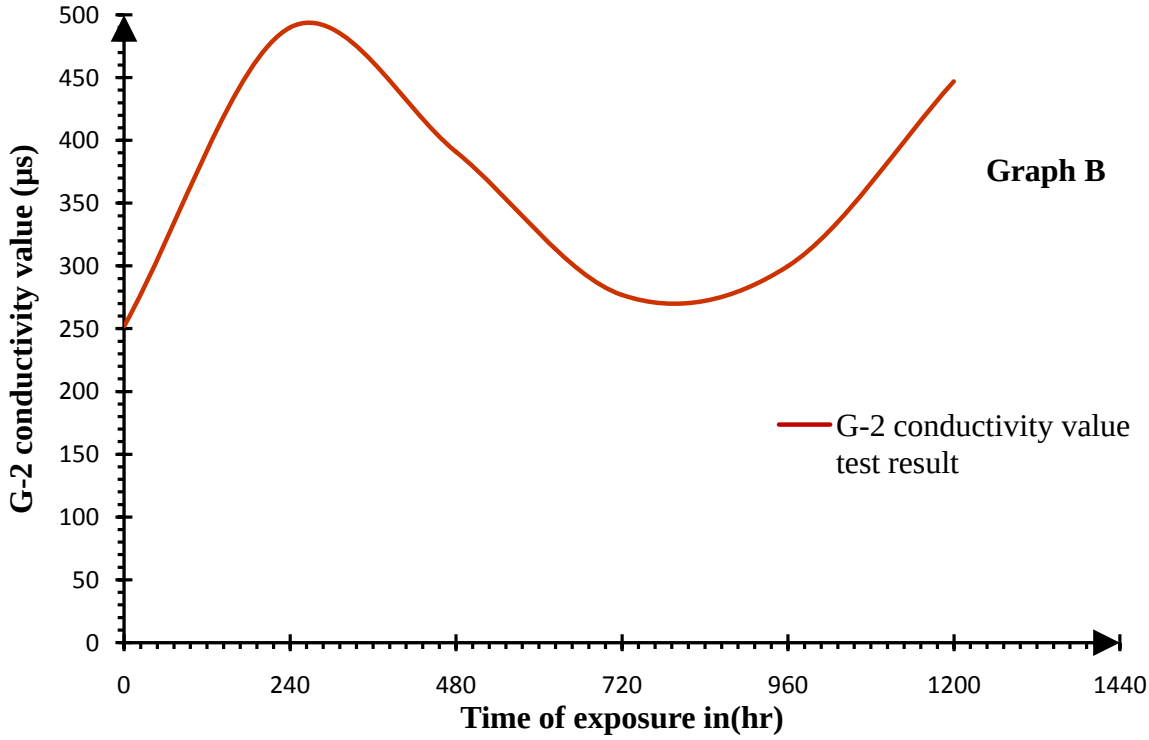


Figure 4.6: graph A and graph B is with conductivity measurement result of group one and group two corrosive environments respectively.

4.1.6 HARDNESS TEST

In the above mentioned on 3.3.1.1(sample preparation for Hardness test) and after the sample immersion is done based on the sequence number from group one and group two respectively by taking within fifteen days in the ten days interval; all the samples hardness measured.

During testing based on the procedure has taken five different results on different position across the diameter then by taking can put the value in tabulation form.

No of test	Original sample (HRC) /Briniel HB-30	First exposure group one Sample-1 (HRC)	Second exposure group two sample-6 (HRC)	First exposure group one Sample-2 (HRC)	Second exposure group two sample-7 (HRC)	First exposure group one Sample-3 (HRC)	Second exposure group two sample-8 (HRC)	First exposure group one Sample-4 (HRC)	Second exposure group two sample-9 (HRC)	First exposure group one Sample-5 (HRC)	Second exposure group two sample-10 (HRC)
01	22/244	21	20	19.5	19	18	21	19	19	21.5	20
02	20/234	19.5	20	21	20	20	21	20	20	21	21
03	22/244	22	24	19.5	21	21	22	21	21	19	20.5
04	21/239	20	22	17	20	22	22	20	21	20	19
05	22/244	20	22	21	21	21	23	22	21	19	19
Average	21.4/241	20.5	21.6	19.6	20.2	20.4	21.8	20.4	20.4	20.1	19.9

Table 4.7: Hardness test results

4.1.7 SPECTROMETER TEST

The sample is prepared based on the requirement of testing machine and tested with the test procedure; the test results are as the following listed chemical composition steel.

Composition element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Sn
Average test composition value	0.53	0.20	0.94	0.1	0.072	0.045	0.0072	0.083	0.17	0.04
From steel key standard	048-0.55	0.15-0.4	0.6-0.9	≥0.03	0.040	≤ 0.25				

Table 4.8: Spectrometer test result of sample steel material

4.1.8 ATOMIC ABSORPTION SPECTROSCOPY AND VOLUMETRIC TITRATION TEST

After prepare the corrosive environment the concentration was measured. Calcium, magnesium and sodium ion measured using Atomic absorption spectroscopy and chlorine ion using volumetric titration test. The measurement result is tabulated as follows:

Group No	Mg^{+2}	Ca^{+2}	Na^{+1}	Cl^{-1}
Group one corrosive environment	0 ppm	0 ppm	230.9ppm	2251.1mg/l
Group two corrosive environment	77.7ppm	29.93ppm	20ppm	289.2mg/l

`

Figure 4.9: atomic absorption spectroscopy and volumetric titration test result

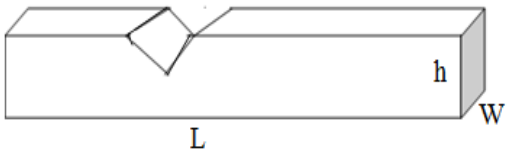
4.2 DISCUSSIONS

4.2.1 CORROSION RATE ANALYSIS

This analysis is based on the weight measurement result and using corrosion rate ASTM standard formula all the specimens is calculated and can predict the wear rate and the wear depth as follows:

$$C_R = \frac{K * W}{D*A*T} \qquad [13]$$

Where C_R = corrosion rate in mm/yr; W = weight loss of sample in mg, D=density of sample in g/cm^3, K= constant, 8.76x10^4, A=Area in cm², T=time in hr.



Exposed surface area of the specimens:

A=4xLxw+2xwxh-cutted area + new made surface area

=4x10x75+2x10x10-(0.5x4x2x2+4x10)+2x8$^{1/2}$x10x2

=3,265.137mm^2

=32.65137cm^2

$$\text{Corrosion rate (mm / yr)} = \frac{\text{Mass loss (g) x8.76x10}^4}{\text{Density (g / cm}^3\text{) x area (cm}^2\text{) x exposure time (hr)}}$$

For group one specimens weight loss and wear by corrosion:

$$\text{Corrosion rate (mm / yr)} = \frac{0.0499\text{g x8.76x10}^4}{7.8\text{ g / cm}^3\text{ x32.65137cm}^2\text{ x 240hr}}$$

= 0.0715150422cm/yr

= 0. 715150422 mm/yr

= 0. 715150422 mm/36.5

After ten days =0.019593162mm/ ten days =19.593162µm/ten days

After twenty days = 0.639909145 mm/yr = 0.639909145 mm/36.5

= 0.03506351479 mm/twenty days

= 35.06351479µm/ twenty days

After thirty days = 0.648302778 mm/yr = 0.648302778 mm/36.5

= 0.053285571 mm/thirty days

= 53.285571 µm/thirty days

After forty days = 0.658923533mm/yr = 0.658923533mm/36.5

= 0.0722107981 mm/forty days

= 72.2107981µm/forty days

After fifty days = 0.643205429mm/yr = 0.643205429mm/36.5

= 0.0881103327mm/fifty days

= 88.1103327µm/fifty days

For group two specimens weight loss and wear by corrosion:

$$\text{Corrosion rate (mm / yr)} = \frac{0.0666\text{g x}8.76\text{x}10^{4}}{7.8\ \text{g / cm}^3\ \text{x}32.65137\text{cm}^2\ \text{x}\ 240\text{hr}}$$

=0.095448934cm/yr

=0.95448934mm/yr = 0.95448934 mm/36.5

After ten days= 0.026150393 mm/ten days = 26.150393 µm/ten days

After twenty days=0.0459006145 mm/twenty days = 45.9006145µm/twenty days

After thirty days= 0.0641587781 mm/thirty days = 64.1587781µm/thirty days

After forty days= 0.079315005479 mm/forty days = 79.315005479µm/forty days

After fifty days= 0.09443197438 mm/fifty days = 94.43197438µm/fifty days

G1 sample No	G-1 Wear due to corrosion (µm)	G2 sample No	G-2 Wear due to corrosion (µm)	Testing date after immerse
1	19.593162	6	26.150393	After ten days/240hrs
2	35.06351479	7	45.9006145	After twenty days/480hrs
3	45.429436	8	64.1587781	After thirty days/720hrs
4	48.649154	9	79.315005479	After forty days/960hr
5	88.1103327	10	94.43197438	After fifty days/1200hr

Table 4.10: G1 and G2 specimens surface wear results

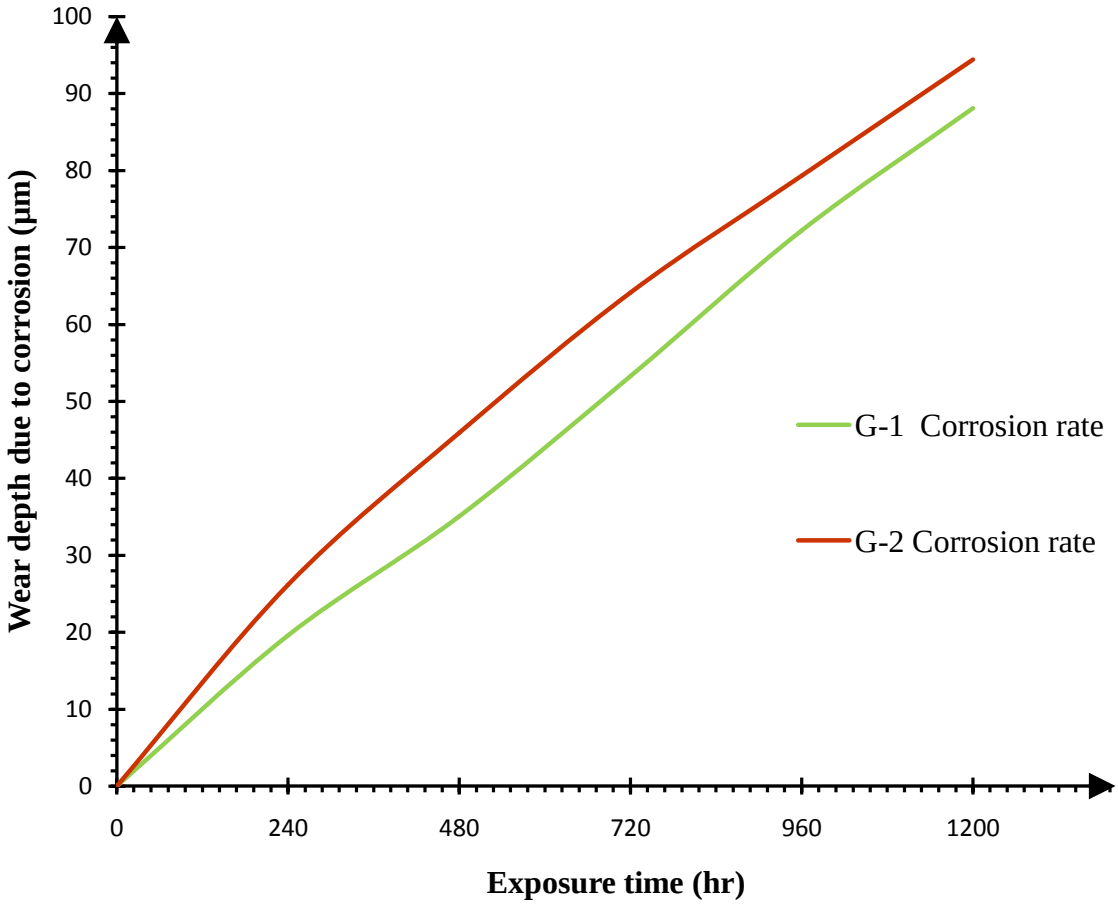


Figure 4.7: Corrosion rate of specimens

The corrosion rate (mm/yr) as shown below in the table based on the above calculation to predict the life of the steel:

Sample No	G-1Corrosion rate (mm/yr)	Sample No	G-2 Corrosion rate (mm/yr)
1	0.715150422	6	0.9544893445
2	0.639909142	7	0.837686215
3	0.648302778	8	0.780598467
4	0.658923533	9	0.723749424
5	0.643205429	10	0.68935412

Table 4.11: corrosion rate comparison table

From the above table 4.11 the corrosion rate for group one samples is 6.432%/year .so in each year this amount of material is wear-out from the surface of the steel and the same thing for group two samples 6.894% /year is loss.

4.2.2 SPECTROMETER TEST RESULT ANALYSIS

From the above table 4.8 measured value and by referring the Steel key standard the material is medium carbon steel C-50 (AISI1050 or ASTM 648A).

Yield stress=430; Tensile 650-800; Elongation 16%; Reduction = 40 and

Property	AISI 1050 Data
Density, kg/m3	7861.09
Modulus of Elasticity, N/m^2	$199.9496x10^9$
Coefficient of Thermal Expansion, 68-212˚F, /˚F	6.39 x 10-6
Thermal Conductivity, Btu/ft hr ˚F	30.0
Specific Heat, Btu/lb ˚F	0.116
Electrical Resistivity, Microohm-in	6.42

Table 4.12: Spectrometer based properties of the selected steel

4.2.3 TENSILE TEST RESULT ANALYSIS

Tensile test result is as shown in 4.1.1 from this the result of all group one samples are almost similar in the elastic part of the stress VS strain graph but at the maximum yield point (ultimate stress) and plastic zone there is a difference value this shows that corrosion has an effect on the tensile strength of the steel.

The result shows that there is a difference in the two corrosive environments. The effect of corrosion in group two environments (Tap water) is more Sevier than in group one environment (3.5% Nacl plus distilled water); even though the concentration and PH of group one corrosive environment is higher than group two corrosive environment.

This shows from chemical reactivity series; which is Na is highly reactive than Ca and Mg though the depletion of oxygen in the generation of hydroxyl ions then the accumulation of positive charges in the form of Fe^{++} then attracts negatively charged Cl^- . The resulting ferrous chloride hydrolyzes then again the reaction proceed and ferrous hydroxide is produce this protects further reaction as a result the corrosion rate become slower than tap water.

In the case of tap water $CaCl_2$ and $MgCl_2$ are in compound and stable form as a result without another active metal disturbance steel will react with oxygen and hydrogen as a result the corrosion rate becomes higher than group one corrosive environment.

Group one (3.5% NaCl plus distilled water) corrosive environment reaction:

$NaCl \longrightarrow Na^+ + Cl^-$ $\quad Fe \longrightarrow Fe^{2+} + e^-$

$4Na + O_2 \longrightarrow 2Na_2O$ $\quad Fe^{2+} + 2Cl^- \longrightarrow Fe^{2+}(Cl^-)_2$

$2Na_2O + H_2O \longrightarrow 2NaOH$ $\quad Fe^{2+}(Cl^-)_2 + 2H_2O \longrightarrow Fe(OH)_2 + 2H^+ + Cl^-$

Ferrous hydroxide protects further reaction; in another case due to hydrogen ion (H^+) and chlorine ion (Cl^-) the corrosion rate will proceed.

In the case of group two (tap water) corrosive environments in the reactivity series Fe is slower than Ca and Mg. In addition the environment is stable and $CaCl_2$ and $MgCl_2$ in compound form as a result Fe will be reacting freely with O_2 and H_2O.

$Fe + 3O_2 + 2H_2O \longrightarrow 2Fe_2O_3H_2O$ Hydrated ferric oxide (rust)

4.2.4 IZOID IMPACT TEST RESULT ANALYSIS

The result was shown in table 4.1 and figure 4.3 has not straight slope; but totally the graph shows the negative effect of the corrosion on the impact energy of the steel.

For detail discussion; the data in the table and the plot in the graph shows that there is a significant difference between group one and group two corrosive environment with the increment of time. Even if the difference at different point is not constant and the slope is not straight this due to the testing error; this mean that during testing the clamping mechanism is manually adjusted, the samples manufacturing problem and the steel microstructure of the material at each point could not be the same.

From this even if it is difficult to predict the life of the steel with respect to design condition and corrosion effect of the steel material; it can show there is an effect on the mechanical properties on the steel.

4.2.5 HARDNESS TEST RESULT ANALYSIS

As shown on the above picture at figure 3.4 the machine used to test the hardness test is Rockwell hardness

test with 120^0 angled diamond tip indenter and the reading was analog type.

The tests have taken five tests across the diameter of each sample as far as possible the point of test taken is from similar position. The results are as shown in the above table 4.7. The test result is not similar and the difference also is not constant throughout the test duration. From this it can be discuss on the test and the results as follows:

1. The nature of steel inter-granular structure is not similar at different parts of the steel material. This shows that during testing, different value at different point of the surface with the same surface finish; the test is taken before and after exposure to corrosion environment. Average result is taken for five different tests but the difference is not that mach significant change to interrelate with the time interval and duration.
2. Before the start of any test the test machine is calibrated with traceable standards then the test is proceed based on the SOP (standard operational procedure).So the second effect on the test variation is the surface finish; in this work the sample surface finish is made by surface grinder with better surface finish. Even the variation is happened.
3. Generally when the average results shows there is a decrease in hardness result with increase of exposure time. May be the result will be more significant if the immersion test time duration is more longer in a year.

∗ Totally the test result shows; Corrosion has an effect on the hardness value of the steel.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The objective of this study was evaluating mechanical properties of given steel subjected to corrosive environment. In order to achieve the goal of the research, this study has shown that the possibility of methods to evaluate the effect of corrosion.

In this study experimental method is used; which includes sample immersion test for 50 days (1200hr) is carried out in the laboratory by measuring weight loss, hardness, tensile and impact test result is taken. The result of the study shows that reduction in mechanical properties (hardness, tensile strength and impact energy) as samples immersion in corrosion environment. It is relatively proportional to corrosion rate. As a result this study has made a stride towards understanding the study shows corrosion has high effect on the mechanical properties of steel AISI 1050 in the incremental of time with corrosion rate.

Corrosion environments were kept in uniform temperature and humidity but the conductivity and PH of the corrosive environment has different variation this variation was due to reaction between the sample material and corrosion environment, but the reaction was not uniform due to the corroded part up to some limit has resistance for further reaction then after some increment it release the surface of the sample at that time again the reaction become increase and so. Totally the result is relatively in group two (Tap water) is higher change than group one (3.5%Nacl plus distilled water) corrosion environment; this shows that there was relatively higher reaction between corrosive environment and the steel. Also all the test results shows more decrease mechanical properties of samples were in group two than group one corrosive environment.

5.2 RECOMMENDATION

The following recommendations for further work are put forward based on this study:

a) From the effect of corrosion

The experimental study and progress was taken in laboratory scale; then the effect of corrosion is shown in corrosion rate and some effect on mechanical properties.

From this during design if the steel is directly used for structure should be consider the corrosion effect based on the corrosion environment.

1. Allowance to accommodate for corrosion effect.
2. Provide barrier between metal and environment
3. Metal coatings :
   - 3.1. Noble: silver, copper, nickel, Cr, Sn, Pb on steel. Should be free of pores/discontinuity coz creates small anode-large cathode leading to rapid attack at the damaged areas.
   - 3.2. Sacrificial – Zn, Al, Cd on steel. Exposed substrate will be cathodic & will be protected.
   - 3.3.Application – hot dipping, flame spraying, cladding, electroplating, vapor deposition, e.t.c.
4. Organic coating: paints, lacquers, varnishes. Coating liquid generally consists of solvent, resin and pigment. The resin provides chemical and corrosion resistance, and pigments may also have corrosion inhibition functions.

5.3. FUTURE WORK

The hardness of AISI 1050 carbon steel could vary from approximately 20-58 HRC depending on its heat treatment [21]. Based on this the following future work is recommended

1. Evaluation mechanical properties of heat treated steel AISI 1050 subjected to corrosion environment.
2. Improvement of Steel for develops corrosion resistant property.
3. Fatigue life prediction for AISI 1050 Carbon steel.

REFERENCES

1. **Andrade. C, Alonso. C: '**Corrosion rate monitoring in the laboratory and on-site.' *Elsevier Science Ltd,* Great Britain, No. 5, Vol. 10, (1996), pp. 315-328.
2. **Melchers R.E.:** 'A new interpretation of the corrosion loss processes for weathering steels in marine atmospheres.' *Elsevier Ltd,* Australia, vol.50, (2008), pp 3446-3454.
3. **Ismail. A, Adan. N.H:** *'*Effect of Oxygen Concentration on Corrosion Rate of Carbon Steel in Seawater' *American Journal of Engineering Research,* Malaysia, Vol.03, (2014), Issue-01, pp-64-67.
4. **Amadi S.A., Ukpaka C.P:** 'Evaluation of corrosion of behavior on pipe line steel structure in swampy environment' *Basic Research Journal of Engineering Innovation,* Nigeria, Vol. 1(4),(2014), pp. 01-06.
5. **James M.N., Hattingh D.G.:** 'Case studies in marine concentrated corrosion.' *Elsevier Science Ltd,* England, **Vol.**47 (2015) PP.1–15.
6. **Ayodele C.O, Nenuwa O.B.: '**Investigation of the Effects of Heat Treatment on the Corrosion behavior of Welded Low Carbon Steel in Different Environments.', *International Journal of Science and Technology,* Nigeria, ISSN 2224-3577, Vol. 3, (2013).
7. **Appuhamy J.M.R.S., Ohga M., Chun P. and Dissanayake P.B.R.:** *'*Consequence of Corrosion on Dynamic Behavior of Steel Bridge Members' *International Journal of Modern Engineering Research,* Japan, Issue.1,Vol.2, (2012), , pp-281-288.
8. **ASM International:** 'The Effects and Economic Impact of Corrosion.' USA, (2000), www.asminternational.org.
9. **Xin Li –Shu , Akid R.: '**Corrosion fatigue life prediction of a steel shaft material in seawater.' *Elsevier Science Ltd,* United Kingdome, Vol. 34,(2013), pp 324-334.
10. **Anees U. Malik, Shahreer Ahmad, Ismaeel Andijani: '**Corrosion behavior of steel in gulf sea water environment.' *4th Gulf Conference,* Bahrain, Vol.123, (1999), PP 205-213.
11. **American Society for Testing and Materials:** 'ASTM A370: Standard Test Method and Definitions for Mechanical Testing of Steel Products' WASHINGTON, D.C, (1980).
12. **American Society for Testing and Materials:** 'ASTM E23 Standard Test Methods for Notched bar impact testing of metallic materials' WASHINGTON, D.C, (1982).

13. **Mahendra Yadav1, Sushil Kumar1, Neelam Kumari1, Indra Bahadur, Ebenso Eno E:** 'Experimental and Theoretical Studies on Corrosion Inhibition Effect of Synthesized Benzothiazole Derivatives on Mild Steel in 15% HCl Solution.' *International Journal of electrochemical science,* India, Received, Vol.10, (2015), pp602-624.
14. **Wang, D.Y. Li X.Y:** 'Application of an electrochemical scratch technique to evaluate contributions of mechanical and electrochemical attacks to corrosive wear of materials.' *Elsevier Science Ltd,* Canada, Vol.259, (2005), PP 1490-1496.
15. **Bringas john E: '**Hand book of comparative world steel standards' *ASTM data series publication,* USA , 3nd edition,(2004).
16. **Kern, Sohn GmbH:** 'Operating instruction Analytical balance' *Wagen –Gewichte-Balances-Weight,* Version 1.9, (2010).
17. **Prof. Dr. Rıza GÜRBÜZ: '**Tension Test.' Metu Department of Metallurgical and Materials Engineering.
18. **Siewert T. A., Vigliotti D. P., Dirling L. B., McCowan C. N:** 'Performance Verification of Impact Machines for Testing Plastics.' *Journal of Research of the National Institute of Standards and Technology,* Colorado ,Vol. 104, Number 6, (1999).
19. **Badea G. E., Cret .P, Lolea M, Setel A.**: 'Studies of carbon steel corrosion in atmospheric conditions.' *Acta technical corviniensis-Bulletin of engineering, ROMANIA* (2011), ISSN 2067-3809.
20. **Guo H.X., Lu B.T., Luo J.L: '**Interaction of mechanical and electrochemical factors in Erosion corrosion of carbon steel' *Elsevier Science Ltd,* Canada,Vol.51, (2005), PP315-323.
21. **Jaiswal Sanjeev Kumar, Sharma T., Rajesh M., Kumar Vineet:** 'Study of the hardness & the microstructure of AISI 1050 medium carbon steel after heat treatment process.' *ELK Asia Pacific Journals,* India, (2014), *ISBN: 978-81-930411-4-7.*
22. **Baboian Robert:**, **Nace corrosion engineer's reference book',** Nace international, Houston, third edition, (2002).

Appendix A: Graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

G-1 Samples Result

Report No. Melaku Tefera AISI

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	
Test Parameter			
Temperature		Relative Humidity(%)	
Speed (mm/min)	0.75	Gauge Length(mm)	200
Standard		Test Date	04-14-2015

Test Data

Sample No.	Diameter mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa		
1	18.05	221.35			36.00	865.05				
2	17.85	217.05			36.00	867.35				
2	17.90	216.90			36.00	861.90				
Average		218.43			36	864.77				
S.D.		2.527				2.736				
C.V.		1.157				.316				

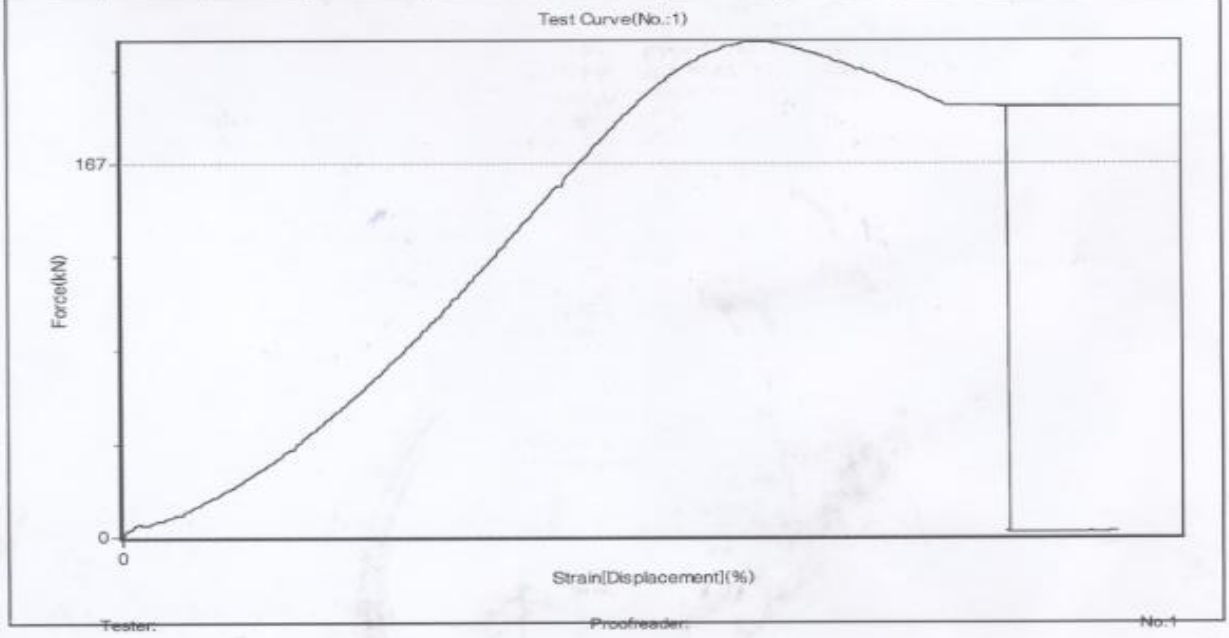


Figure A.1: Print out of G1 sample result from Computer-Electro-hydraulic Universal Test Machine

G-2 samples result

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. Melaku Tefera G2 A

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	
Test Parameter			
Temperature		Relative Humidity(%)	
Speed (mm/min)	0.75	Gauge Length(mm)	200
Standard		Test Date	04-14-2015

Test Data

Sample No.	Diameter mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa		
1	17.83	218.28			36.00	874.22				
2	17.95	221.97			36.00	877.14				
2	17.88	212.14			36.00	844.87				
Average		217.46			36	865.41				
S.D.		4.966				17.85				
C.V.		2.283				2.062				

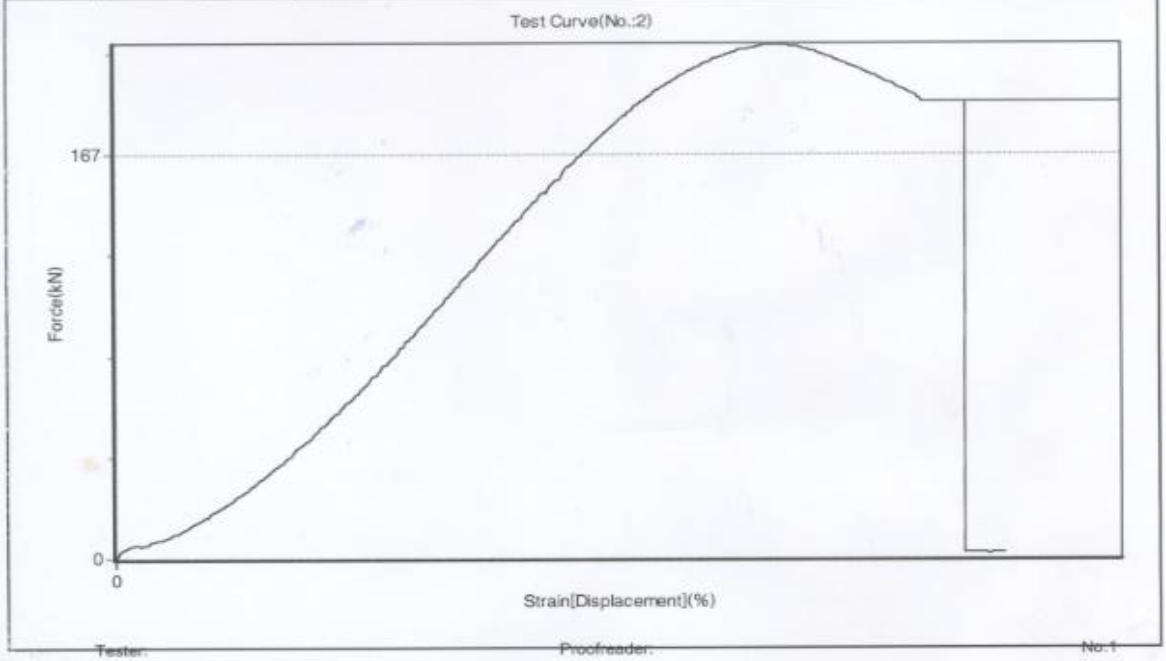


Figure A.2: Print out of G2 sample result from Computer-Electro-hydraulic Universal Test Machine

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. Melaku Tefera AISI 1050

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	
Test Parameter			
Temperature		Relative Humidity(%)	
Speed (mm/min)	1.0	Gauge Length(mm)	200
Standard		Test Date	03-12-2015

Test Data

Sample No.	Diameter mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa		
1	18.00	215.67				847.52				
2	18.00	216.44				850.54				
3	18.00	222.12				872.88				
4	18.00	213.36				838.47				
5	18.00	213.98				840.88				
Average		216.31				850.06				
S.D.		3.475				13.66				
C.V.		1.607				1.607				

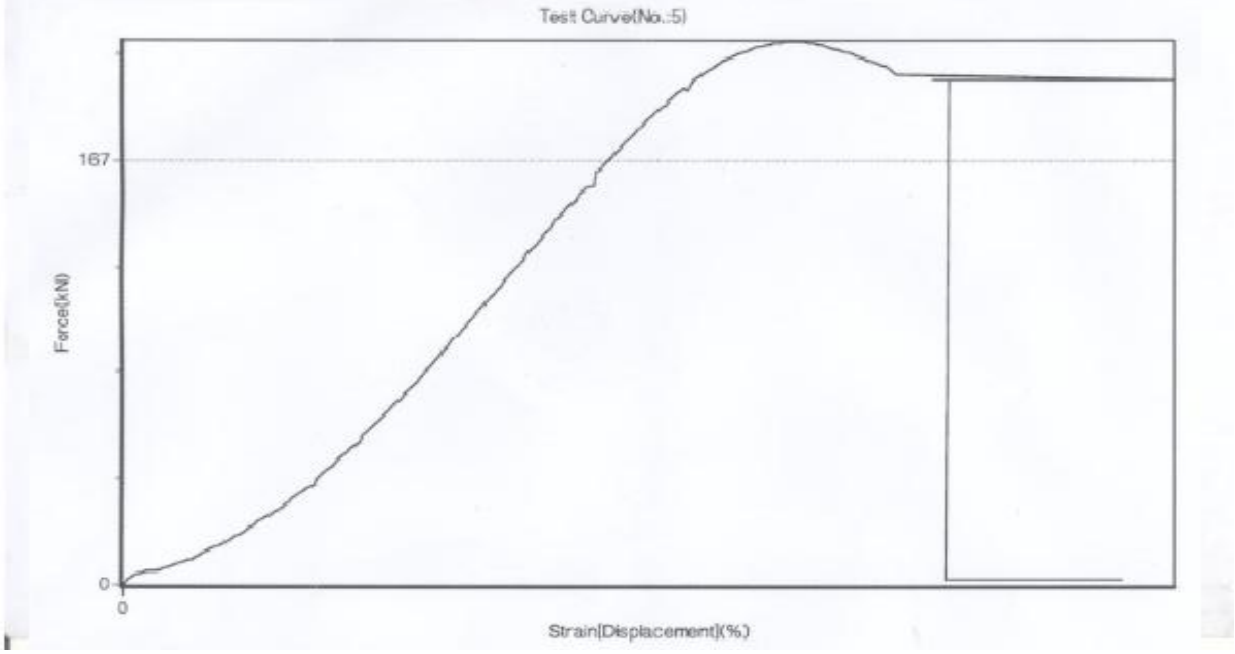


Figure A.3: Print out of G1and G2 sample result from Computer-Electro-hydraulic Universal Test Machine.

Sample No 3 is original sample

Samples No 4 and 5 is for G-1 samples

Samples No 1 and 2 is for G-2 samples

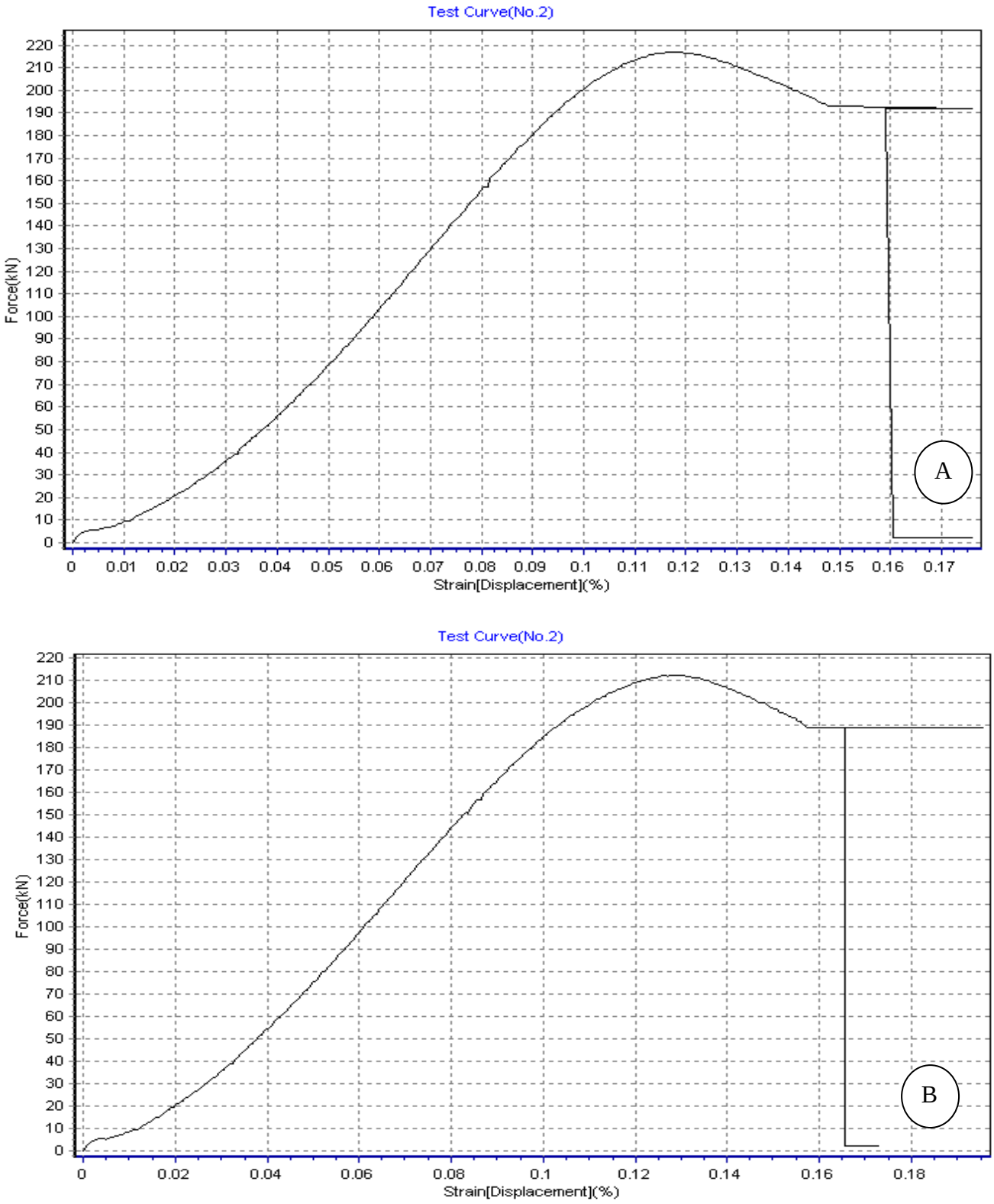


Figure A.4: Print out of sample A (5) and B (10) result from Computer-Electro-hydraulic Universal Test Machine

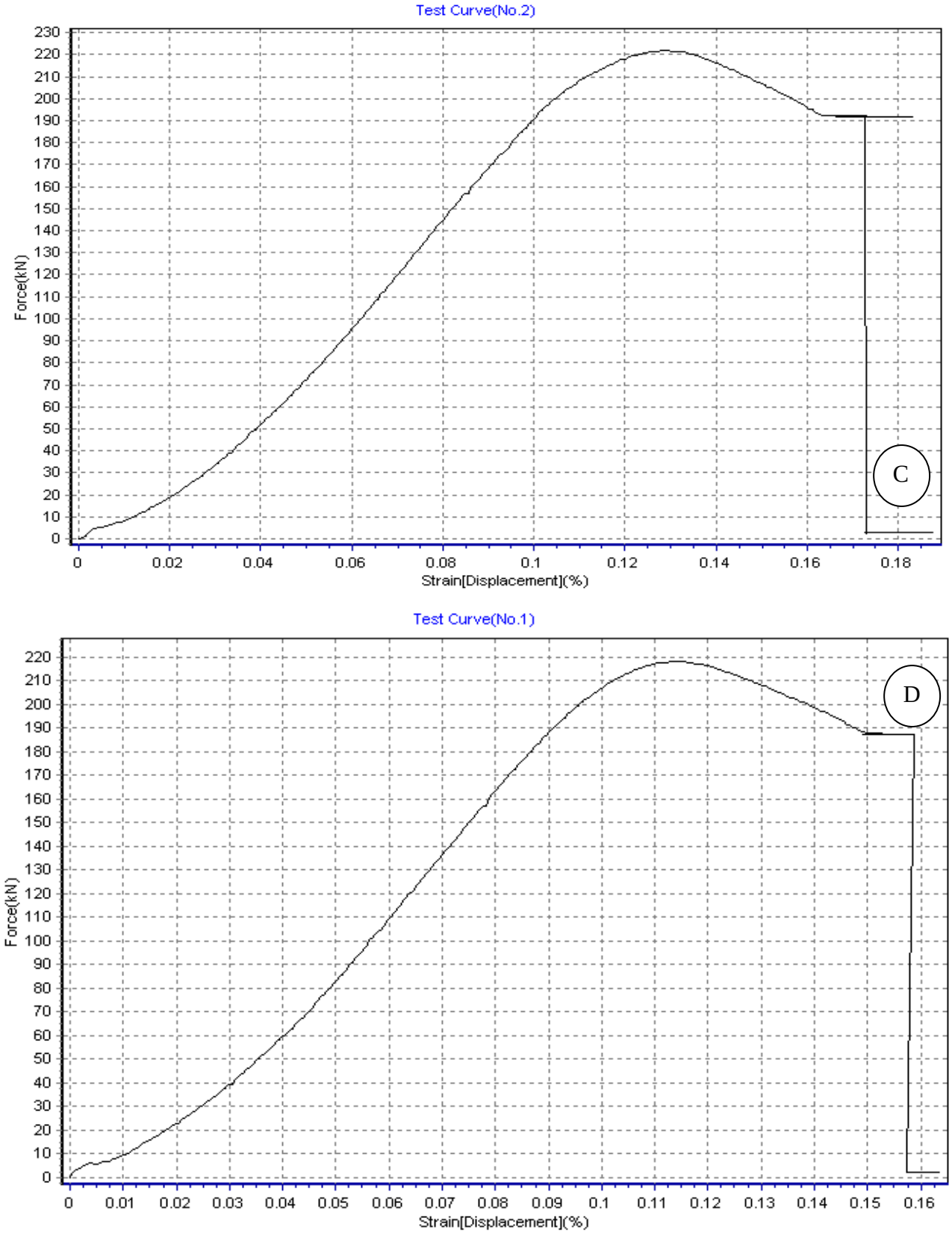


Figure A.5: Print out of sample C (4) and D (9) result from Computer-Electro-hydraulic Universal Test Machine

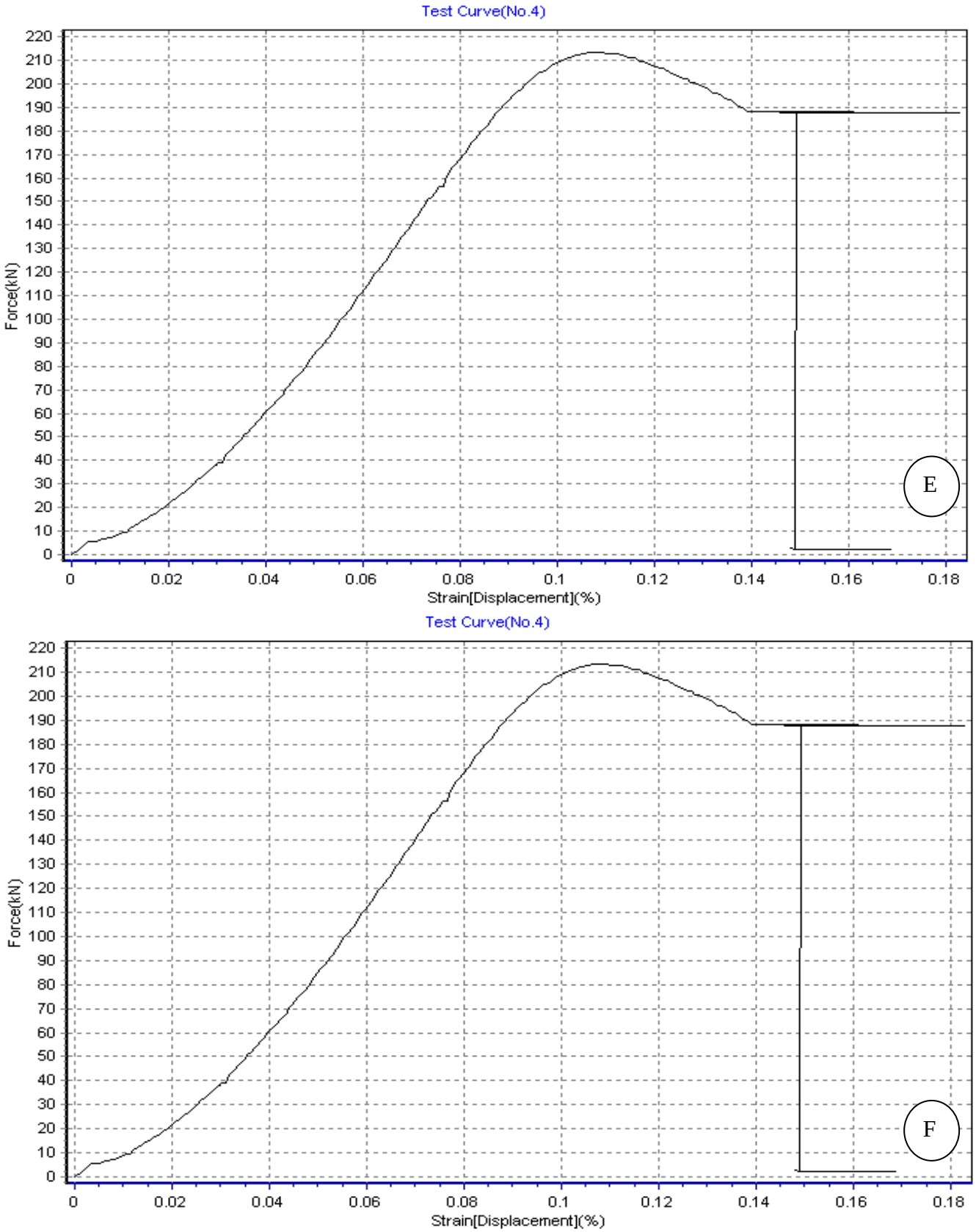


Figure A.6: Print out of sample E (3) and F (8) result from Computer-Electro-hydraulic Universal Test Machine

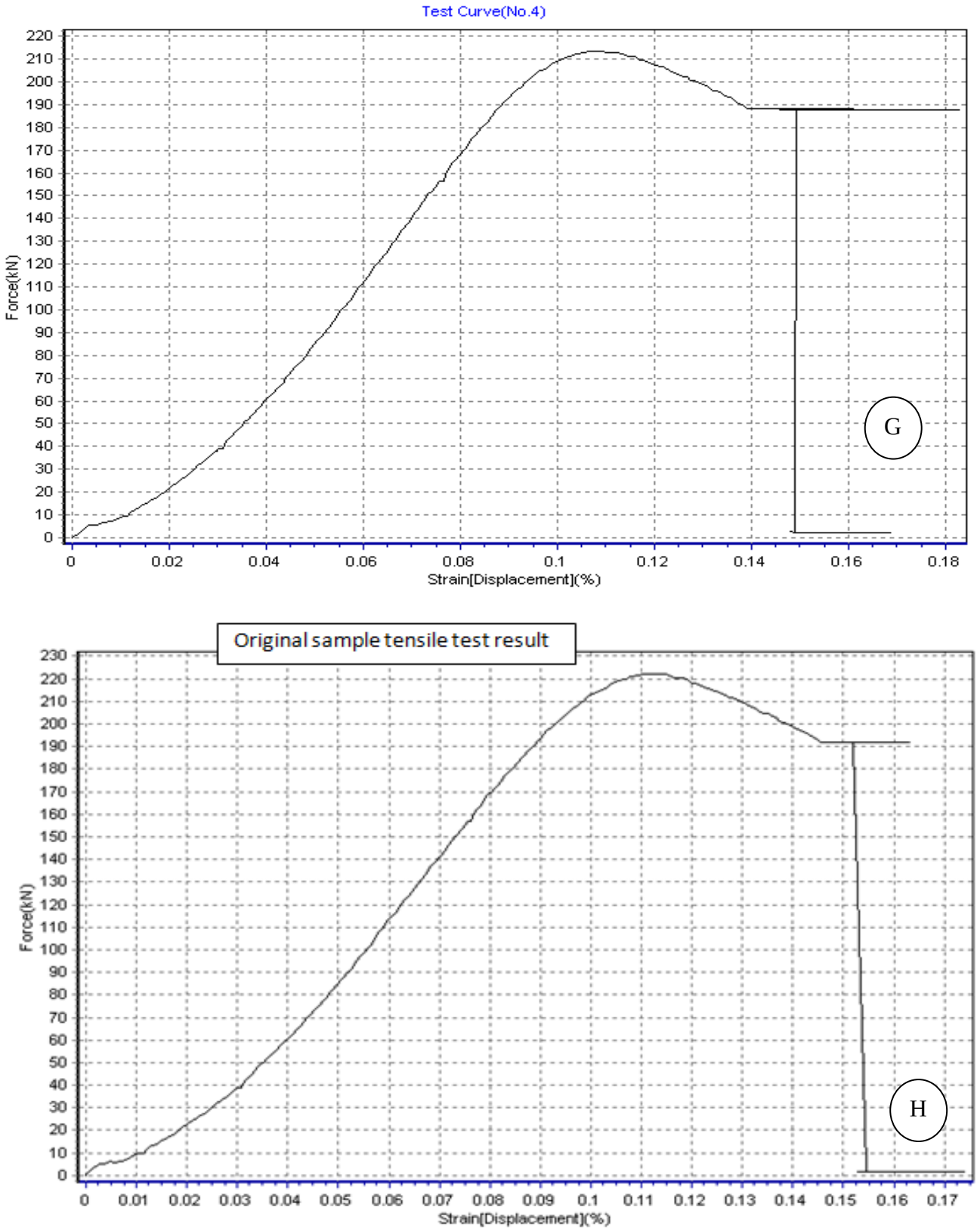


Figure A.7: *Print out of sample G (2) and H (Original sample) result from Computer-Electro-hydraulic Universal Test Machine*

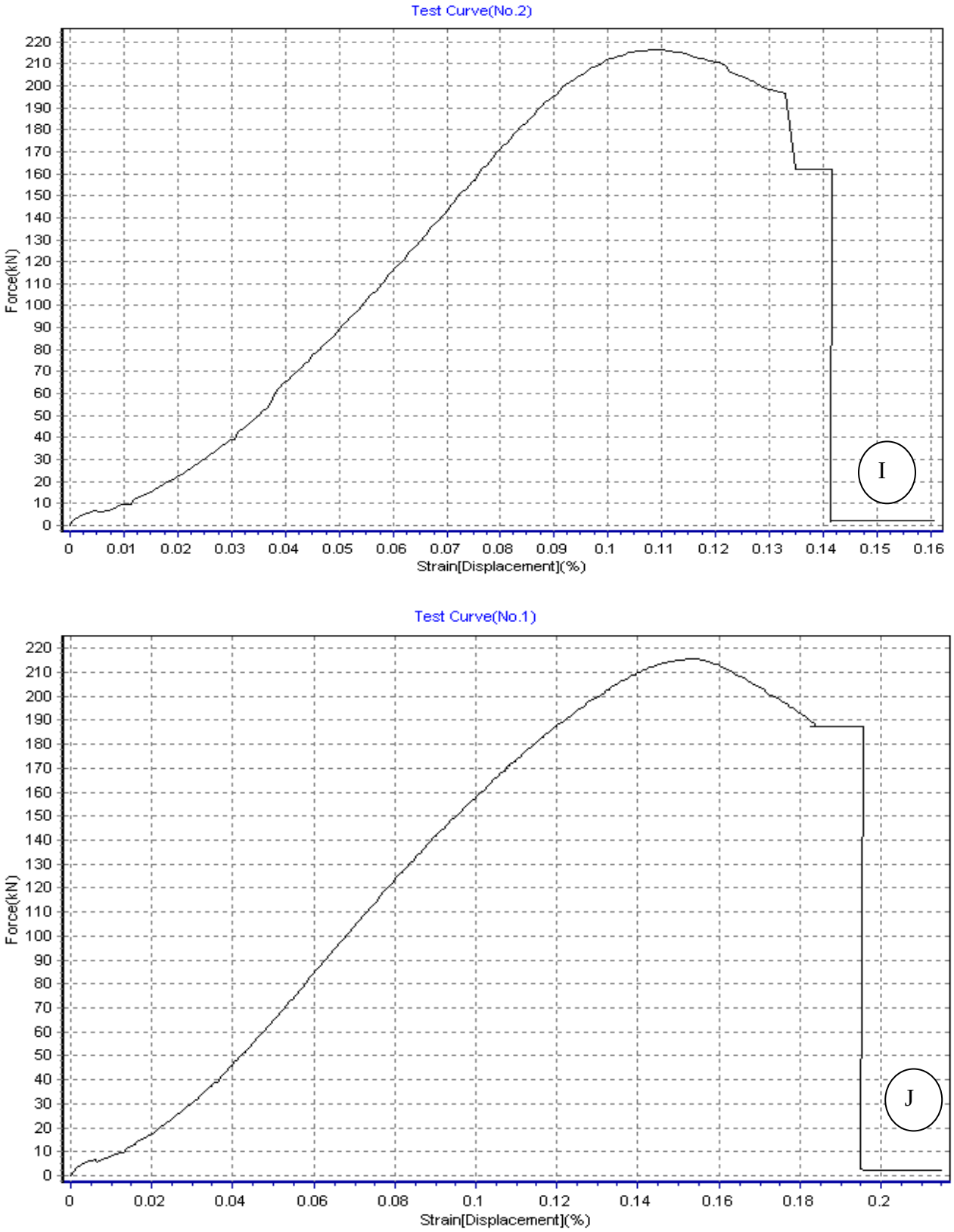


Figure A.8: Print out of sample I (1) and J (7) result from Computer-Electro-hydraulic Universal Test Machine

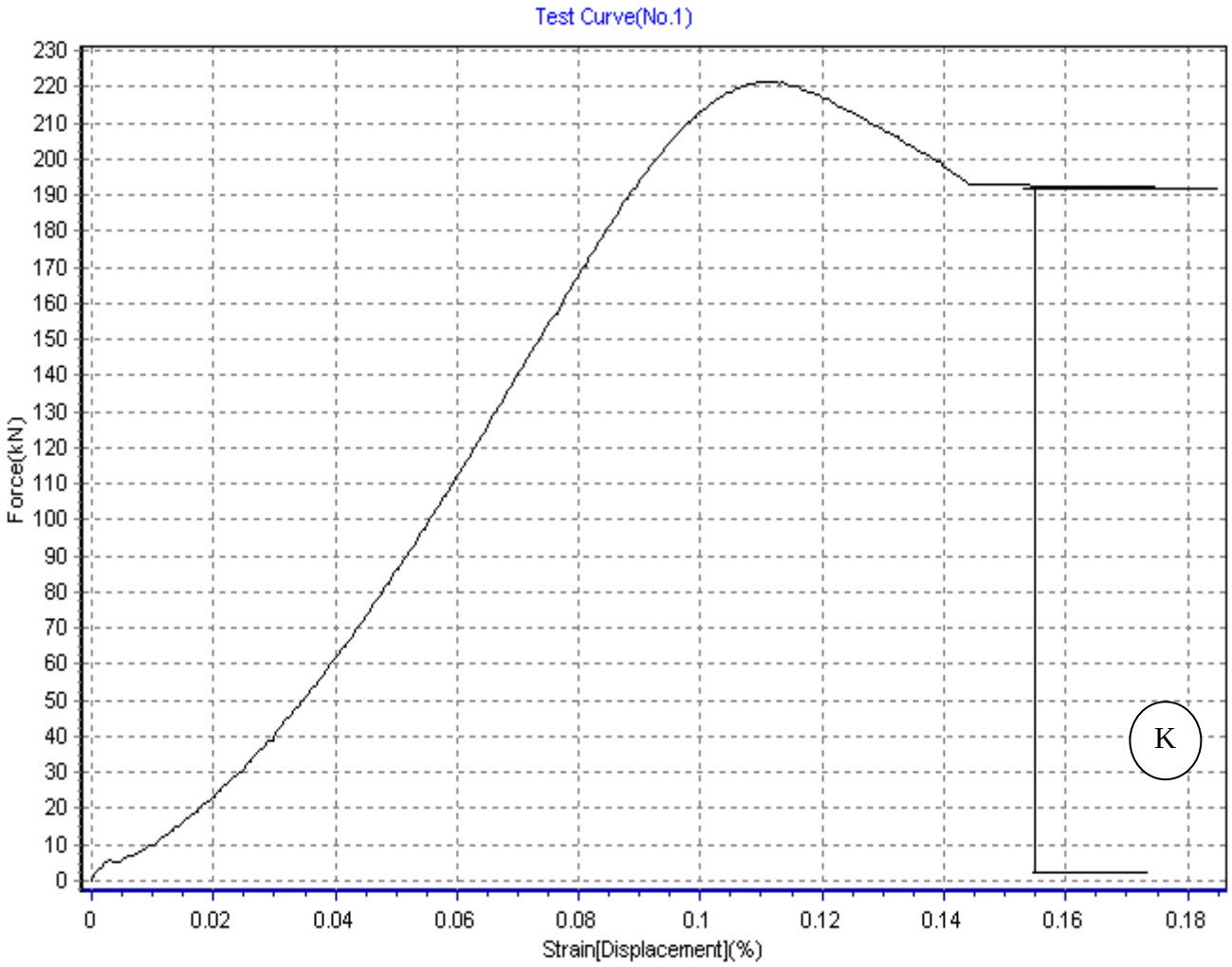


Figure A.9: Print out of sample K (6) result from Computer-Electro-hydraulic Universal Test Machine