MODELLING THE ENVIRONMENTAL EFFECTS OF CORROSION IN A TUNGSTEN INERT GAS WELD JOINTS ON A MILD STEEL PIPE USING RESPONSE SURFACE METHODOLOGY

BY

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FACULTY OF ENGINEERING

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CERTIFICATION

This work was carried out by **ORIAKHI NOSA** in the department of Production Engineering (Industrial Engineering), Faculty of Engineering, University of Benin, Benin City and is hereby certified.

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CERTIFICATION OF THESIS/DISSERTATION ON PLAGIARISM

We the undersigned attest and declare that the thesis of**ORIAKHI NOSA**"modelling the environmental effects of corrosion in a tungsten inert gas weld joints on a mild steel pipe using response surface methodology", has successfully passed the anti-plagiarism test and does not violate any copyright regulations.

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DEDICATION

This work is dedicated to God Almighty for his infinite mercy, guidance and unending provision throughout these years of my higher education.

To my lovely parents, Mr and Mrs E.O Oriakhi, my siblings and my niece. God bless you all richly

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I am indeed grateful to God Almighty for His unimaginable strength and speed, His abundant grace and protection in making my masters education a reality.

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ABSTRACT

Welding is the process to join two or more similar or dissimilar metal with the application of heat and sometime pressure. Gas Tungsten Arc Welding (GTAW) is commonly known as Tungsten Inert Gas Welding (TIG Welding). Corrosion of metal is an ubiquitous phenomenon that occurs in various forms. Atmospheric or uniform, galvanic, crevice, pitting, and microbial corrosion are most familiar forms of corrosion. The service life of engineering structures is affected by the quality and strength of the welded joints. The effects of corrosion affects the quality of the welded joints and the general structure. The offshore structures are exposed to the various environments, and it is well known that the corrosion rate and the corrosion mechanism under each environment, marine atmosphere, splash zone, tidal zone, underwater zone and bottom zone, are different. The aim of this study is to model the environmental effects of corrosion on tungsten inert gas weld joints of a mild steel pipe using response surface methodology.

Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick with a power hacksaw, grinded and cleaned before the welding process. The experimental matrix was made of twenty (20) runs, generated by the design expert software adopting the central composite design. The response was measured, which is the rate of corrosion and then modelled using the response surface methodology.

The result obtained in this study shows that the current has a very strong influence on the rate of corrosion. Based on the findings, it is summarized that the corrosion rate is minimum when a welding voltage of V = 18V, current = 120A and gas flow rate = 13lit/min. The response surface methodology employs certain statistical tools which are Anova, goodness of fit, coefficient of determination and noise to signal ratio which determines the adequacy and significance of the model developed. The result from this study shows that the model has a very good variance inflation factor and p-value < 0.05. The model posseses favourable coefficient of correlation (R)value for the rate of corrosion

CHAPTER ONE

INTRODUCTION

1.0Background to the study

Carbon steel is the most widely used engineering material despite its relatively limited corrosion resistance. It is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction and metal-processing equipment. Carbon steel has been the popular choice of structural material as it is abundantly available, inexpensive and has adequate mechanical properties, but it has a high general corrosion rate.

Most of the structures, especially in marine applications, are fabricated by the technique of welding. Welding is a reliable and efficient metal-joining process which is widely used in industry. However, during the welding process, due to the different quantities of heat input as well as the quality of the weldments, many problems arise from the process, especially in corrosion. The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of the welds and adjacent base metal. The metallurgical factor is one of the primary concerns with the corrosion of welded carbon steel (Davis JR., 2006). When a welded structure is exposed to water containing corrosion-aggressive ions such as chloride ions, corrosion becomes severe, even in a short period of exposure. In such a condition, localized corrosion such as galvanic corrosion or intergranular corrosion, coupled with a reduction reaction of dissolved oxygen, can occur because the welded structure is composed of different metals or has heterogeneity in the heat-affected zone (HAZ) induced by the welding process. Furthermore, these weldments are usually more vulnerable to stress corrosion cracking than the corresponding base plates, while the welded zones represent potential weak links which may limit or impair performance. Thus, improvements in weldment properties are critical to increase the reliability of high-performance structures utilizing welded carbon materials.

Several studies have been done to investigate the effect of welding parameters on the corrosion behaviour of various metals. Rajakumar, Muralidhara (2011) reported that all welding parameters have a significant effect on the corrosion rate of AA6061-T6 aluminium alloy. He mentioned that the corrosion rate was at its maximum when the tool rotational speed was at lower and higher levels, whereas the corrosion rate was found to be the minimum when the welding speed was at 80 mm/min. Yousefieh, Shamanian (2011), while investigating the optimization of the pulsed current gas tungsten arc welding (PCGTAW) parameters for corrosion resistance, found that the percentages of pulse current, background current, percentage on time and pulse frequency on the corrosion resistance were 66.28%, 25.97%, 2.71% and 5.04% respectively. Another study done by Fahimpour, Sadrnezhaad in 2012 mentioned that friction stir welding results in joints having higher resistance to corrosion as compared to gas tungsten arc welding, and T6 heat treatment improved the corrosion resistance of welds.

Although a number of investigations and studies have been conducted, to the best of the authors' knowledge and according to the literature study, work on the effects of welding parameters and combined with the heat treatment process on the corrosion behaviour. Thus, this research work concentrates purely on the corrosion behaviour of mild steel.

The welding process is widely used in the construction and repairs of equipment in the gas and petroleum industry. Welds between different metals are commonly called Dissimilar Metal Weld (DMW). With an increasing demand in the application requirements, dissimilar material joining becomes inevitable in engineering industries.

The offshore structures are exposed to the various environments, and it is well known that the corrosion rate and the corrosion mechanism under each environment, marine atmosphere, splash zone, tidal zone, underwater zone and bottom zone, are different.

Tungsten Inert gas (TIG) welding is a process that is being widely used in industry for sheet joining purposes. Many applications of welding made of carbon steel (e.g. bridge structure, fuel tanks, pipelines, shipbuilding etc) are subjected to various stresses (mechanical, thermal etc). The toughness and resistance of the welded piece to failure depending on many factors such as welding parameters (current, voltage, speed etc), geometric shape, design of the welding piece, the method implemented for welding and the nature of the applied stresses and others. It is well known that the welding process relies on an intensely localized heat input, which tends to generate undesired residual stresses and deformations in welded structures, especially in the case of thin plates.

Carbon steel pipes and vessels are often required to transport water or a submerged in water to some extent during service. This exposure can be conditions varying temperature, flow rate, pH, and other factors, all of those alter the corrosion rate.

Nowacki and Zając [2008] determined the impact of the wide-gap welding with increased root facegap, on structure and corrosion properties of the welded joints executed on duplex steel by one-side welding on ceramic backings. The performed tests and examinations of welded joints with root face gap ranging from 6 to 10 mm were intended for extending the standard range from 2 to 6 mm. They concluded that the wide-gap welding (with root face gap up to 10 mm) of duplex steel joints in vertical position does not have an adverse effect on structural and corrosion-resistance properties. When the technological process is carried out in an appropriate way, the welded construction can be executed (without the necessity to repair the welded joints geometry) using the extended range of the root face gap.

Hani and Khaiyria (2010) studied experimentally and numerically the influence of single butt MIG welding shapes design on the microstructure and stresses of low carbon steel. This research describes the corrosion rate in the butt welding and microstructure of welded region and the modeling of the welding process using the response surface methodology technique to model this process.

Vargas-Arista *et al* [2011] investigated the corrosion behavior of welded joints in API5L-X52 pipe steel aged at 250°C at different times under electrochemical technique like Tafel polarization, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies. The electrochemical results which were performed in a solution of brine containing hydrogen sulfide at

25ºC, revealed an increase of the general corrosion rate in the weld bead, the heat affected zone and the base metal as the aging time was elapsed. The deterioration of the corrosion resistance was confirmed by the formation of brittle porous corrosion products of iron sulfide and iron oxide with considerable differences in the morphology for the three different microstructural zones.

1.1 Statement of problem

Awareness about the importance of welding technology in Nigeria is massively increasing. This was due to the increase in the failure of welded structures due to corrosion which led to the application of novel optimization tools meant to improve on welded joints as the performance of the existing process parameters are in doubt. These existing process parameters were at one time, optimized and suggested as the proper process parameters to be used. Since there is a steep increase in failure rate of welded joints due to corrosion, there has become a need for new methods of welding process to be carried out in other to ascertain the least rate of corrosion of a simple weld joint using tungsten inert gas welding process.

This study has adopted the use of Response Surface Methodology approach, as a method whose findings would be compared to those obtained from using other or known methods.

1.2 Aim and objectives of the study

1.2.1 Aim of the study

The aim of this study is to model the environmental effects of corrosion on tungsten inert gas weld joints of a mild steel pipe.

1.2.2 Objectives of the study

The specific objectives are;

- To optimize the Tungsten Inert Gas (TIG) process parameters such as current, weld speed and gas flow rate using response surface methodology technique (RSM)
- To obtain the least rate of corrosion by varying the process parameters of tungsten inert gas weld process.
- To predict the process parameters of a tungsten inert gas welding process using Response Surface Methodology to obtain the least rate of corrosion of a mild steel pipe.

1.3 Scope of study

In order to achieve the objective, it should have proper arrangement of scopes project. The lists of scopes are as followed:

1. Sample preparation including raw material preparation and cutting process
2. Compositional analysis before and after welding process

3. Welding process with different welding speed, voltage and current using Tungsten Inert Gas (TIG) process to the mechanical properties of low carbon steel.
4. Corrosion test and analysis.

1.4 Significance of study

This study was carried out to determine the least rate of corrosion on mild steel butt joint weld using Tungsten Inert Gas (TIG) when the input parameters were varied for successive weldments.

CHAPTER TWO

LITERATURE REVIEW

2.1 Welding overview

Welding is the process of joining together two pieces of metal so that bonding takes place at their original boundary surface. When two parts to be joined are melted together, heat or pressure or both is applied and with or without added metal for formation of metallic bond.

The basic welding techniques are about as old as metalworking itself. Even before the Iron Age started, the ancient gold workers knew how to heat up two pieces of gold and hammer them together. The early process of brazing is found in different gold objects in Egyptian tombs, and has been dated to go back as far as 3000 BC. However, the earliest process that is similar to modern day welding where carried out by blacksmiths in the middle ages. The process then was to heat up the ends of two pieces of metal, stick them together and hammer it until the two ends had cooled down. The hammering had two functions: The first, and obvious one, was to forge the two ends together. The second function was to keep slag from forming. Slag is the solidification of unwanted materials, or pollutions, that can get trapped inside the weld and weakening it. The welding techniques remained more or less the same until the end of the 19th century.

In 1881, French scientist Auguste De Meritens succeeded in fusing lead plates by using the heat generated from an electrical arc. This method is in some ways the bridge between blacksmithing and welding. Auguste used the arc to heat and fuse lead. However, he did not add any filler, so it was not a completely melted bond between the two plates. Later that same year the Russian inventor Benardos was the first to demonstrate the principle of arc welding. He was able to form an electric arc between the work piece and a carbon electrode. When the arc had stabilized, a small metal rod where introduced. The metal rod melted in the arc and filled the gap in the work piece, thus completing the first electric arc weld. He had invented the first process similar to Tungsten Inert Gas (TIG) welding. He is therefore considered the “father of welding” In Russia. The drawback to his invention was the energy needed. The electric current required where generated by a steam engine, making the equipment needed for welding large and impractical. There did exist batteries capable of storing and delivering the needed current, but they did not last very long due to the short – circuiting. The heavy equipment needed, combined with the accidental discovery of how to produces acetylene (1892), halted the development of arc welding. In January 1941, Russell Meredith working for Northrop Aircraft, filed a patent for the first practical and complete TIG system. The invention was driven by the need to weld magnesium, aluminium and other lightweight metals in the production of aircrafts. It was a complete system with voltage and current control and nozzle for an inert gas.

2.1.1 Need for welding

With ever increasing demand for both high production rates and high precision, fully mechanized or automated welding processes have taken a prominent place in the welding field. The rate at which automation is being introduced into welding process is astonishing and it may be expected that by the end of this century more automated machines than men in welding fabrication units will be found. In addition, computers play critical role in running the automated welding processes and the commands given by the computer will be taken from the programs, which in turn, need algorithms of the welding variables in the form of mathematical equations. To make effective use of the automated systems it is essential that a high degree of confidence be achieved in predicting the weld parameters to attain the desired mechanical strength in welded joints. To develop mathematical models to accurately predict the weld strength to be fed to the automated welding systems has become more essential.

2.1.2 Classification of welding processes

Welding is not new. The earliest known form of welding, called forge welding, dates back to the year 2000 B.C. Forge welding is a primitive process of joining metals by heating and hammering until the metals are fused (mixed) together. Although forge welding still exists, it is mainly limited to the blacksmith trade.

There are many types of welding techniques used to join metals. The welding processes differ in the manner in which temperature and pressure are combined and achieved. The welding process is divided into two major categories: Plastic Welding or Pressure Welding and Fusion Welding or Non-Pressure Welding.

Plastic Welding or Pressure Welding: When the metal piece acquires plastic state on heating, external pressure is applied. In this process, externally applied forces play an important role in the bonding operation. "A group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined without the addition of a filler metal" is Pressure Welding Process. Without melting the base metal, due to temperature, time and pressure coalescence is produced. Some of the very oldest processes are included in solid state welding process. The advantage of this process is the base metal does not melt and hence the original properties are retained with the metals being joined.

Fusion Welding or Non-Pressure Welding: The material at the joint is heated to a molten state and allowed to solidify. In this process the joining operation involves melting and solidification and any external forces applied to the system do not play an active role in producing coalescence. Usually fusion welding uses a filler material to ensure that the joint is filled. All fusion welding processes have three requirements: Heat, Shielding and Filler material.

2.1.3 Types of welding

Welding process can also be classified as follows

- GAS WELDING: One of the most popular welding methods uses a gas flame as a source of heat. In the oxyfuel gas welding process, heat is produced by burning a combustible gas, such as MAPP (methylacetylene-propadiene) or acetylene, mixed with oxygen. Gas welding is widely used in maintenance and repair work because of the ease in transporting oxygen and fuel cylinders. Once you learn the basics of gas welding, you will find the oxyfuel process adaptable to brazing, cutting, and heat treating all types of metals. Gas welding include the following;
    - I. Oxy Acetylene Welding
    - II. Oxy Hydrogen Welding
    - III. Pressure Gas Welding
- ARC WELDING: Arc welding is a process that uses an electric arc to join the metals being welded. A distinct advantage of arc welding over gas welding is the concentration of heat. In gas welding the flame spreads over a large area, sometimes causing heat distortion. The concentration of heat, characteristic of arc welding, is an advantage because less heat spread reduces buckling and warping. This heat concentration also increases the depth of penetration and speeds up the welding operation; therefore, you will find that arc welding is often more practical and economical than gas welding. All arc-welding processes have three things in

common: a heat source, filler metal, and shielding. The source of heat in arc welding is produced by the arcing of an electrical current between two contacts. The power source is called a welding machine or simply, a **welder.** This should not be confined with the same term that is also used to describe the person who is performing the welding operation. The welder (welding machine) is either electric or motor-powered. In the Naval Construction Force (NCF), there are two main types of arc-welding processes with which you should become familiar. They are shielded metal arc welding and gas shielded arc welding. Arc welding include the following;

I. Carbon Arc Welding
II. Shield Metal Arc Welding
III. Submerged Arc Welding
IV. Metal Inert Gas Welding
V. Tungsten Inert Gas Welding
VI. Electro Slag Welding
VII. Plasma Arc Welding

- RESISTANCE WELDING: Resistance welding is a welding technology widely used in manufacturing industry for joining metal sheets and components. The weld is made by conducting a strong current through the metal combination to heat up and finally melt the metals at localized point(s) predetermined by the design of the electrodes and/or the work pieces to be welded. A force is always applied before, during and after application of current to confine the contact area at the weld interfaces and, in some applications, to forge the work pieces. Resistance welding process includes the following;

I. Spot Welding

II. Flash Welding

III. Resistance Butt Welding

IV. Seam Welding

- SOLID STATE WELDING: Solid state welding is a group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing filler metal. Pressure may or may not be used. These processes are sometimes erroneously called 'solid state bond process.' This group of welding process include the following;

I. Forge Welding

II. Cold Welding

III. Friction Welding

IV. Explosive Welding

V. Diffusion Welding

VI. Ultrasonic Welding

In all of these processes time, temperature and pressure individually or in combination produce coalescence of the base metal without significant melting of the base metals. Solid state welding includes some of the oldest of the welding processes and some of the very newest. Some of the processes offer certain advantages since the base metal does not melt or form nugget. The metals being joined retain their original properties without the heat affected zone problems involved when there is base metal melting. When dissimilar metals are joined, their thermal expansion and conductivity is of much less importance with solid state welding than with arc welding process.

- THERMO-CHEMICAL WELDING

I. Thermit Welding

II. Atomic hydrogen Welding

- RADIANT ENERGY WELDING

I. Electron Beam Welding

II. Laser Welding

2.1.4 Welding of different materials

The most available metal in the earth's crust is aluminum whereas, steel is the most used metal. In majority of cases aluminum alloys are replacing steels in industrial applications. Aluminum alloys have low density i.e. nearly one third when compared to steels. Some of these materials are allowing for a significant reduction of weight when compared with structural steels. Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. The aluminum alloys can resist the oxidation process, corrosion by water and salt, which steel cannot. The most desirable properties of aluminum and its alloys are the light weight, appearance, ability for fabrication, strength and corrosion resistance and hence it is used for wide variety of applications. When used in aerospace, rail and road vehicles these attributes enable energy efficient operation. In the aerospace applications, materials with high strength-to-weight ratio are required such as aluminum alloys. The production of components of aluminum alloys is not very complex; but joining of these materials can sometimes cause serious problems. Among all aluminum alloys, alluminium-manganese-silicon alloy plays a major role in the aerospace industry. They are widely used in the aerospace applications because it has good formability, weldability, machinability, corrosion resistance and good strength when compared to other series of aluminum alloys.

2.1.5 Defects in welding

The lack of training to the operator or careless application of welding technologies may cause discontinuities in welding. In aluminum joints obtained by fusion welding, the defects such as porosity, slag inclusion, solidification cracks etc., are observed and these defects deteriorates the weld quality and joint properties.

Common weld defects found in welded joints: These defects may result in sudden failures which are unexpected as they give rise to stress intensities. The common weld defects include

i. Porosity
ii. Lack of fusion
iii. Inclusion
iv. Cracking
v. Undercuts
vi. Lamellar tearing

i. **Porosity:** Porosity occurs, when the solidifying weld metal has gases trapped in it. The presence of porosity in most of the welded joints is due to dirt on the surface of the metal to be welded or damp consumables. It is found in the shape of sphere or as elongated pockets. The region of distribution of the porosity is random and sometimes it is more concentrated in a certain region. By storing all the consumables in dry conditions and degreasing and cleaning the surface before welding, porosity can be avoided.

ii. **Lack of fusion:**Due to too little input or too slow traverse of the welding torch, lack of fusion arises. By increasing the temperature, by properly cleaning the weld surface before welding and by selecting the appropriate joint design and electrodes, a better weld can be obtained. On extending the fusion zone to the thickness of the joints fully, a good quality joint can be obtained.

iii. **Inclusions:** Due to the trapping of the oxides, fluxes and electrode coating materials in the weld zone the inclusions are occurred. Inclusions occur while joining thick plates in several runs using flux cored or flux coated rods and the slag covering a run is not totally removed after every run and before the next run starts. By maintaining a clean surface before the run is started, providing sufficient space for the molten weld metal between the pieces to be joined, the inclusions can be prevented.

iv. **Cracking:** Due to thermal shrinkage, strain at the time of phase change, cracks may occur in various directions and in various locations in the weld area. Due to poor design and inappropriate procedure of joining high residual stresses, cracking is observed. A stage-wise pre-heating process and stage-wise slow cooling will prevent such type of cracks. This can greatly increase the cost of welded joints. Cracks are classified as hot cracking and hydrogen induced cracking. The cracking can be minimized by preferring fillers with low carbon and low impurity levels. The solidification cracking can be avoided by reducing the gaps and cleaning the surface before welding.

v. **Undercutting:** The undercut is caused due to incorrect settings or using improper procedure. Undercutting can be detected by a naked eye and the excess penetration can be visually detected.

vi. **Lamellar tearing:** Due to non-metallic inclusions, the lamellar tearing occurs through the thickness direction. This is more evidently found in rolled plates. As the fusion boundary is parallel to the rolling plane in T and corner joints, the lamellar tearing occurs.

By redesigning the joint and by buttering the weld area with ductile material, the lamellar tearing can be minimized.

2.2 Tungsten inert gas (tig) welding

TIG (Tungsten Inert Gas) welding also known as GTA (Gas Tungsten Arc) in the USA and WIG (Wolfram Inert Gas) in Germany, is a welding process used for high quality welding of a variety of materials, especially, Stainless Steel, Titanium and Aluminium. As the abbreviation implies, this is a gas shielded electrical welding process utilizing a non-consumable electrode. The gas is used to shield the weld pool from the oxygen in the atmosphere. Liquid iron is very reactive, and will make a bond with the oxygen in the atmosphere, this is known as oxidation and can weaken the weld. The gas protects the weld pool until the iron solidifies, making it far less likely to oxidize. The gas also increases the conductivity between the electrode and work piece, making it possible to strike an electric arc. The electrode is made of tungsten, which has a melting point of 3422 degrees Celsius, this enables the electrode to remain solid during the weld. This allows a precise control of the electric arc, and there for the heat. The method is also known as TIG, tungsten inert gas. In welding standards and literature, it is often just referred to as “method 141”. A GTAW (gas tungsten arc welding) system consist of a constant current power supply, typically operating from 3 to 300 A, and 10 to 35 V. Both direct and alternating current. TIG welding can be carried out using DC for Stainless Steel, Mild Steel, Copper, Titanium, Nickel Alloys etc and AC for Aluminium and its Alloys and Magnesium. DC power sources could be of 1 phase or 3 phase design, with an inductor to provide a smooth output. AC and AC / DC Power Sources are of a single phase design. The GTAW can be manual or semi-automatic. Meaning that the filler metal can be hand-fed into the arc when welding. Alternatively, it can be continually fed. It is possible to weld without a filler, then referred to as autogenous welding. This method is used on thin metals, edge joints and flange joints. This unit also contains a gas flow regulator and gas supply. The torches used are lightweight, compared to the other systems. It has a small gas nozzle, a tungsten electrode and a power switch. The only real weight comes from the cables attached to it. The torches come in four basic designs: for automatic welding, for manual welding, air cooled for low current welding and water-cooled for high current welding. A workpiece clamp is needed to complete the welding circuit. Differing from the other systems, the GTAW usually have a "throttle pedal" giving the operator direct control over the current, and in turn direct control over the arc and melting pool.

GTAW is the best method to use when welding together different metals. In addition, it creates a very smooth, uniformed surface. Therefore, needing little or none after work. When operating manually it requires a highly skilled worker, compared to the other methods. When welding manual GTAW the operator need one hand operating the torch, one hand to feed the filler and a foot to control the current. This is why manual GTAW is referred to as "three arm welding".

Prachya. P and Anucha. W (2012) studied the effect of shielding gas parameter on mechanical properties and microstructures of heat-affected zone and fusion zone on gas tungsten arc welding (GTAW) in aluminium alloy AA 5083. The factorial experiment was designed for this research. The factors of AA 5083 weld used in the study types of shielding gas in argon and helium, gas flow rate at 6, 10 and 14 liters per minute. Then the results were using microstructure and Vickers hardness test. The result showed that types of shielding gas and gas flow rate interaction hardness at heat affected zone and fusion zone with a P – value $< .05$. The factor which was the most effective to the hardness at heat affected zone and fusion zone was argon with a flow rate of 14 liters per minute at heat-affected zone with 74.27HV and fusion zone with 68.97HV.

Experimental results showed that the argon condition provided smaller grain size, suitable size resulting in higher hardness both in weld metal and HAZ. They also indicated that the grain size and precipitation Mg affect the hardness of sample.

R.Ramchandran (2015) studied the various effect of the TIG welding on the Austenitic stainless steel 316L on micro structural changes through destructive and nondestructive method and various parameters such as tensile strength, hardness on varying the current, voltage and gas flow ratio respectively.

S.M.Ravi Kumar and DR.P.Vijian (2014) studied the weld bead geometry in shielded metal arc welding and that is of multiple performance characteristics into the optimization of the single performance characteristics called grey relational garden and found the process parameters of welding current 140 A, welding speed 4 mm/sec and wind velocity 7m/s .Also found by ANOVA heat the most significant welding process parameter (47.71%) followed by welding speed (30.40%) and wind velocity (19.54%) respectively.

Dr.Simhachalam et al.(2015) carried on the effect of welding process parameters on the mechanical properties of stainless steel -316 (18Cr-8N) welded by TIG welding. The specimen size is 40x15x5mm for experimentation observed that the welding current has a significant effect though filler rod do have some effect similar to current but compared to current it is less significant. MINITAB software is used forthe prediction of the hardness, impact strength , depth of penetrations.

Advantages:

1. Makes high quality welds in almost all metals and alloys.

2. Almost none post weld clean up required.

3. The arc and weld pool are clearly visible to the welder.

4. The arc carries no filler, so there is little to none splatter.

5. GTAW consumes almost 1/3 of the gas compered to GMAW.

6. No slag produced that can be trapped in the weld.

7. Welding can be performed in all positions.

Disadvantages:

1. The GTAW is not a high production or high deposit-rate welding process.

2. Requires a highly skilled operator.

3. Prone to pollution due to unclean work area.

4. Hard to weld in difficult operator positions.

2.2.1 Multi-pass welding

When welding together thick pieces of metal, the amount of energy or filler required to make a complete fusion may be too large to do in one pass. This means that a multi pass technique must be applied.

The maximum depth of the groove before making the leap from single pass welding to multi pass is not a constant value. It all depends on what welding method is used and what metal is being welded on. Even when welding on different steels, the maximum energy input ranges from 0.8 to 3 kJ /mm.

If the temperature in the parent metal gets too high, it may crack under the cooling process. Hot cracks can occur if the temperature is above 0,5 x T_m, this is caused by the lack of ductility in the material when the metal is contracting when cooling down. Cold cracks can occur at lower temperatures, sometimes long after the weld is completed. Even as long as 48 hours if the weld is very deep.

2.2.2 Arc efficiency

Different studies have indicated values for the arc efficiency from 0.36 up to 0.9, a meta study from 2013 have analysed several articles from 1955 to 2011 and found that the value is likely to be 0.77. The effectiveness is regardless of the metal used. The study also indicated that the most effective arc-length is around 5 millimetres. The arc efficiency is reduced when the arc length is increased. On the other hand, the meta study found conflicting results in the literature as to the influence of arc current and travel speed.

The Norwegian standard NS-EN 1011-1:2009 recommends using 0.6 for the efficiency of the GTAW process. This is the governing standard for welding procedures, so their value will be used.

2.2.3 Welding parameter

The amount of energy the metal can tolerate before the mechanical properties get altered dictates to a large degree the amount of filler that can be added in every pass. It is therefore good to have guidelines, or a maximum value, for the amount of filler the arc can melt and fuse.

A good weld is a result of the correct relationship between current, arc speed and feed rate. In addition, when using the AVCH – software, voltage represents a fourth parameter that can be manually set. However, every welder has his own speed, movement and work height. When searching and inquiring for guidelines and/or approximate values for the different settings, one can get as many different answers as the number of sources. In addition, most of welders asked start with the sentence: “you just start the welding process, and you will see how it goes”. In accordance to the experts, several test welds will be made. Before testing can begin, analyses of the impact on the weld by the different parameters must be analysed.

The settings and parameters for the welding operation is one side of the problem, another regard is the amount of heat / energy the parent metal can handle. In other words, how easy is it to weld? Different metals and alloys have different thresholds for heat. One indicator for the weldability in carbon steel is the carbon equivalent.

2.2.4 The four dominating parameters

Current, voltage and arc speed are the three parameters that affect the energy input to the parent metal. Increasing current and voltage increases the energy input per mm, on the other hand increasing arc speed has the opposite effect. The fourth is the feed rate of the filler material.

Voltage: To compensate for the varying height of the weld torch, the voltage varies automatic. This information is in this case, used to keep the arc height constant. Too low voltage, and therefore arc, may cause the electrode to get into the weld pool. Too high and the efficiency of the arc will have a dramatic fall, and may cause the weld pool to cool down, or the arc can just extinguish. Experiments show that increasing the arc length, with constant current, typical will increase the voltage with 0.5 – 2 V per millimetre. This value is dependent of the gas, but is linear for the respective gas. The same happens when decreasing the arc length. The voltage has little effect on the penetration of the weld. However, it has an effect on the width, higher voltage means longer arc. This effect is due to the bell-shape of the arc.

Current: The dominating parameter regarding energy input. This is the main parameter that is adjusted in manual GTAW, as previously stated the voltage will “self-adjust”. When altering the current, the penetration of the weld, and therefore HAZ, will change. Higher current means deeper penetration.

Arc speed: Also called robot speed. The higher this movement is, the lower energy input per millimetre. This is one of the strength with robot welding; a robot can have a higher and more accurate arc speed, over longer distances than a human can.

Feed rate: The amount of filler added, this is controlled independently of the other parameters. The feed rate is adjusted according to the type of weld and the arc energy. A filler pass will have higher feed than a root / cover pass, while the other settings can remain the same.

2.2.5 Carbon equivalent

A good indicator for the weldability and need of pre-heat and post-heat is the carbon equivalent. The hardenability of a steel, is approximately, related to its carbon content, and the content of certain other alloying elements. The contribution to the hardenability of other alloys are known, and can be calculated as a percentage if all the alloys where carbon. There exist different formulas too calculating the carbon equivalent, all based on the different alloying metals on the steel.

2.2.6 Working of tig welding

A long tungsten electrode is used to produce arc between the electrode and base metal which are connected to the power supply. Since electrode is made up of tungsten so it is non-consumable though filler metal may or may not be used depending upon base metal. As the arc produce the metal started melting forming weld pool. However, for the protection of weld formed from atmospheric air the inert gases like Helium, Argon or mixture of Helium-Argon is used to eliminate the possibility of weld contamination. The above figure also describes the same process of TIG welding.

There are three types of polarities used for TIG welding.

- DCSP (Direct Current Straight Polarity):- In this tungsten electrode is attached to negative (-) terminal and work piece is attached to positive (+) terminal of power supply. It is used for deep penetration as 2/3 heat is at the work piece and 1/3 heat is at the tungsten electrode. Thus resulting weld will have good penetration and narrow profile.

- DCRP (Direct Current Reverse Polarity):- In this tungsten electrode is connected to positive (+) terminal and the work piece is connected to negative (-) terminal. It gives more heat on tungsten due to which tungsten electrode get over heated sometime burn away. This type of connection is very rarely used.

- ACHF (Alternating Current High Frequency) or AC (Alternating Current):- The heat input to the tungsten is average at both electrode and work piece as the AC wave passes from one side to another. It is used for welding mostly for white metals such as aluminum and magnesium.

2.2.7 Electrode used in tig welding

There are five types of electrode which are used in TIG welding and identified with their colour.

1)Pure Tungsten (W) (Geen Colour).

2)1% Thoriated Tungsten (Yellow Colour).

3).2% Thoriated Tungsten (Red Colour).

4)Striped Tungsten (Blue Colour).

5)Zirconium Tungsten (Brown Colour).

2.3 Corrosion of metals

In broad terms, corrosion is defined as the interaction between a material and its environment that results in the degradation of the physical, mechanical, or even aesthetic properties of that material. More specifically, corrosion is usually associated with a change in the oxidation state of constituent elements within the metal oxide. J.O'M, Bockris and A.K Reddy (1970) stated that the stability of metals depend upon the events taking place on their surface when they are in contact with an electrolyte.

Yunan Prawoto (2009) evaluated the corrosion rates and pitting morphology of the selected duplex stainless steel and found that decreasing pH increases the corrosion rate. Similarly, increasing temperature increases corrosion rates this can be achieved well using different solutions with different temperature and periods of immersion.

D.C.Oliver (2003) investigates the relative exterior corrosion resistance of three alloys- two ferritic stainless steel (AISI Types 409 and 441) and an aluminized mild steel; concluded that the De-icingsalts have a clearly detrimental effecton corrosion resistance and stated that primary external corrosion mechanism causingfailure at the cold end of the exhaust system in the presence of de-icing salts is pitting. The higher chromium type 441 alloy was far more resistant than type 409.

Corrosion is the deterioration of materials by chemical interaction with their environment. The term corrosion is sometimes also applied to the degradation of plastics, concrete and wood, but generally refers to metals. The most widely used metal is iron (usually as steel) and the following discussion is mainly related to its corrosion. Corrosion is the destructive result of electrochemical reaction between a metal or alloy and its surrounding environment. The metals are generally in high energy state because some energy is added during their manufacturing process from the ores.

Low energy-state ores are more stable than the high energy-state metals. For this reason, the metals tend to release the energy and go back to their original form. Hence, the metals revert to their parent state or ore under a suitable corrosive environment. This conversion phenomenon is nothing but the corrosion. The electrochemical process involved in corrosion is by nature opposite to the extractive metallurgy involved in manufacturing of the metals. Therefore, corrosion is sometimes considered as the reverse process of extractive metallurgy.

Corrosion of metal is indeed an omnipresent phenomenon. It can occur wherever an active corrosive environment is present. However, the forms of corrosion differ based on the factors that affect the corrosion process. The form of corrosion could be either more general such as pitting and crevice or more specific such as hydrogen embrittlement and stress corrosion cracking. This note mainly presents very common cases of atmospheric, galvanic, pitting, crevice and microbial corrosion. In addition, this note points to the rational causes of corrosion, and suggests possible solutions for protecting the metals with regard to the depicted cases.

Rajakumar, Muralidhara (2011) reported that all welding parameters have a significant effect on the corrosion rate of AA6061-T6 aluminium alloy. He mentioned that the corrosion rate was at its maximum when the tool rotational speed was at lower and higher levels, whereas the corrosion rate was found to be the minimum when the welding speed was at 80 mm/min.

Vargas-Arista et al (2011) investigated the corrosion behavior of welded joints in API5L-X52 pipe steel aged at 250°C at different times under electrochemical technique likeTafel polarization, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies. The electrochemical results which were performed in a solution of brine containing hydrogen sulfide at 25ºC, revealed an increase of the general corrosion rate in the weld bead, the heat affected zone and the base metal as the aging time was elapsed. The deterioration of the corrosion resistance was confirmed by the formation of brittle porous corrosion products of iron sulfide and iron oxide with considerable differences in the morphology for the three different microstructural zones.

2.3.1 Consequences of corrosion

The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple loss of a mass of metal. Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. Some of the major harmful effects of corrosion can be summarised as follows:

1. Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localised zones so as to give a crack like structure, very considerable weakening may result from quite a small amount of metal loss.

2. Hazards or injuries to people arising from structural failure or breakdown (e.g. bridges, cars, aircraft).

3. Loss of time in availability of profile-making industrial equipment.

4. Reduced value of goods due to deterioration of appearance.

5. Contamination of fluids in vessels and pipes (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion).

6. Perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For example a leaky domestic radiator can cause expensive damage to carpets and decorations, while corrosive sea water may enter the boilers of a power station if the condenser tubes perforate.

7. Loss of technically important surface properties of a metallic component. These could include frictional and bearing properties, ease of fluid flow over a pipe surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface.

8. Mechanical damage to valves, pumps, etc, or blockage of pipes by solid corrosion products.

9. Added complexity and expense of equipment which needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

2.3.2 Chemistry of corrosion

Common structural metals are obtained from their ores or naturally-occurring compounds by the expenditure of large amounts of energy. These metals can therefore be regarded as being in a metastable state and will tend to lose their energy by reverting to compounds more or less similar to their original states. Since most metallic compounds, and especially corrosion products, have little mechanical strength a severely corroded piece of metal is quite useless for its original purpose.

Virtually all corrosion reactions are electrochemical in nature, at anodic sites on the surface the iron goes into solution as ferrous ions, this constituting the anodic reaction. As iron atoms undergo oxidation to ions they release electrons whose negative charge would quickly build up in the metal and prevent further anodic reaction, or corrosion. Thus, this dissolution will only continue if the electrons released can pass to a site on the metal surface where a cathodic reaction is possible. At a cathodic site the electrons react with some reducible component of the electrolyte and are themselves removed from the metal. The rates of the anodic and cathodic reactions must be equivalent according to Faraday's Laws, being determined by the total flow of electrons from anodes to cathodes which is called the "corrosion current", I_{cor}.

Since the corrosion current must also flow through the electrolyte by ionic conduction the conductivity of the electrolyte will influence the way in which corrosion cells operate. The corroding piece of metal is described as a "mixed electrode" since simultaneous anodic and cathodic reactions are proceeding on its surface. The mixed electrode is a complete electrochemical cell on one metal surface.

The most common and important electrochemical reactions in the corrosion of iron are thus

Anodic reaction (corrosion)

$$Fe \rightarrow Fe^{2+} + 2e \qquad 2.1$$

Cathodic reactions (simplified)

$$2H^{+} + 2e \rightarrow H_2 \qquad 2.2$$

Or

$$2H_2O + \frac{1}{2}O_2 + 2e \rightarrow 2OH^{-} \qquad 2.3$$

Reaction 2.2 is most common in acids and in the pH range 6.5 – 8.5 the most important reaction is oxygen reduction 2.3. In this latter case corrosion is usually accompanied by the formation of solid corrosion debris from the reaction between the anodic and cathodic products.

$$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2 \text{ , iron (II) oxide} \qquad 2.4$$

Pure iron (II) hydroxide is white but the material initially produced by corrosion is normally a greenish colour due to partial oxidation in air.

$$2Fe(OH)_2 + H_2O + \frac{1}{2}O_2 \rightarrow 2Fe(OH)_3 \text{ , iron (III) oxide} \qquad 2.5$$

Further hydration and oxidation reactions can occur and the reddish rust that eventually forms is a complex mixture whose exact constitution will depend on other trace elements which are present. Because the rust is precipitated as a result of secondary reactions it is porous and absorbent and tends to act as a sort of harmful poultice which encourages further corrosion.

For other metals or different environments different types of anodic and cathodic reactions may occur. If solid corrosion products are produced directly on the surface as the first result of anodic oxidation these may provide a highly protective surface film which retards further corrosion, the surface is then said to be "passive". An example of such a process would be the production of an oxide film on iron in water, a reaction which is encouraged by oxidizing conditions or elevated temperatures.

$$2Fe + 3H_2O \rightarrow Fe_2O_3 + 6H^+ + 6e \qquad 2.6$$

2.3.3 Factors that control the corrosion rate

Certain factors can tend to accelerate the action of a corrosion cell.

These include:

(a) Establishment of well-defined locations on the surface for the anodic and cathodic reactions. This concentrates the damage on small areas where it may have more serious effects, this being described as "local cell action". Such effects can occur when metals of differing electrochemical properties are placed in contact, giving a "galvanic couple". Galvanic effects may be predicted by means of a study of the Galvanic Series which is a list of metals and alloys placed in order of their potentials in the corrosive environment, such as sea water. Metals having a more positive (noble) potential will tend to extract electrons from a metal which is in a more negative (base) position in the series and hence accelerate its corrosion when in contact with it. The Galvanic Series should not be confused with the Electrochemical Series, which lists the potentials only of pure metals in equilibrium with standard solutions of their ions. Galvanic effects can occur on metallic surfaces which contain more than one phase, so that "local cells" are set up on the heterogeneous surface. Localised corrosion cells can also be set up on surfaces where the metal is in a varying condition of stress, where rust, dirt or crevices cause differential access of air, where temperature variations occur, or where fluid flow is not uniform.

(b) Stimulation of the anodic or cathodic reaction. Aggressive ions such as chloride tend to prevent the formation of protective oxide films on the metal surface and thus increase corrosion. Sodium chloride is encountered in marine conditions and is spread on roads in winter for de-icing. Quite small concentrations of sulphur dioxide released into the atmosphere by the combustion of fuels can dissolve in the invisibly thin surface film of moisture which is usually present on metallic surfaces when the relative humidity is over 60-70%. The acidic electrolyte that is formed under these conditions seems to be capable of stimulating both the anodic and the cathodic reactions. In practical terms it is not usually possible to eliminate completely all corrosion damage to metals used for the construction of industrial plant. The rate at which attack is of prime importance is usually expressed in one of two ways:

(1) Weight loss per unit area per unit time, usually mdd (milligrams per square decimeter per day)

(2) A rate of penetration, i.e. the thickness of metal lost. This may be expressed in American units, mpy (mils per year, a mil being a thousandth of an inch) or in metric units, mmpy (millimetres per year).

Taking as an example the corrosion of heat exchanger tubes in industrial cooling water a typical corrosion rate in untreated water would be 40-50 mpy (210-260 mdd); the use of a corrosion inhibitor could reduce this to less than 5 mpy (26 mdd). The mild steel tubing used in heat exchangers is a maximum of 200 thousandths of an inch thick, thus with corrosion rates of 40-50 mpy in untreated water, severe problems might be expected within four or five years. If suitable water treatment with corrosion inhibitors is used a life of at least twenty years might be expected. This, of course, is ignoring the fact that at some time before the metal corrodes away the tubing may have thinned to a point where its required mechanical strength is not attained. When designing equipment for a certain service life engineers often add a "corrosion allowance" to the metal thickness, permitting a certain amount of thinning before serious weakening occurs. In a cooling water system the factors influencing the rate of attack are:

Table 2.1: factors that affects the rate corrosion

1	the condition of the metal surface Corrosion debris and other deposits	corrosion under the deposits, with a possibility of pitting (severe attack in small spots)
2	the nature of the environment Ph	in the range of 4-10 corrosion rate is fairly independent of pH, but it increases rapidly when the pH falls below 4.
3	Oxygen content	Increase in oxygen concentration usually gives an increase in corrosion rate.
4	Flow rate	Increased water flow increased oxygen access to the surface and removes protective surface films, so usually increases corrosion, but can sometimes improve access for corrosion inhibiting reactants.
5	Water type	very important, in general low corrosion rates

		are found with scale-forming (hard) waters. Aggressive ions which accelerate corrosion are Cl^-, SO_4^{2-} but quite complex interactions may occur between the various dissolved species in natural waters.

2.3.4 Corrosion prevention

By retarding either the anodic or cathodic reactions the rate of corrosion can be reduced. This can be achieved in several ways:

1. Conditioning the Metal

This can be sub-divided into two main groups:

(a) *Coating the metal*, in order to interpose a corrosion resistant coating between metal and environment. The coating may consist of:

(i) Another metal, e.g. zinc or tin coatings on steel,

(ii) A protective coating derived from the metal itself, e.g. aluminium oxide on "anodised" aluminium,

(iii) Organic coatings, such as resins, plastics, paints, enamel, oils and greases.

The action of protective coatings is often more complex than simply providing a barrier between metal and environment. Paints may contain a corrosion inhibitor. Zinc coating in iron or steel confers cathodic protection.

(b) *Alloying the metal* to produce a more corrosion resistant alloy, e.g. stainless steel, in which ordinary steel is alloyed with chromium and nickel. Stainless steel is protected by an invisibly thin, naturally formed film of chromium sesquioxide Cr_2O_3.

2. Conditioning the Corrosive Environment

(a) Removal of Oxygen:By the removal of oxygen from water systems in the pH range 6.5-8.5 one of the componentsrequired for corrosion would be absent. The removal of oxygen could be achieved by the useof strong reducing agents e.g. sulphite.

However, for open evaporative cooling systems this approach to corrosion prevention is not practical since fresh oxygen from the atmosphere will have continual access.

(b) Corrosion Inhibitors:A corrosion inhibitor is a chemical additive, which, when added to a corrosive aqueousenvironment, reduces the rate of metal wastage. It can function in one of the following ways:

(i) Anodic inhibitors – as the name implies an anodic inhibitor interferes with the anodic process.

$$Fe \rightarrow Fe^{++} + 2e^{-} \qquad 2.7$$

If an anodic inhibitor is not present at a concentration level sufficient to block off all the anodic sites, localised attack such as pitting corrosion can become a serious problem due to the oxidising nature of the inhibitor which raises the metal potential and encourages the anodic reaction (equation 1). Anodic inhibitors are thus classified as “dangerous inhibitors”. Other examples of anodic inhibitors include orthophosphate, nitrite, ferricyanide and silicates.

(ii) Cathodic inhibitors – the major cathodic reaction in cooling systems is the reduction of oxygen.

$$\tfrac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^{-} \qquad 2.8$$

There are other cathodic reactions and additives that suppress these reactions called cathodic inhibitors. They function by reducing the available area for the cathodic reaction. This is often achieved by precipitating an insoluble species onto the cathodic sites. Zinc ions are used as cathodic inhibitors because of the precipitation of $Zn(OH)_2$ at cathodic sites as a consequence of the localised high pH. (See reaction 2.8). Cathodic inhibitors are classed as safe because they do not cause localised corrosion.

(iii) Adsorption type corrosion inhibitors– many organic inhibitors work by an adsorption mechanism. The resultant film of chemisorbed inhibitor is then responsible for protection either by physically blocking the surface from the corrosion environment or by retarding the electrochemical processes. The main functional groups capable of forming chemisorbed bonds with metal surfaces are amino ($-NH_2$), carboxyl (-COOH), and phosphonate ($-PO_3H_2$) although other functional groups or atoms can form co-ordinate bonds with metal surfaces.

(iv) Mixed inhibitors – because of the danger of pitting when using anodic inhibitors alone, it became common practice to incorporate a cathodic inhibitor into formulated performance was obtained by a combination of inhibitors than from the sum of the individual performances. This observation is generally referred to a ‘synergism’ and demonstrates the synergistic action which exists between zinc and chromate ions.

3. Electrochemical Control

Since corrosion is an electrochemical process its progress may be studied by measuring the changes which occur in metal potential with time or with applied electrical currents. Conversely, the rate of corrosion reactions may be controlled by passing anodic or cathodic currents into the metal. If, for example, electrons are passed into the metal and reach the metal/electrolyte interface (a cathodic current) the anodic reaction will be stifled while the cathodic reaction rate increases. This process is called cathodic protection and can only be applied if there is a suitable conducting medium such as earth or water through which a current can flow to the metal to be protected In most soils or natural waters corrosion of steel is prevented if the potential of the metal surface is lowered by 300 or 400 mV. Cathodic protection may be achieved by using a DC power supply (impressed current) or by obtaining electrons from the anodic dissolution of a metal low in the galvanic series such as aluminium, zinc or magnesium (sacrificial anodes). Similar protection is obtained when steel is coated with a layer of zinc. Even at scratches or cut edges where some bare metal is exposed the zinc is able to pass protective current through the thin layer of surface moisture. In certain chemical environments it is sometimes possible to achieve anodic protection, passing a current which takes electrons out of the metal and raises its potential. Initially this stimulates anodic corrosion, but in favourable circumstances this will be followed by the formation of a protective oxidised passive surface film.

2.3.5 Types of corrosion

- **Atmospheric corrosion**

Atmospheric corrosion is a most common form of corrosion that can be seen almost everywhere. It is also known as uniform or general corrosion. The rational causes of the atmospheric or uniform corrosion on manhole top are as follows:

a. Corrosive urban atmosphere

b. Uniform exposure to air and its pollutants

c. Equal exposure to sunlight

d. Uniform distribution of temperature

e. Favorable humidity and wetness

f. Damp moisture films over metal surface

g. Uniform adsorption of water molecules

h. Wet films of dew and rainwater

The probable solutions for preventing the atmospheric corrosion are given below:

a. Use galvanized manhole top

b. Do painting or polymer coating

c. Use glass and cement coatings

d. Use corrosion resistant metal or alloy

e. Select non-metallic materials

f. Reduce attack time with good drainage

g. Reduce atmospheric pollutants

h. Use suitable corrosion inhibitors

- **Galvanic corrosion**

Galvanic corrosion generally occurs between two unlike metals. It is also known as bimetallic corrosion. The intensity of galvanic corrosion mainly depends on the electrical activity of the coupled metals. The rational causes of the presented case of galvanic corrosion are as follows:

a. Formation of galvanic corrosion cell

b. Electrochemical contact of two dissimilar metals under corrosive environment

c. Extensive exposure to corrosive environment

d. Disparity in corrosive environment

e. Greatest anodic activity on iron part compared to stainless steel rim

f. Coating defects or coating damage

g. Large cathode to anode area ratio

h. Chloride road salts stimulating the corrosivity of the environment, particularly in cold regions

The possible solutions for preventing the galvanic corrosion are given below:

1. Make both car components with the same metal

2. Place a separable metal piece of intermediate potential or sacrificial anode between two metals

3. Select bimetals with minimum potential difference

4. Avoid contact between dissimilar metals using good insulation

5. Reduce cathode to anode area ratio

6. Avoid coating defects and repair coating damage

7. Use a suitable coating material on corroded area

8. Use a suitable corrosion inhibitor on corroded area

- **Crevice corrosion**

Crevice corrosion usually occurs in crevices, splits, and gaps or cracks present in metal structures.

It is also a widely occurring form of corrosion.

The rational causes of the crevice corrosion cited above are as follows:

a. Presence of crevices or shielded areas

b. Disparate micro and macro environments

c. Failure of passive films

d. Stagnant corrosive solutions

e. Lack of oxygen within crevices

f. Moisture entrapped in crevices

g. Occasional chloride contamination

h. Deposition of corrosive pollutants from air

The probable solutions for preventing the crevice corrosion are given below:

a. Minimize number of crevices

b. Avoid using bare metal connectors

c. Use coated metal connectors, nuts, and bolts

d. Use insulating washers in bolted connections

e. Employ crevice corrosion resisting alloys

f. Use non-metallic rail connectors

g. Use polymer clad metal connectors

h. Include impervious rubber or teflon gaskets

i. Remove debris and surface deposits

j. Ensure good drainage

- **Pitting**

Pitting is a well known form of corrosion that causes a lot of pits on metal surfaces. The pits are primarily very small in size but they become bigger with time. Generally, the pits become deeper and wider, as the corrosion process continues. The growing rate of pitting depends upon the corrosivity of the surrounding environment.

The rational causes of the illustrated case of pitting corrosion are as follows:

a. Localized breakdown of protective coating and passive film

b. Presence of moisture film in coating defects

c. Penetration of corrosive agents through defects

d. Rapid anodic dissolution by autocatalytic process in presence of corrosive agents

e. Low content of dissolved oxygen

f. Higher temperature

g. Poor maintenance

The possible solutions for preventing the pitting corrosion are given below:

a. Do regular surface cleaning

b. Use anti-corrosion foam or liquid spray over corroded area

c. Avoid coating defects

d. Select pitting resistant materials

e. Add corrosion inhibitors

f. Use protective coatings

g. Passivate the corroded metal by strong acid such as nitric acid

- **Microbial corrosion**

Microbial corrosion is another form of corrosion that often occurs in metals contacted with soil or sludge.

The rational causes of the illustrated case of microbial corrosion are as follows:

a. Direct contact with damp soil

b. Dominant de-aerated sheltered environment

c. Aerobic and anaerobic soil microbes

d. Dominant presence of sulfate-reducing bacteria

e. Highly resisting and waterlogged condition of soil

f. Long residence time of water on metal surface

g. Higher clay content of soil

h. Poor drainage facility

i. Removal or leaching of iron

j. Catalyzing effect of biological slime deposits

The probable solutions for preventing the microbial corrosion are given below:

a. Avoid contact with soil using a thick layer of gravel or crushed stone

b. Clean the surface by mechanical means and treats with biocides

c. Employ cathodic protection

d. Use alternative metal or alloy toxic to microbes

e. Replace the cross timber supports of the train rails when necessary

f. Avoid sludge deposition

g. Allow complete drainage

2.4 Optimization technique

Haken ates et al (2007). has performed an experiment in which low carbon steel plates (15 x 150 x 450 mm) were welded under 180 A and 28 V. A MIG/MAG welding machine was used, and CO_2, Ar and O_2 mixtures of three gases were used as the shielding media. The flow rate of the shielding gas was 15l/min, and the experiment was performed by setting the contact tip to the workpiece distance of 15 mm. The electrode wire has a diameter of 1.2 mm. A test conducted to analyze the mechanical properties in these experiments. Artificial neural networks (ANNs) using for prediction of gas metal arc welding parameters. Input parameters of the model consist of gas mixtures, whereas, the outputs of the ANN model include mechanical properties such as tensile strength, impact strength, elongation and weld metal hardness, respectively. The study has shown the possibility of the use of neural networks for the calculation of the mechanical properties of welded low alloy steel using the GMA method.

Joseph I. Achebo et al (2011) showed by his work that on selecting input parameters such as welding current, voltage, speed and time against response of ultimate tensile strength of steel, optimization was achieved with the help of Taguchi Method. From the analysis conducted by applying the Taguchi Method, an optimum process parameter of welding current of 240A, welding time of 2.0mins, welding speed of 0.0062 m/s, and welding voltage of 33V, was suggested. These optimum parameters were found to have an improvement of 2.32dB of the S/N ratio, and 1.11 times over the UTS of the existing process parameters. This study elucidates a step by step approach for applying the Taguchi Method.

D. S. Correia et al (2004) presented the optimization of MIG welding parameter using Genetic algorithm (GAs). The search for the near-optimal was carried out step by step, with the GA predicting the next experiment based on the earlier and without information of the modelling equations between the inputs and outputs of the MIG welding process. The GA was able to establish near optimum conditions with a relatively small number of experiments. But, the optimization by GA technique requires a good setting of its own parameters, such as number of generations, population size, etc. Otherwise, there is a risk of an inadequate extensive of the search space.

Amit Kumar et al (2014) have done work on optimization of MIG welding parameters using Artificial Neural Network (ANN) and Genetic Algorithm (GA). In this research work they make mathematical model by using ANN method for prediction effect of welding parameter such as welding voltage, welding speed and welding current on ultimate tensile stress during the welding of dissimilar material such as stainless steel grade 304 and grade 316. The argon gas was taken as shielding gas and experiment was done on full factorial. The Genetic Algorithm (GA) used to optimize the value of output parameter. From the analysis it is concluded that the maximum ultimate tensile strength is meet at 110 A welding current, 18 V welding voltage and 43.362 cm/min travel speed. Also they have shown that the Artificial Neural Network (ANN) successfully integrated as other regression model.

C. N. Patel et al (2013) evaluated the parameters; welding current, wire diameter and wire feed rate to investigate their influence on weld bead hardness for MIG welding and TIG welding by Taguchi's method and Grey Relational Analysis (GRA). From the study it was concluded that the welding current was most significant parameter for MIG and TIG welding. By use of GRA optimization technique the optimal parameter combination was found to be welding current, 100 Amp; wire diameter 1.2 mm and wire feed rate, 3 m/min for MIG welding.

Kumar CR A et al. (2016) studied the influence of process parameters i.e. current, welding speed and gas flow rate of 316LN stainless steel using TIG welding. The response surface methodology is employed to develop the empirical relationship. Using the Finite Element analysis numerical data generated on the influence of process variables on weld-bead geometry, regression models correlating the weld-bead shape parameters with the process parameters and the experimental result shows that the welded steel joint is at 95 % confidence level.

Pujari KS. et al. (2014) performed TIG welding of AA 7075-T6 Aluminium alloy and compares the weld pool geometry. On the basis of Taguchi approach and Utility concept, a model was developed to optimize various process parameters. The experimental result analysis showed that the combination of higher levels of Peak current, Base current, Gas flow rate and lower level of welding speed and intermediate level of Pulse on time and Frequency is essential to achieve simultaneous maximization of Penetration and minimization of Face width and Back width.

2.5 Response surface methodology (rsm)

Palani.P.K, et al, (2013) researched the effect of TIG welding process parameters on welding of Aluminium65032. Response Surface Methodology was used to conduct the experiments. The parameters selected for controlling the process are welding speed, current and gas flow rate. Strength of welded joints were tested by a UTM.

Response surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for analysing problems where several independent variables influence a dependent variable or response, and the goal is to optimise this response. We denote the independent variables by x_1, x_2,x_3…..x_k. It is assumed that these variables are continuous and controllable by the experimenter with negligible error. The response, 'v' is assumed to be a random variable.

Palani. P.K, Saju. M applied Response Surface Methodology was used to conduct the experiments. The parameters selected for controlling the process are welding speed, current and gas flow rate. Strength of welded joints was tested by a UTM. Percent elongation was also calculated to evaluate the ductility of the welded joint. From the results of the experiments, mathematical models have been developed to study the effect of process parameters on tensile strength and percent elongation. Optimization was done to find optimum welding conditions to maximize tensile strength and percent elongation of welded specimen. Confirmation tests were also conducted to validate the optimum parameter settings.

RSM is used for the design and analysis of experiments; it seeks to relate an average response to the value of quantitative variables that effect response. RSM answers different kind of questions, such as the following,

(i) How is a particular response affected by a given set of input variables over some specified region of interest?

(ii) To what level the inputs are to be controlled, to give a product simultaneously satisfying desired specifications?

(iii) What values of inputs will yield a maximum for a specific response, and what is the nature of response surface close to the maximum?

Figure 2.1 is a flow diagram, showing possible paths that can be taken in response surface studies.

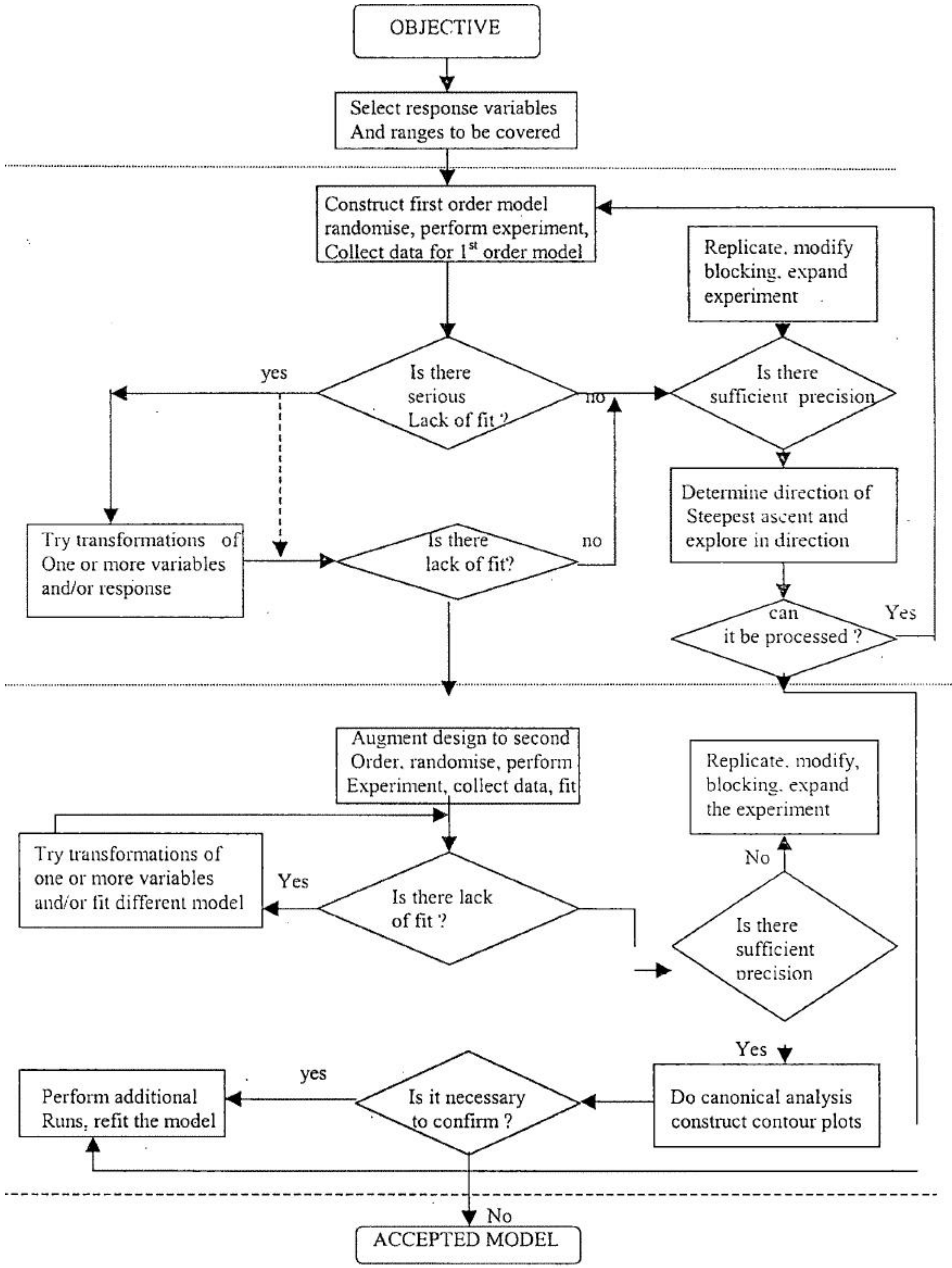


Fig 2.1 Flow Diagram Showing Different Paths in RSM

The relationship between the dependent variable and independent variables can be represented as.

$y = f(x_1, x_2, x_3, \ldots\ldots. x_k) + \mathcal{E}$ 2.9

where, $\mathcal{E}$ represents the noise or error observed in the response '*y*'.

If we denote the expected response by

$E(y) = f(x_1, x_2, x_3, \ldots\ldots. x_k) = \eta$ 2.10

then, the surface represented by

$\eta = f(x_1, x_2, x_3 \ldots\ldots x_k)$ 2.11

is called the **response surface.** This surface is drawn between some response such as material removal rate whose levels are denoted m, and number of quantitative variables (or factors), whose levels are denoted by $x_1, x_2, x_3, \ldots\ldots. x_k$

The feature of the surface of greatest interest is often the values of variables $x_1, x_2, x_3, \ldots\ldots. x_k$ for which m is a maximum or minimum.

In most RSM problems, the form of the relationship between the response and the independent variables is unknown. Thus, the first step in RSM is to find suitable approximation for the true functional relationship between *y* and the set of independent variables. Usually, a low-order polynomial in some region of the independent variable is employed.

If the response is well modelled by a linear function of the independent variables, then the approximating function is the **first-order model**.

$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots\ldots. \beta_k x_k + \mathcal{E}$ 2.12

If there is curvature in the system, then a polynomial of higher degree must be used, such as **second-order model**

Almost all RSM problems use one or both of these models. Of course, it is unlikely that a polynomial model will be a reasonable approximation of the true functional relationship over tire entire space of the independent variables, but for a relatively small region they usually work.

The method of least squares is used to estimate the parameters in the approximating polynomials. The response surface analysis is then performed using the fitted surface; If the fitted surface is an adequate approximation of the true response function, then analysis of the fitted surface will be approximately equivalent to analysis of the actual system. The model parameters can be estimated most effectively if proper designs are used to collect the data. Designs for fitting response surface are called **response surfacedesigns.**

2.5.1 First Order Designs

In this case the response surface is fitted with polynomials of first degree.

$$\eta = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \dots\dots\dots\dots \beta_k x_k \qquad 2.13$$

or

$$\hat{y} = b_0\, x_0 + b_1 x_1 + b_2\, x_2 + \dots\dots\dots + b_k\, x_k \qquad 2.14$$

Fitting of a polynomial can be treated as a particular case of multiple linear regressions. The 2^k factorial design in single or fractional replication, are convenient in exploratory work, for fitting a linear relation between the response and variables. Box et al have discussed the suitable fractional designs for exploring response surfaces.

These designs do not provide any estimate of the experimental error variance. This can be obtained

i. by replication of the whole experiment;
ii. by the use of an estimate from previous experimentation, if there is convincing evidence that error variance remains stable through time;

iii. by adding to the 2^k factorial a number of tests made at the point at which all 'x' have the value '0' in the coded scale.

The linear equation in k (x) variables contains (k+1) regression coefficients that must be estimated. The smallest experiment to which a linear equation can be fitted is one that has (k + 1) observations.

If there is no lack of fit and sufficient precision is obtained, on the basis of this, direction of steepest ascent is determined and exploration is continued. Otherwise try with transformations of one or more variables and response. Careful blocking and expanding the size of design can increase precision. If satisfactory fit and precision is not obtained then second order design are to be resorted.

2.5.2 Second - Order Design

The general form of second-degree polynomial can be represented as equation 2.15

$$y= (b_0x_0 + b_1x_1 + b_2x_2 + \ldots+b_kx_k) + (b_{12}x_1x_2 + b_{13}x_1x_3 +\ldots+b_{(k-1)}x_{(k-1)}x_k) + (b_{11}x_1^2 + b_{22}x_2^2 +\ldots+b_{kk}x_k^2) \quad 2.15$$

The source contains linear terms, $x_1,x_2\ldots x_k$; squared terms $x_1^2,x_2^2,\ldots.x_k^2$ and cross product tens $x_1x_2,x_1x_3\ldots x_{(k-1)}x_k$.

In order to estimate the regression coefficients in this model, each variable must take at least three different levels. Use of factorial designs of 3^k will be necessary in this case.

Main disadvantage of a 3^k factorial design is that with more than three variables experiments become large. Further, Box and Wilson pointed out that coefficient $b_{11}, b_{22},\ldots.b_{kk}$of squared terms are estimated with relatively low precision.

Box and Wilson developed a new design for fitting the second order response surface.

The composite designs are constructed by adding further treatment combinations to the first order design. Central composite designs consist of additional (2k + 1) treatments,

(0, 0, 0, ... 0); (-a, 0, 0, ...0); (a, 0, 0,...........0); (0, -a, 0, ... 0);

(0, a, 0, ...0); .... (0, 0, 0, ...a)

Total number of treatment combinations is (2^k + 2k + 1). The value of ‘a’ can be chosen to make the regression coefficient orthogonal to one another. Central composite design can be fitted into a sequential program of experimentation.

CHAPTER THREE

MATERIALS AND METHOD

3.0 Introduction

The rate of corrosion is the speed at which any given metal deteriorates in a specific environment. The rate or speed is dependent upon environmental conditions as well as the type and condition of the metal.

In order to calculate the rate of corrosion, the following information must be collected:

- Weight loss (the decrease of metal weight during the reference time period).
- Density (the density of the metal).
- Area (total initial surface area of the metal piece).
- Time (the length of the reference time period).

➢ Converting corrosion rate

- 1mpy = 0.0254 mm/y = 25.4 microm/y
    - 1mpy – 1 mils per year

➢ Calculate the corrosion rate from metal loss:

$$\frac{mm}{y} = 87.6X(\frac{W}{DAT})$$

W = weight loss in milligrams

D = metal density in g/cm3

A = area of sample in cm^2

T = time of exposure of the metal sample in hours.

➢ m/y = 0.0254mm/y

3.1 Materials

The materials used in this study contain mild steel pipe.Mild steel pipe was cut into dimension 40mm in length, 12mm diameter and 3mm thick with a power hacksaw, grinded and cleaned before the welding process. Two pieces of the mild steel pipes were welded together using the input process parameters contained in Tungsten Inert Gas welding machine. 100% Argon gas was the shielding gas. The input process parameters comprise of the welding voltage, welding current, and Gas flow rate. The layout of the input process parameters is made into a matrix design. The Design matrix shows the random distribution of input parameters.

3.1.1 Design of Experiment

Design of experiment is a scientific method of planning and conducting an experiment that will yield a cause and effect relationship between variables or can be a systematic way of changing process inputs and analysing the resulting process outputs in order to quantify the cause and effect relationship between them as well as the random variability of the process while using a minimum number of runs.Experimentation is a very important aspect of scientific study, which can be developed using computer software like design expert and Minitab. For proper polynomial approximation an experimental design is used to collect the data. There are different types of experimental designs which includes central composite circumscribed, central composite face centered, full factorial, and latin hyper cube designs.

3.1.2 Samples and sampling technique

The tungsten inert gas welding equipment was used to weld the pipes. Figure 3.3 shows the TIG welding setup.

Figure 3.1: TIG equipment

Figure 3.2: shielding gas cylinder and regulator

3.2 Method

The experimenter chose three process factors to study. Their names and levels are shown in the following table.

Table 3.1 showing the three process parameters to be studied and their range

Factor	Units	Low Level (-1)	High Level (+1)
A – Current	I	120	170
B – Voltage	V	18	24
Gas Flow Rate	Percent	13	16

The three-factor layout for this central composite design (CCD) is pictured below. It is composed of a core factorial that forms a cube with sides that are two coded units in length (from -1 to +1 as noted in the table above). The stars represent axial points.

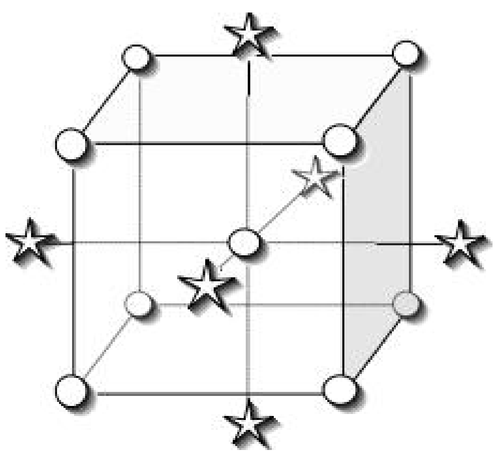


Figure 3.3: Central Composite Design for three factors

Assumptions

In carrying out this experiment, the following assumptions are made

1. the experiments will be conducted in a day, so we select one block:

2. Twenty runs: composed of eight factorial points, plus six center points and six axial (star) points.

Table 3.2: Experimental data

Std	Run	Factor 1 A:Current I	Factor 2 B:Voltage V	Factor 3 C:Gas Flow Rate Lit/min
4	1	145	21	14.5
6	2	145	21	14.5
5	3	145	21	14.5
8	4	145	21	14.5
3	5	145	21	14.5
19	6	145	21	14.5
18	7	145	15.95	14.5
17	8	145	26.05	14.5
12	9	102.96	21	14.5
13	10	187.04	21	14.5
16	11	145	21	11.96
9	12	145	21	17.02
7	13	120	18	13
1	14	120	24	13
10	15	170	18	13
15	16	170	24	13
20	17	120	18	16
2	18	120	24	16
14	19	170	18	16
11	20	170	24	16

The above table shows the varying welding input parameters.

3.2.1 Method of Data Analysis

The data obtained were analyzed using the Response surface methodology (RSM)

Response Surface Methodology

Engineers often use Response Surface Methodology (RSM) to search for the conditions that would optimize the process of interest. In other words, they want to determine the values of the process input parameters at which the responses reach their optimum. The optimum could be either a minimum or a maximum of a particular function in terms of the process input parameters. RSM is one of the optimization techniques currently in widespread usage to describe the performance of the welding process and find the optimum of the responses of interest. RSM is a set of mathematical and statistical techniques that are useful for modelling and predicting the response of interest affected by several input variables with the aim of optimizing this response.

3.2.2 Testing the adequacy of the models developed

The analysis of variance (ANOVA) was used to test the adequacy of the models developed. The statistical significance of the models developed and each term in the regression equation were examined using the sequential F-test, lack-of-fit test and other adequacy measures (i.e. $R^{2,}$ Adj-R~, Pred. R^2 and Adeq. Precision ratio) using the same software to obtain the best fit. The Prob.>F (sometimes called p-value) of the model and of each term in the model can be computed by means of ANOVA. If the Prob.> F of the model and of each term in the model does not exceed the level of significance (0.05) then the model may be considered adequate within the confidence interval For the lack-of-fit test, the lack of fit could be considered insignificant if the Prob.>F of the lack of fit exceeds the level of significance. To ensure that the fitted model provides an adequate approximation to the true system and to verify that the least square assumptions are not violated.

Table 3.3: Analysis of Variance Components

Variation Source	**Degree of Freedom Df**	**Sum of Squares SS**	**Mean Square MS**	**Fisher Ratio F-value**

Error of residuals	n-2	$SSE = \sum_{i=1}^{c}\sum_{j=1}^{ni}(y_{ij} - \hat{y}_{ij})^2$	$MSE = \frac{SSE}{n-2}$	
Regression	1	$SSR = \sum_{i=1}^{c}\sum_{j=1}^{ni}(\hat{y}_{ij} - \bar{y})^2$	$MSR = \frac{SSR}{1}$	$F = \frac{MSR}{MSE}$
Lack of fit	C -2	$SSLF_i = \sum_{i=1}^{c}\sum_{j=1}^{ni}(\bar{y}_{ij} - \hat{y}_{ij})^2$	$MSLF = \frac{SSLF}{c-2}$	$F^* = \frac{MSLF}{MSPE}$
Total	n-1	$SSTD = \sum_{i=1}^{c}\sum_{j=1}^{ni}(y_{ij} - \bar{y}_{ij})^2$	-	-

3.2.3 Model Validation for ANOVA

i) Coefficient of determination R^2

The coefficient of determination R^2 was used to validate the developed model equation 3.1 shows the expression for the diagnostic tool. The model targetis predicted using the R^2.

$$R^2 = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \qquad 3.1$$

The experimental observation is represented with y_i. $\hat{y}$ is the fitted observation.

$\bar{y}$ is the average observation

$R^2 \leq 1$ (R^2 is less than or equal to one in most cases)

ii) The adjusted coefficient of determination is determined and used to validate the developed model.

It is expressed in equation 3.2.

$$AdjR^2 = \frac{\sum (y_i - \hat{y}_i) \big/ n-k}{\sum (y_i - \bar{y}) \big/ n-1} \qquad 3.2$$

When n is the input process parameters, K is the no of responses and the observation for the experiment is represented with y_i and y is fitted observation with y as the average observation. R^2 value is always below 1 (Ibrahim IBN, 2009).

3.2.4 Methods of Model Validation for Response Surface Methodology (RSM)

Different validation techniques were used to validate the predictions from the response surface methodology (RSM) model and the genetic algorithm model developed. Validation techniques used were: Desirability plots, residuals, DFITS, mean square errors (MSE), least significant difference (LSD) bars, Ramp plots, overlay plots, perturbation plots, contour plots, steepest ascent optimization comprising 3-D plots and response surface plots.

3.3 Desirability Plots

Like all scale values, desirability can be interpreted using a Deringer's desirability function scale. The scale varies between zero and one (0 and 1) as shown in fig. 3.4

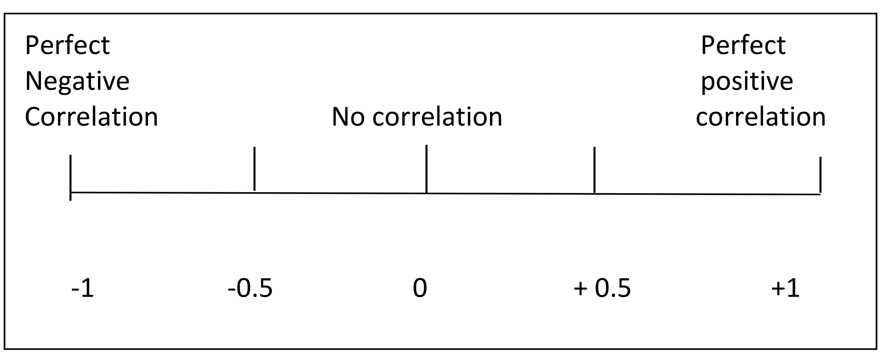


Figure 3.4. Desirability scale value

Source: Ibrahim IBN (2009)

On a zero scale, the desirability is undesirable while on a scale of one (1), the response is fully desirable with a perfect target value. The closer to the value of one for all response, the more desirable is the response. A single global desirability (Dg) is a summation of individual desirability value of responses represented in equation 3.

$Dg = (d_1^{w1} \text{ x } d_2^{w2} \text{ x } d_3^{w3} \ldots X\, d_n^{wn})^{1/n}$ (3.33) (Ibrahim IBN, 2009) 3.3

Where Dg = Global desirability

di – dn = Individual desirability from 1 – n

n = number of responses

w = weight of responses

3.4 Residual Analysis

The fitted model does not explain residuals but residual are analyzed as large residuals or low residuals in order to be fitted into the model to test for adequacy. Large residuals accounts for poorly fitted model while low residuals accounts for "good behavior" in most robust models and well fitted models. It is expressed as the difference between the actual and the predicted values in an observation as shown in equation 3.4.

$e_i = y_i - y$ 3.4

Where

e_i= residuals (error)

y_i = actual values

y = predicted values

3.5 Cooks Distance (D)

Cooks distance (D) indicates influential points worth checking for validity. Points greater than 1 are influential points, while points less than 1 are not influential. Cooks distance is used in regression analysis to find a set of predictor values or responses. It was introduced by an American Dennis R. Cook (1957).

Cooks distance is commonly used to estimate influence of data point when performing a least square regression analysis.

D > 1 (influential point)

D > 4/n

(n = number of observations, least influential point)

D is the distance.

$$D = \frac{\sum_{j=1}^{n} (y_j - y_{j(1)})^2}{(K+1) MS_E} \qquad 3.5$$

3.6 Leverage (h)

This is a measure of how far away the data point of input process parameter values are from those of the other observations. Points made at extreme values of input parameters shows that fitted regression model will pass close to the value and identify influential observations. In linear regression, the leverage score for the ith data unit is defined as:

$h_{ii} = [H]_{ii}$

$H = X (X^T X)^{-1} X^T$ 3.6

3.7 Studentized Residuals

Studentized residuals do not fully compensate for high leverage points in a regression model as they have equal variance when the model is correct. When the model is not correct, the variances are not equal.

3.8 Deleted Residuals

Deleted residuals is defined as the prediction of the height point from the least square line fitted to all the data point except the observation of the height point. Deleted residuals give an extra weight to the leverage point that are high. It also helps to highlight outliers as an alternative approach to residual analysis.

$e_{ti} - i = y_i - y_{ti} - 1$ 3.7

3.9 Differential Functioning of Items and Texts (DFIT)

The differential functioning of items and texts (DFIT) is a measure of fitted values and its influence on the observation. Using number of predictors and observations, the differential functioning of items and text (DFIT) represents he changes in the fittest values as a result of standard deviation changes when removed from a set of data. A cut off point using the predictors and observation is established in equation 3.36.

Cut off point = $2\sqrt{p}/n$ 3.8

3.10 Mean Square Error (MSE)

Mean square error measures the average of the squares of the errors or deviations. It is the difference between the estimator and what is estimated. It is a risk function which corresponds with expected value of the square error loss or quadratic loss. It is always non-negative with values closer to O (better).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2$$ 3.9

$MSE = \frac{1}{n}\sum_{i=1}^{n}$ is the mean of the square of the errors $(\hat{Y}_i - Y_i)^2$

MSE is used to evaluate the performance of models (predictors)

3.11 Least significant Difference (LSD) Bar Plots

This is a plot showing interactions. Interactions occur when the level of a factor depends on the effect of another factor. On the plot, appears two lines with a least significant difference bar with brackets at both ends. Far from parallel are the lines with +Δ and -□. When the line is flat, it shows that the significant difference in interaction is zero. With a steep downward of the line angle, there is an increase in the L.S.D. In the case of overlap of the two lines in the graph, there is not much difference in the LSD bar plot. Where there is no overlap in the LSD bars, effect of the x-axis fact or becomes significant. Use the bullets as gauge. For a multi-response optimization, the settings best are high top at low bottom.

3.12 Contour plots

Contour plots show distinctive saddle shape indicative of possible dependence on factors with their responses. Contour plots usually display the origin of optimal factors settings in an optimization setting for RSM. It displays stationary points which characterizes the response surface showing maximum saddle, minimum points or ridge points (characterizing the shape of the surface, contour locates with reasonable accuracy, using contour of the region, optimal response points using a set of input process parameter that produces values of responses (Shetty et al., 2006), provides a precise mathematical definition of the model. It represents a standard for a perfect correlation. It provides the basis for making predictions for responses (and the input process parameter x and y).

3.13 Ramp plot

Ramp plots show heights of dots using two colors; red and blue to indicate high and low values respectively. This show how desirable the plots are: A ramp plot showing results with red colour on a value indicates high values (maximization) and blue color indicates low values (minimization).

3.14 Perturbation plots: These are plots of desirability versus deviation from reference points (coded units) of input process parameters and responses. These responses that deviate from the reference point with a low desirability values of less than 1.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Modeling and Optimization using RSM

Response Surface Model is a popular optimization technique to determine the best possible combination of variables for a specific response to a phenomenon. RSM is particularly useful to understand the relationship between multiple input variables with one or more response variables. The technique is popular in industries where process and statistical optimization plays a key role. In this study, three input variables were used namely; current, voltage and gas flow rate. The response variable is the rate of corrosion. The focus of the optimization model is to:

i. Minimize the rate of corrosion

The final solution of the optimization process is to determining the optimum value of each input variable namely: current (Amp), voltage (volts) and gas flow rate (L/min) that will minimize the rate of corrosion.

To generate the experimental data for the optimization process;

i. Statistical design of experiment (DOE) using the central composite design method (CCD) was done. Central composite design (CCD) is unarguably the most acceptable design for response surface methodology (RSM). The design and optimizationwere done using statistical software and for this particular problem, Design Expert 7.01 was employed.
ii. Experimental design matrix having six (6) center points, six (6) axial points and eight (8) factorial points resulting to about 20 experimental runs was generated.

The randomized design matrix comprising of three input variables namely; current (Amp), voltage (volts) and gas flow rate (L/min) and a single response in real values is presented in table 4.1

Table 4.1: Design matrix showing the real values and experimented values

Std	Block	Run	Space Type	Factor 1 A:Current I	Factor 2 B:Voltage V	Factor 3 C:Gas Flow Rate Lit/min	Response 1 Corrosion rate mpy
17	Block 1	1	Center	145	21	14.5	3.24829
2	Block 1	2	Center	145	21	14.5	3.24829
1	Block 1	3	Center	145	21	14.5	3.24966
14	Block 1	4	Center	145	21	14.5	3.24829
20	Block 1	5	Center	145	21	14.5	3.24966
16	Block 1	6	Center	145	21	14.5	3.24829
11	Block 1	7	Axial	145	15.95	14.5	3.07885
3	Block 1	8	Axial	145	26.05	14.5	4.5337
7	Block 1	9	Axial	102.96	21	14.5	3.06139
8	Block 1	10	Axial	187.04	21	14.5	3.57162
5	Block 1	11	Axial	145	21	11.96	3.82674
12	Block 1	12	Axial	145	21	17.02	4.33697
18	Block 1	13	Factorial	120	18	13	2.95048
9	Block 1	14	Factorial	120	24	13	4.17462
6	Block 1	15	Factorial	170	18	13	2.92224
13	Block 1	16	Factorial	170	24	13	4.7558
15	Block 1	17	Factorial	120	18	16	3.3397
19	Block 1	18	Factorial	120	24	16	3.3397
10	Block 1	19	Factorial	170	18	16	3.54843
4	Block 1	20	Factorial	170	24	16	4.80218

The model summary which shows the factors and their lowest and highest values including the standard deviation is presented as shown in table below

Table 4.2: Model summary showing highest and lowest values of factors

Name	Units	Type	Changes	Std. Dev.	Low	High
Current	I	Factor	Easy	0	120	170
Voltage	V	Factor	Easy	0	18	24
Gas Flow Rat	Lit/min	Factor	Easy	0	13	16
Corrosion ra	mpy	Response		0.141258	2.92224	4.80218

Result of Table 4.2 revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The minimum value of the rate of corrosion was observed to be 2.92224mpy with a maximum value 4.80218mpy and standard deviation of 0.141258.

Table 4.3 RSM build information

File Version	11.1.0.1		
Study Type	Response Surface	**Subtype**	Randomized
Design Type	Central Composite	**Runs**	20
Design Model	Quadratic	**Blocks**	No Blocks
Build Time (ms)	1.0000		

Table 4.4: RSM coded design summary

Factor	Name	Units	Type	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev.
A	Current	I	Numeric	102.96	187.04	-1 ↔ 120.00	+1 ↔ 170.00	145.00	21.19
B	Voltage	V	Numeric	15.95	26.05	-1 ↔ 18.00	+1 ↔ 24.00	21.00	2.54
C	Gas Flow Rate	Lit/min	Numeric	11.96	17.02	-1 ↔ 13.00	+1 ↔ 16.00	14.50	1.27

The above table shows response surface methodology coded design summary. It shows the maximum and minimum value of the input parameter. As well as the respective mean and standard deviation.

Table 4.5: RSM Response

	Response	Name	Units	Observations	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Transform	Model
	R1	Corrosion rate	mpy	20	Polynomial	2.92224	4.80218	3.59	0.6025	1.64	None	Quadratic

Table 4.5 shows the summary of the response (rate of corrosion). Its maximum and minimum value, mean and standard deviation and the nature of the model developed.

Before focusing on modeling the response as a function of the factors varied in this RSM experiment, it will be good to assess the impact of the blocking via a simple scatter plot. The correlation grid that pops up with the Graph Columns can be very interesting. First off, observe that it exhibits red along the diagonal—indicating the complete (r=1) correlation of any variable with itself (Run vs Run, etc).The graph in fig. 4.1 is used to visually show or compare in the cases whereby more than one blocks is selected for our design, to see if there is a difference between block 1 and 2 or as the case may be and to see how strong the correlation between blocks factors and responses are.

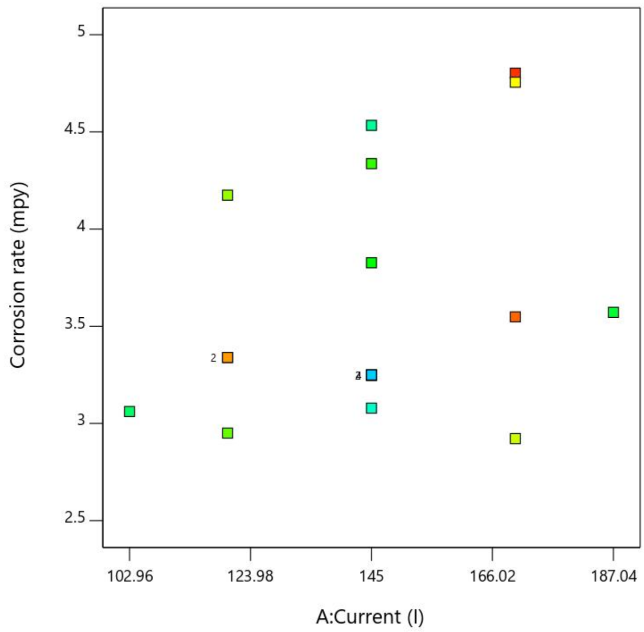


Figure 4.1 Graph Columns feature for design layout

Table 4.6: Model terms

Term	Standard Error*	VIF	R_i^2	Power
A	0.2706	1	0.0000	91.4 %
B	0.2705	1	0.0000	91.4 %
C	0.2703	1.00005	0.0001	91.4 %
AB	0.3536	1	0.0000	72.2 %
AC	0.3536	1	0.0000	72.2 %
BC	0.3536	1	0.0000	72.2 %
A^2	0.2635	1.01857	0.0182	99.9 %
B^2	0.2631	1.01865	0.0183	99.9 %
C^2	0.2622	1.01884	0.0185	99.9 %

For a standard deviation of 1. Power calculations are performed using response type "Continuous" and parameters:

Delta=2, Sigma=1

Power is evaluated over the -1 to +1 coded factor space. Standard errors should be similar to each other in a balanced design. Lower standard errors are better.

The ideal VIF value is 1.0. VIFs above 10 are cause for concern. VIFs above 100 are cause for alarm, indicating coefficients are poorly estimated due to multicollinearity.

Ideal R_i^2 is 0.0. High R_i^2 means terms are correlated with each other, possibly leading to poor models.

If the design has multilinear constraints, then multicollinearity will exist to a greater degree. This inflates the VIFs and the R_i^2, rendering these statistics useless. Use FDS instead.Power is an inappropriate tool to evaluate response surface designs.

Use prediction-based metrics provided in this program via Fraction of Design Space (FDS) statistics.

Click on the Graphs tab to find the FDS graph. More information about FDS is available in the Help.

Be sure that the model you selected contains only terms you expect to be significant.

Degrees of Freedom

Model	9
Residuals	10
Lack of Fit	5
Pure Error	5
Corr Total	19

We recommend at least 3 lack of fit DF and 4 pure error DF to ensure a valid lack of fit test.

Table 4.7: Leverage

Run	Leverage	Space Type
1	0.1664	Center
2	0.1664	Center
3	0.1664	Center
4	0.1664	Center
5	0.1664	Center
6	0.1664	Center
7	0.6076	Axial
8	0.6076	Axial
9	0.6069	Axial
10	0.6069	Axial
11	0.6128	Axial
12	0.6049	Axial
13	0.6690	Factorial
14	0.6690	Factorial
15	0.6690	Factorial
16	0.6690	Factorial
17	0.6698	Factorial
18	0.6698	Factorial
19	0.6698	Factorial
20	0.6698	Factorial
Average	**0.5000**	

Watch for leverages close to 1.0. Consider replicating these points or make sure they are run very carefully.

Table 4.8: matrix measures

Description	Value
Condition Number of Coefficient Matrix	1.34
Maximum Variance Mean	0.6698
Average Variance Mean	0.2140
Minimum Variance Mean	0.1603
G Efficiency	74.65
Scaled D-optimality Criterion	1.62
Determinant of $(X'X)^{-1}$	1.22731E-11
Trace of $(X'X)^{-1}$	0.9682
I (Cuboidal)	0.2138

If the condition number is 100-1000, there is moderate to strong multicollinearity. Values above 1000 indicate severe multicollinearity.

When comparing designs, a smaller Scaled D-optimality Criterion is better.

The determinant, trace, and 'I' values can only be used when comparing designs with the same number of runs. A smaller value is better.

Table 4.9: fit summary

Response 1: Corrosion rate

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.0018	< 0.0001	0.5228	0.3305	
2FI	0.1114	< 0.0001	0.6240	0.3633	
Quadratic	**< 0.0001**	**< 0.0001**	**0.9450**	**0.7686**	**Suggested**
Cubic	< 0.0001		1.0000		Aliased

The table of “Sequential Model Sum of Squares” (technically “Type I”) shows how terms of increasing complexity contribute to the total model.

Table 4.10: sequential model sum of squares (type 1)

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	257.29	1	257.29			
Linear vs Mean	4.13	3	1.38	7.94	0.0018	
2FI vs Linear	0.9970	3	0.3323	2.44	0.1114	
Quadratic vs 2FI	**1.57**	**3**	**0.5249**	**26.31**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	0.1995	5	0.0399	79733.41	< 0.0001	Aliased
Residual	2.503E-06	5	5.005E-07			
Total	264.19	20	13.21			

Select the highest order polynomial where the additional terms are significant and the model is not aliased. The selected model should have insignificant lack-of-fit.

Table 4.11: Lack of fit tests

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Linear	2.77	11	0.2519	5.034E+05	< 0.0001	
2FI	1.77	8	0.2218	4.431E+05	< 0.0001	
Quadratic	**0.1995**	**5**	**0.0399**	**79733.41**	**< 0.0001**	**Suggested**
Cubic	0.0000	0				Aliased
Pure Error	2.503E-06	5	5.005E-07			

Table 4.12: Model summary statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.4162	0.5982	0.5228	0.3305	4.62	
2FI	0.3694	0.7427	0.6240	0.3633	4.39	
Quadratic	**0.1413**	**0.9711**	**0.9450**	**0.7686**	**1.60**	**Suggested**
Cubic	0.0007	1.0000	1.0000		*	Aliased

Focus on the model maximizing the Adjusted R^2 and the Predicted R^2.

Table 4.13: ANOVA for quadratic model

Response 1: Corrosion rate

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.70	9	0.7441	37.29	< 0.0001	significant
A-Current	0.6957	1	0.6957	34.86	0.0002	
B-Voltage	3.34	1	3.34	167.59	< 0.0001	
C-Gas Flow Rate	0.0898	1	0.0898	4.50	0.0599	
AB	0.4339	1	0.4339	21.75	0.0009	
AC	0.1563	1	0.1563	7.83	0.0188	
BC	0.4068	1	0.4068	20.39	0.0011	
A^2	0.0041	1	0.0041	0.2055	0.6600	
B^2	0.5200	1	0.5200	26.06	0.0005	
C^2	1.19	1	1.19	59.48	< 0.0001	
Residual	0.1995	10	0.0200			
Lack of Fit	0.1995	5	0.0399	79733.41	< 0.0001	significant
Pure Error	2.503E-06	5	5.005E-07			
Cor Total	6.90	19				

The Model F-value of 37.29 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case A, B, AB, AC, BC, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The Lack of Fit F-value of 79733.41 implies the Lack of Fit is significant. There is only a 0.01% chance that a Lack of Fit F-value this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.

Table 4.14: Fit statistics

Std. Dev.	0.1413		**R^2**	0.9711
Mean	3.59		**Adjusted R^2**	0.9450
C.V. %	3.94		**Predicted R^2**	0.7686
			Adeq Precision	19.0828

The Predicted R^2 of 0.7686 is in reasonable agreement with the Adjusted R^2 of 0.9450; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 19.083 indicates an adequate signal. This model can be used to navigate the design space.

Model Comparison Statistics

PRESS	1.60
-2 Log Likelihood	-35.39
BIC	-5.43
AICc	9.05

Table 4.15: Coefficients in terms of coded factors

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	3.25	1	0.0576	3.12	3.38	
A-Current	0.2257	1	0.0382	0.1405	0.3109	1.0000
B-Voltage	0.4946	1	0.0382	0.4095	0.5798	1.0000
C-Gas Flow Rate	0.0810	1	0.0382	-0.0041	0.1661	1.00
AB	0.2329	1	0.0499	0.1216	0.3442	1.0000
AC	0.1398	1	0.0499	0.0285	0.2511	1.0000
BC	-0.2255	1	0.0499	-0.3368	-0.1142	1.0000
A^2	0.0169	1	0.0372	-0.0661	0.0998	1.02
B^2	0.1897	1	0.0372	0.1069	0.2725	1.02
C^2	0.2857	1	0.0370	0.2032	0.3682	1.02

The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average based on the factor settings. When the factors are orthogonal the VIFs are 1; VIFs greater than 1 indicate multi-colinearity, the higher the VIF the more severe the correlation of factors. As a rough rule, VIFs less than 10 are tolerable.

Final Equation in Terms of Coded Factors

Corrosion rate	=
+3.25	
+0.2257	* A
+0.4946	* B
+0.0810	* C
+0.2329	* AB
+0.1398	* AC
-0.2255	* BC
+0.0169	* A^2
+0.1897	* B^2
+0.2857	* C^2

4.1

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors

Corrosion rate	=
+36.28818	
-0.118063	* Current
-0.444048	* Voltage
-3.11632	* Gas Flow Rate
+0.003105	* Current * Voltage
+0.003728	* Current * Gas Flow Rate
-0.050110	* Voltage * Gas Flow Rate
+0.000027	* $Current^2$
+0.021077	* $Voltage^2$
+0.126970	* $Gas Flow Rate^2$

4.2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

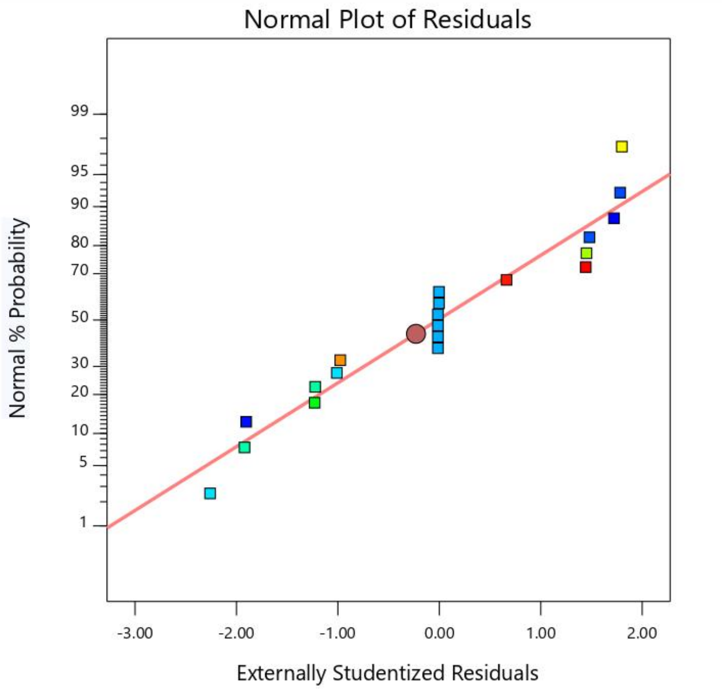


Figure 4.2: Normal probability plot of the residuals

Data points should be approximately linear. A non-linear pattern (such as an S-shaped curve) indicates non-normality in the error term, which may be corrected by a transformation. The only sign of any problems in this data may be the point at the far right.

Notice that residuals are “externally studentized” unless you change their form on the drop-down menu at the top of your screen (not advised).

- Externally calculating residuals increases the sensitivity for detecting outliers.
- Studentized residuals counteract varying leverages due to design point locations. For example, center points carry little weight in the fit and thus exhibit low leverage.

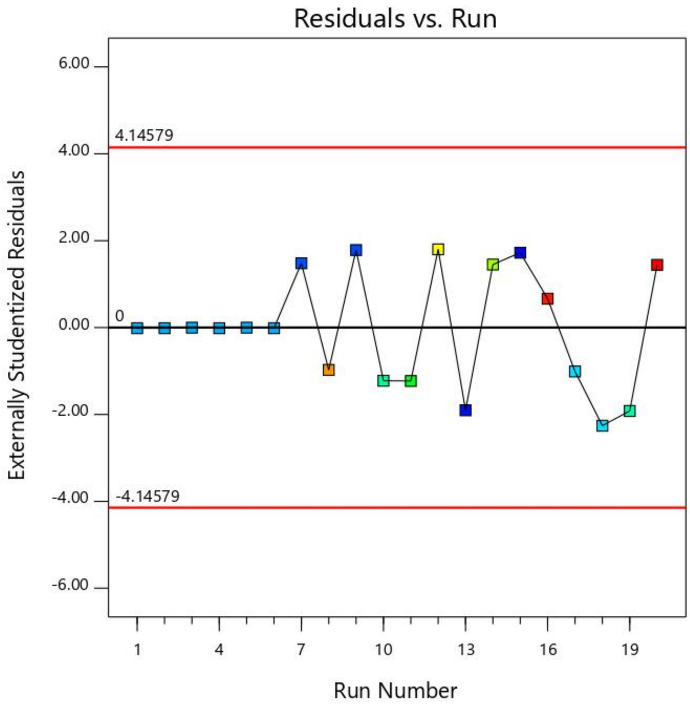


Figure 4.3: Residuals versus run

Now you can see that, although the highlighted run does differ more from its predicted value than any other, there is really no cause for alarm due to it being within the red control limits.

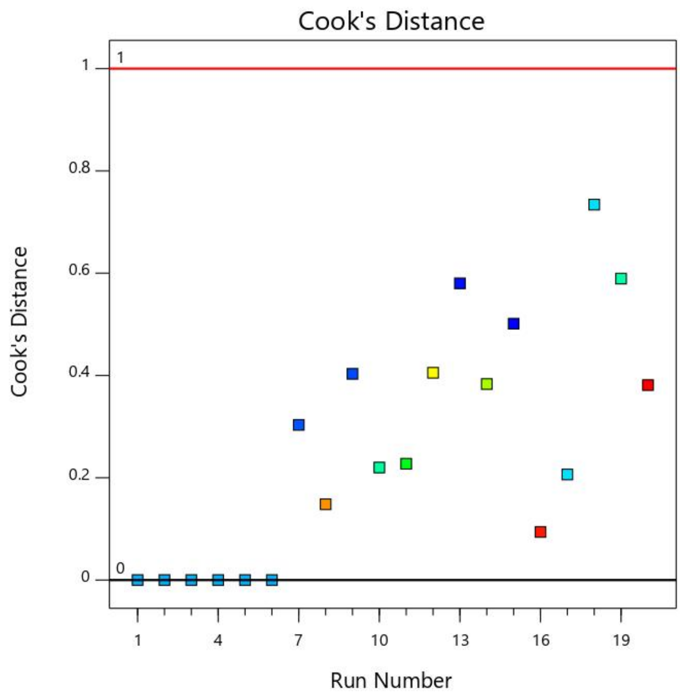


Figure 4.4 Cook's Distance — the first of the Influence diagnostics

To determine the presence of a possible outlier, the cook's distance plot was generated for the rate of corrosion. The cook's distance is a measure of how much the regression would change if the outlier is omitted from the analysis. A point that has a very high distance value relative to the other points may be an outlier and should be investigated. The cook's distance plot has an upper bound of 1.00 and a lower bound of 0.00. Experimental values smaller than the lower bound or greater than the upper bounds are considered as outliers and must be properly investigated.

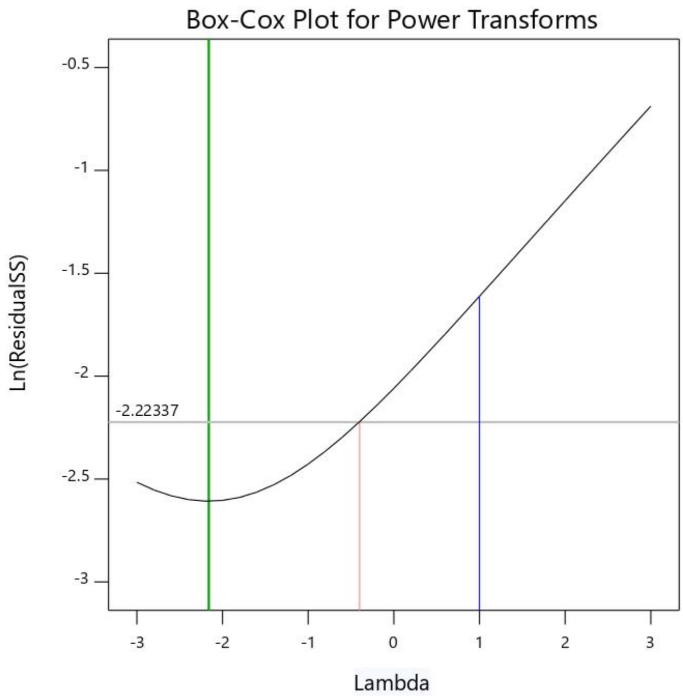


Figure 4.5: Box-Cox plot for power transforms

The Box-Cox plot is a tool to help you determine the most appropriate power transformation to apply to response data. Most data transformations can be described by the power function, As a reminder, here are the commonly used transformations:

$\lambda = 1$ no transformation

$\lambda = 0.5$ square root

$\lambda = 0$ natural log

$\lambda = -0.5$ inverse square root.

$\lambda = -1$ inverse

Power law transformations can only be performed on responses that are greater than zero, so you may need to add a constant, k, to all the responses.

The plot shows the minimum lambda values, as well as lambdas at the 95% confidence range. The plot also shows the current power transformation so you can see where that fits. It is possible that the 95% confidence interval will not be shown due to it being outside the +/- 3 lambda limits.

Leverage: A measure of how much each point influences the model fit.Leverage of a point varies from 0 to 1 and indicates how much an individual design point influences the model's predicted values. A leverage of 1 means the predicted value at that particular case will exactly equal the observed value of the experiment, i.e., the residual will be 0. The sum of leverage values across all cases equals the number of coefficients (including the constant) fit by the model. The maximum leverage an experiment can have is 1/k, where k is the number of times the experiment was replicated. If a point has a leverage of 1.0, then the model exactly fits the observation at that point. That point controls the model.

Leverage Limits: A run with leverage greater than 2 times the average is generally regarded as having high leverage. Such runs have few other runs near them in the factor space.

The average leverage is the number of terms in the model divided by the number of runs in the design.

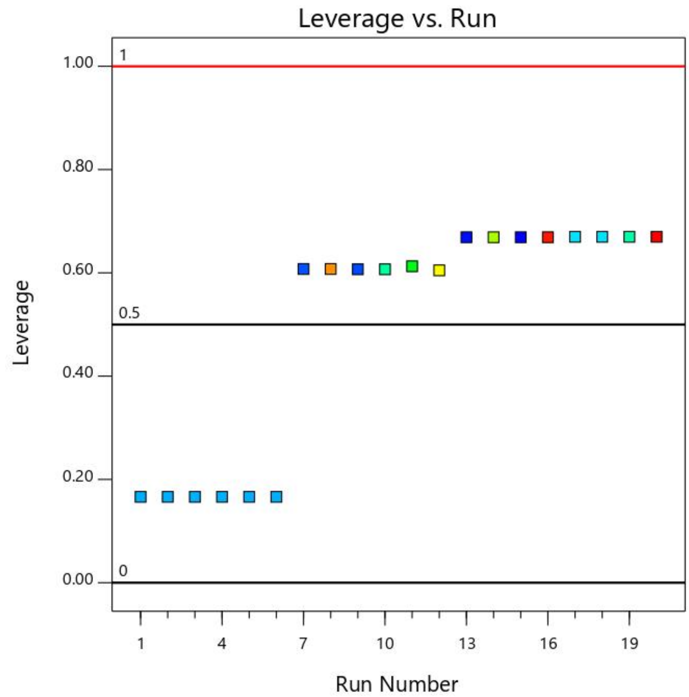


Figure 4.6: leverage vs run

DFBETAS, breaks down the changes in the model to each coefficient, which statisticians symbolize with the Greek letter β, hence the acronym DFBETAS. The difference in betas. For the **Term** click the down-list arrow and select A as shown in the following screen shot.

DFBETAS for term A

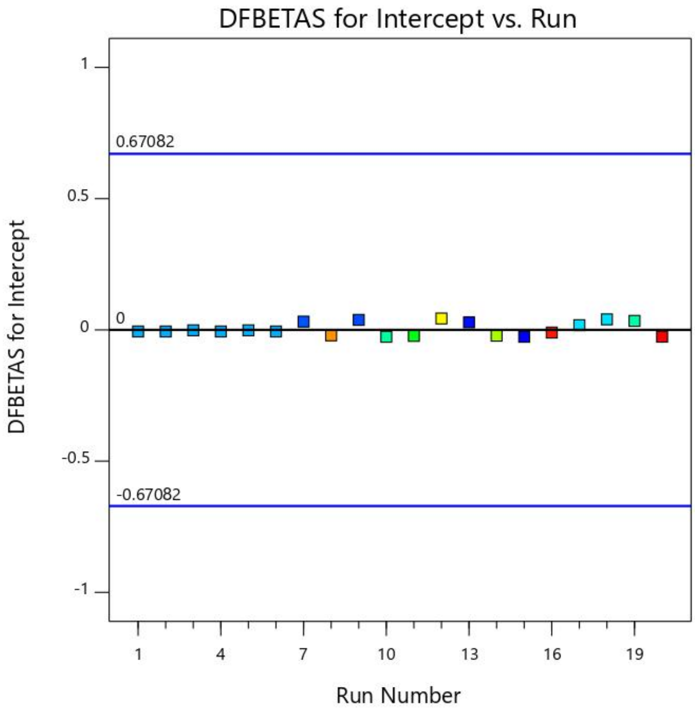


Figure 4.7: Diagnostics report

Table 4.16: Numerical optimization

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	3.25	3.25	-0.0018	0.166	-0.014	-0.013	0.000	-0.006	17
2	3.25	3.25	-0.0018	0.166	-0.014	-0.013	0.000	-0.006	2
3	3.25	3.25	-0.0004	0.166	-0.003	-0.003	0.000	-0.001	1
4	3.25	3.25	-0.0018	0.166	-0.014	-0.013	0.000	-0.006	14
5	3.25	3.25	-0.0004	0.166	-0.003	-0.003	0.000	-0.001	20
6	3.25	3.25	-0.0018	0.166	-0.014	-0.013	0.000	-0.006	16
7	3.08	2.95	0.1239	0.608	1.400	1.481	0.303	1.843	11
8	4.53	4.62	-0.0866	0.608	-0.978	-0.976	0.148	-1.215	3
9	3.06	2.92	0.1431	0.607	1.616	1.784	0.403	2.216[1]	7
10	3.57	3.68	-0.1057	0.607	-1.194	-1.223	0.220	-1.520	8
11	3.83	3.93	-0.1054	0.613	-1.199	-1.229	0.227	-1.546	5
12	4.34	4.19	0.1445	0.605	1.627	1.800	0.405	2.227[1]	12
13	2.95	3.09	-0.1377	0.669	-1.694	-1.904	0.580	-2.706[1]	18
14	4.17	4.06	0.1119	0.669	1.377	1.452	0.383	2.064	9
15	2.92	2.79	0.1280	0.669	1.575	1.723	0.501	2.449[1]	6
16	4.76	4.70	0.0555	0.669	0.683	0.663	0.094	0.943	13
17	3.34	3.42	-0.0819	0.670	-1.009	-1.010	0.207	-1.439	15
18	3.34	3.49	-0.1544	0.670	-1.902	-2.259	0.734	-3.218[1]	19
19	3.55	3.69	-0.1384	0.670	-1.705	-1.920	0.589	-2.735[1]	10
20	4.80	4.69	0.1113	0.670	1.371	1.443	0.381	2.056	4

The perturbation plot helps to compare the effects of all the factors at a particular point in the design space. The response is plotted by changing only one factor over its range while holding all the other factors constant. By default, Design-Expert sets the reference point at the midpoint (coded 0) of all the factors.

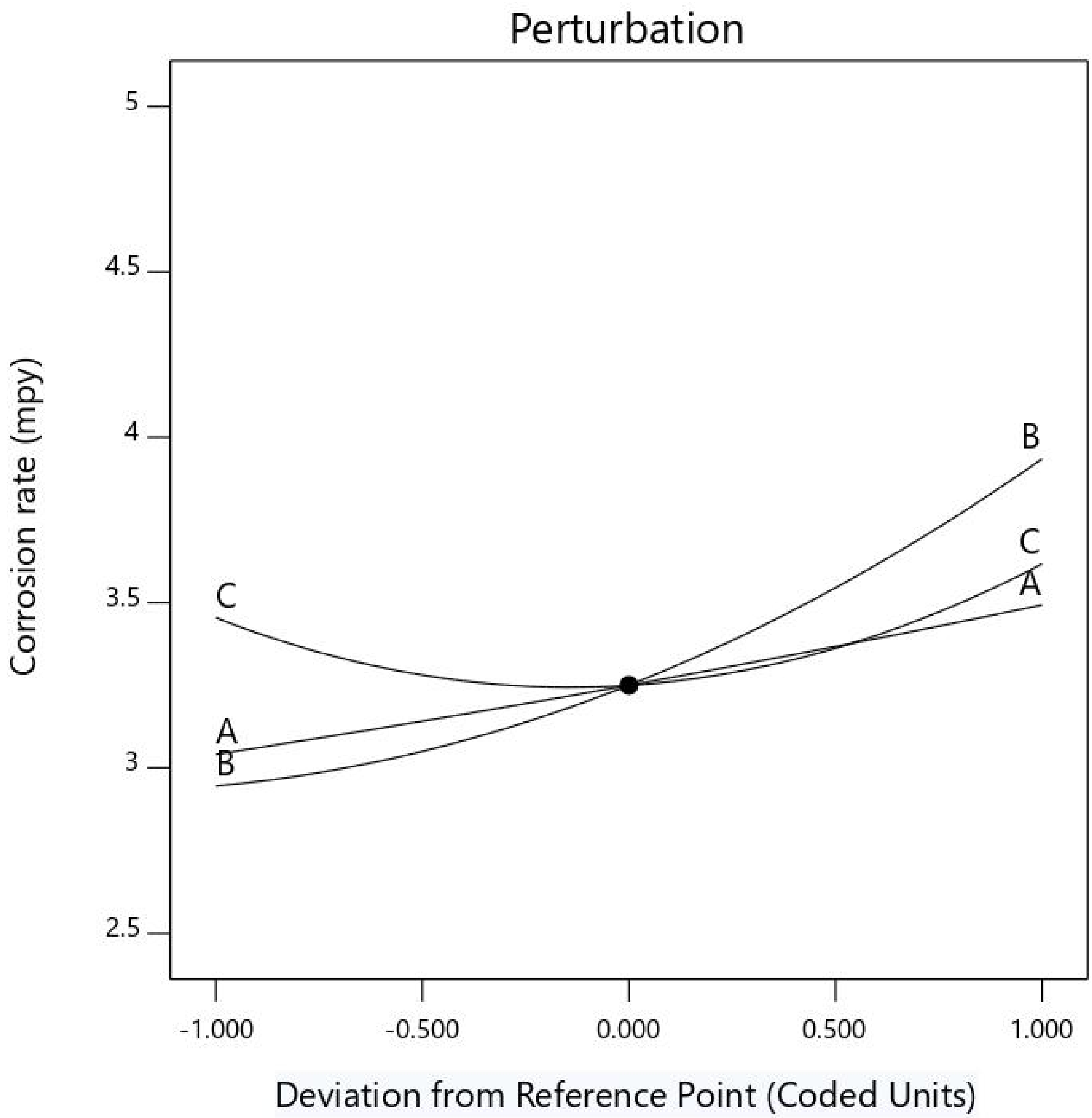


Figure 4.8: perturbation plot

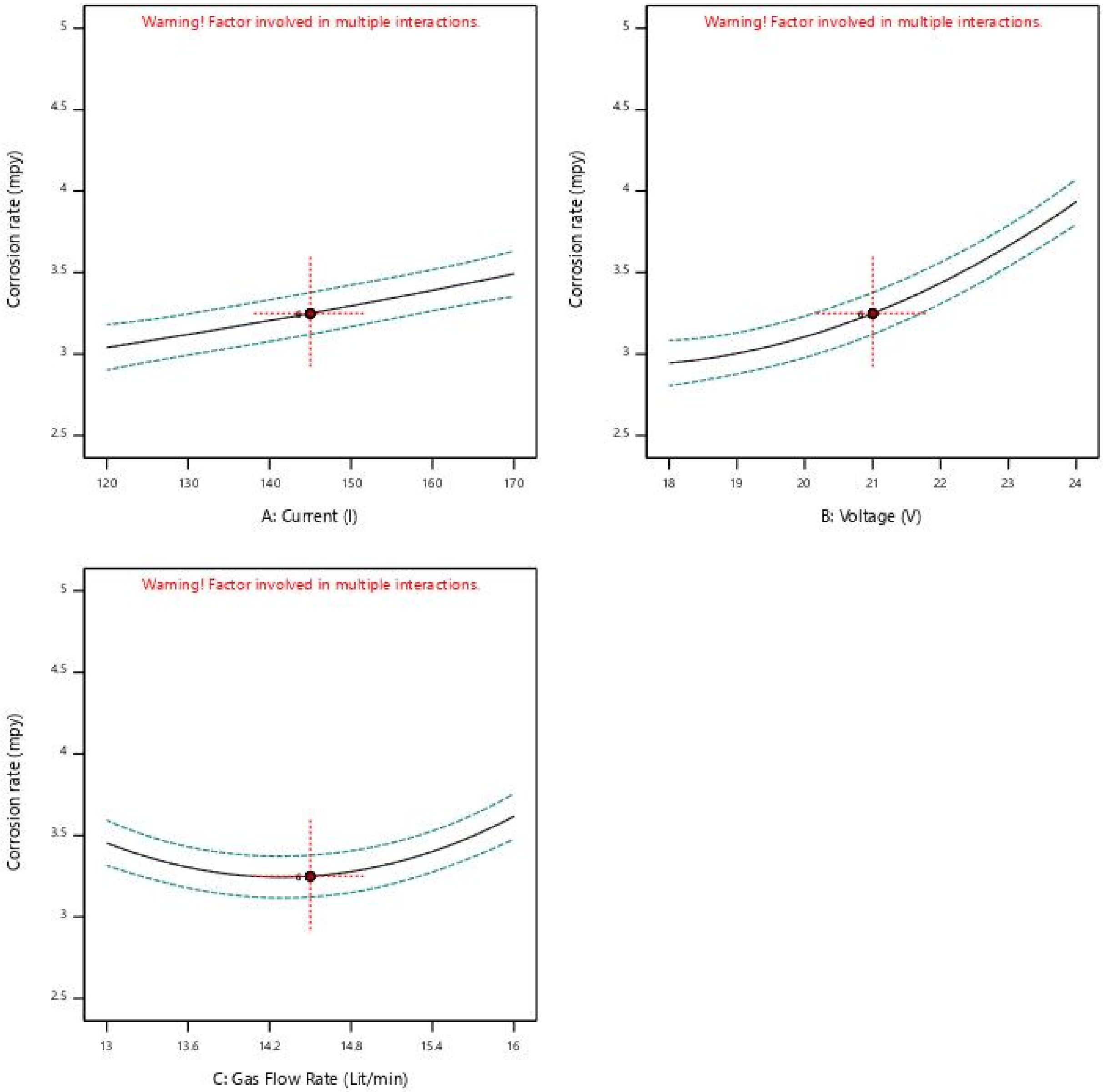


Figure 4.9: contour plot

The contour plot is a two-dimensional (2D) representation of the response plotted against combinations of numeric factors and/or mixture components. It can show the relationship between the responses, mixture components and/or numeric factors.

Design-Expert displays any actual point included in the design space shown. In this case you see a plot of corrosion rate as a function of current and voltage at a mid-level slice of gas flow rate. This slice includes six center points as indicated by the dot at the middle of the contour plot. By replicating center points, you get a very good power of prediction at the middle of your experimental region.

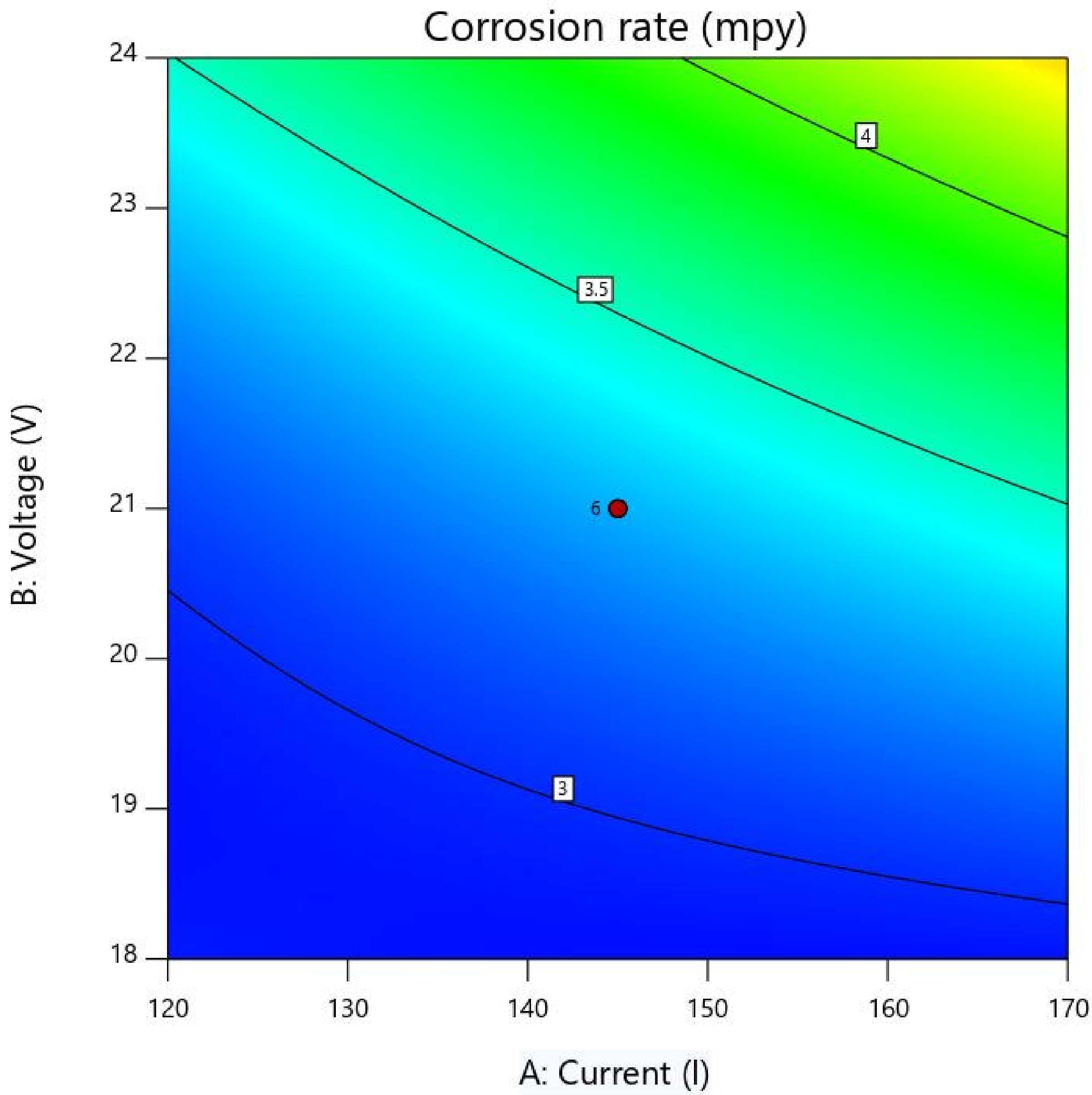


Figure 4.10: Contour plot

The 3D surface plot is a projection of the contour plot giving shape in addition to the colour and contour. The 3D surface plot as shows the relationship between the input variables (current, voltage and gas flow rate) and the response variables (rate of corrosion). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. Although not as useful as the contour plot for establishing responses values and coordinates, this view may provide a clearer view of the surface. The presence of a coloured hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface.

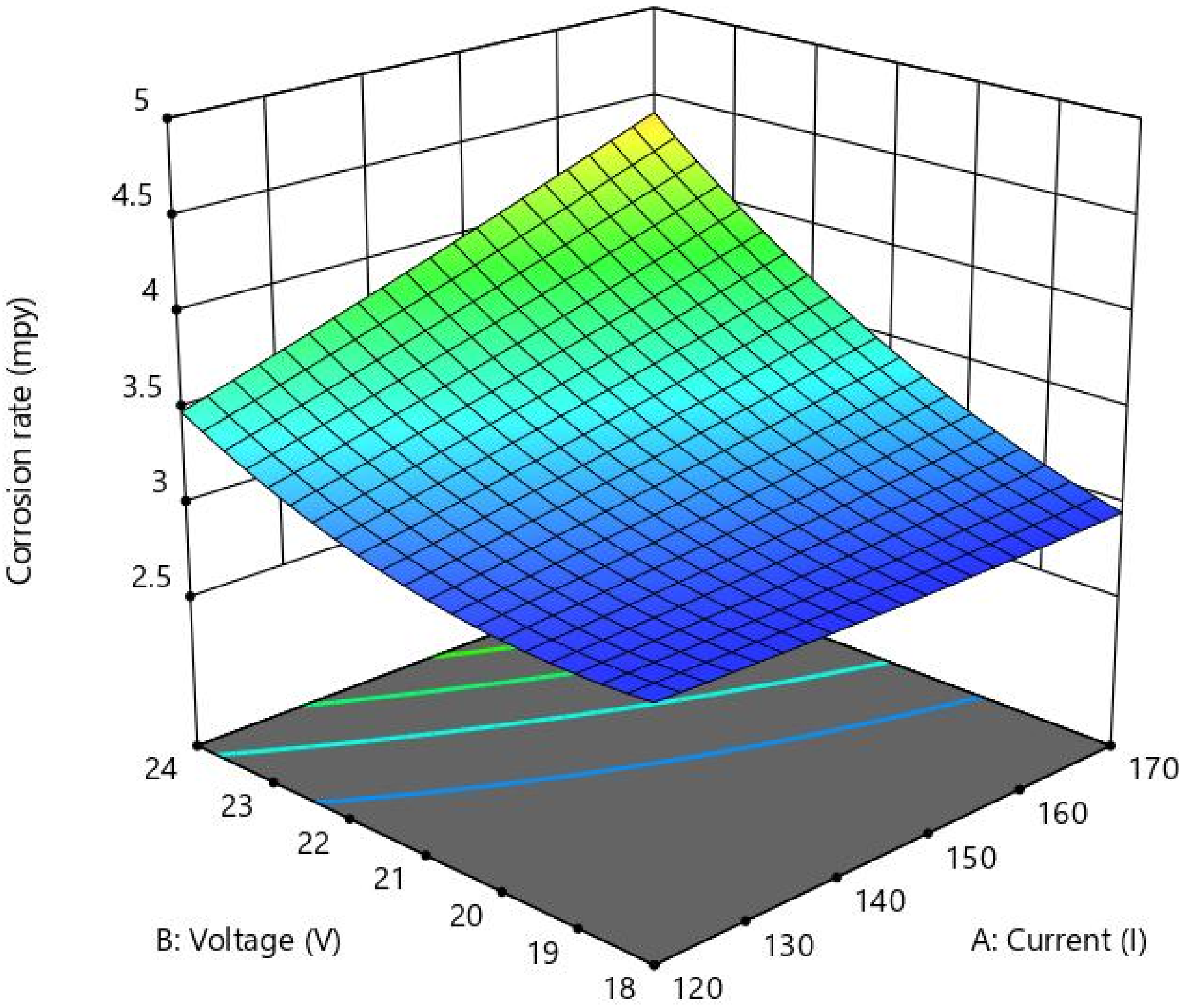


Figure 4.11: Surface plot

The cube plot shows the predicted values from the coded model for the combinations of the -1 and +1 levels of any three factors. Non-selected factors, numerical or categorical, can be set to a specific level via the Factors Tool palette.

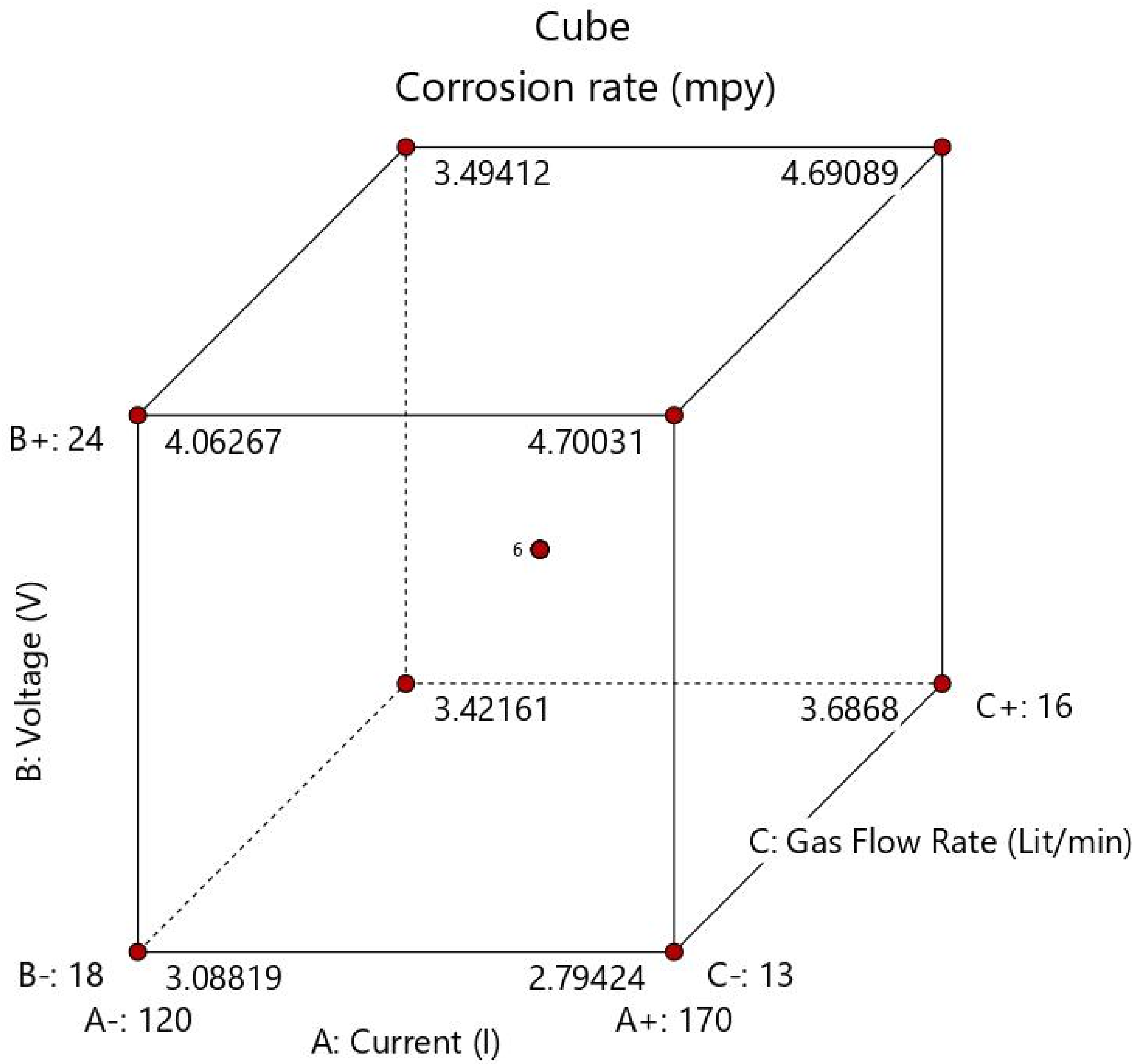
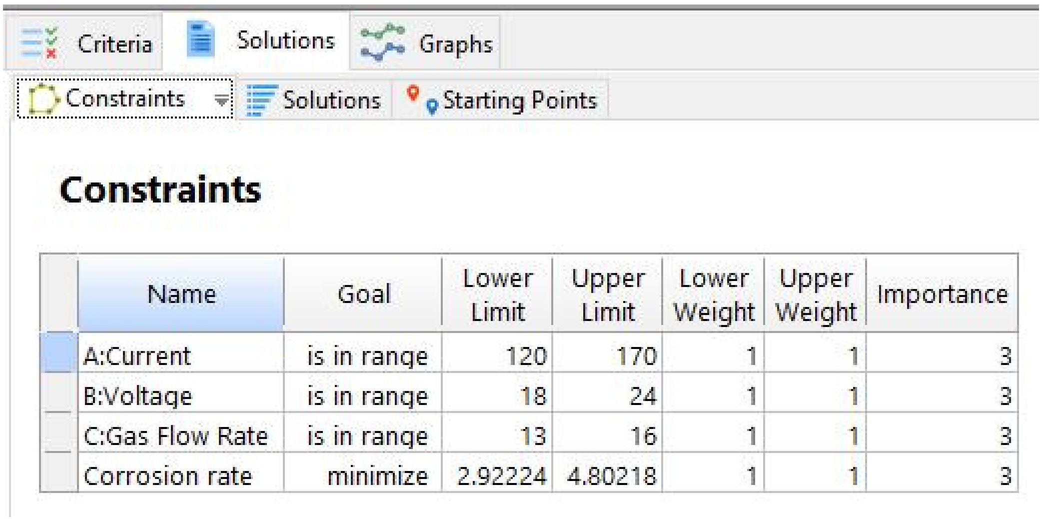


Figure 4.12: Cube plot for optimization by CCD

Table 4.17: Constraints for numerical optimization of selected responses



Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Current	is in range	120	170	1	1	3
B:Voltage	is in range	18	24	1	1	3
C:Gas Flow Rate	is in range	13	16	1	1	3
Corrosion rate	minimize	2.92224	4.80218	1	1	3

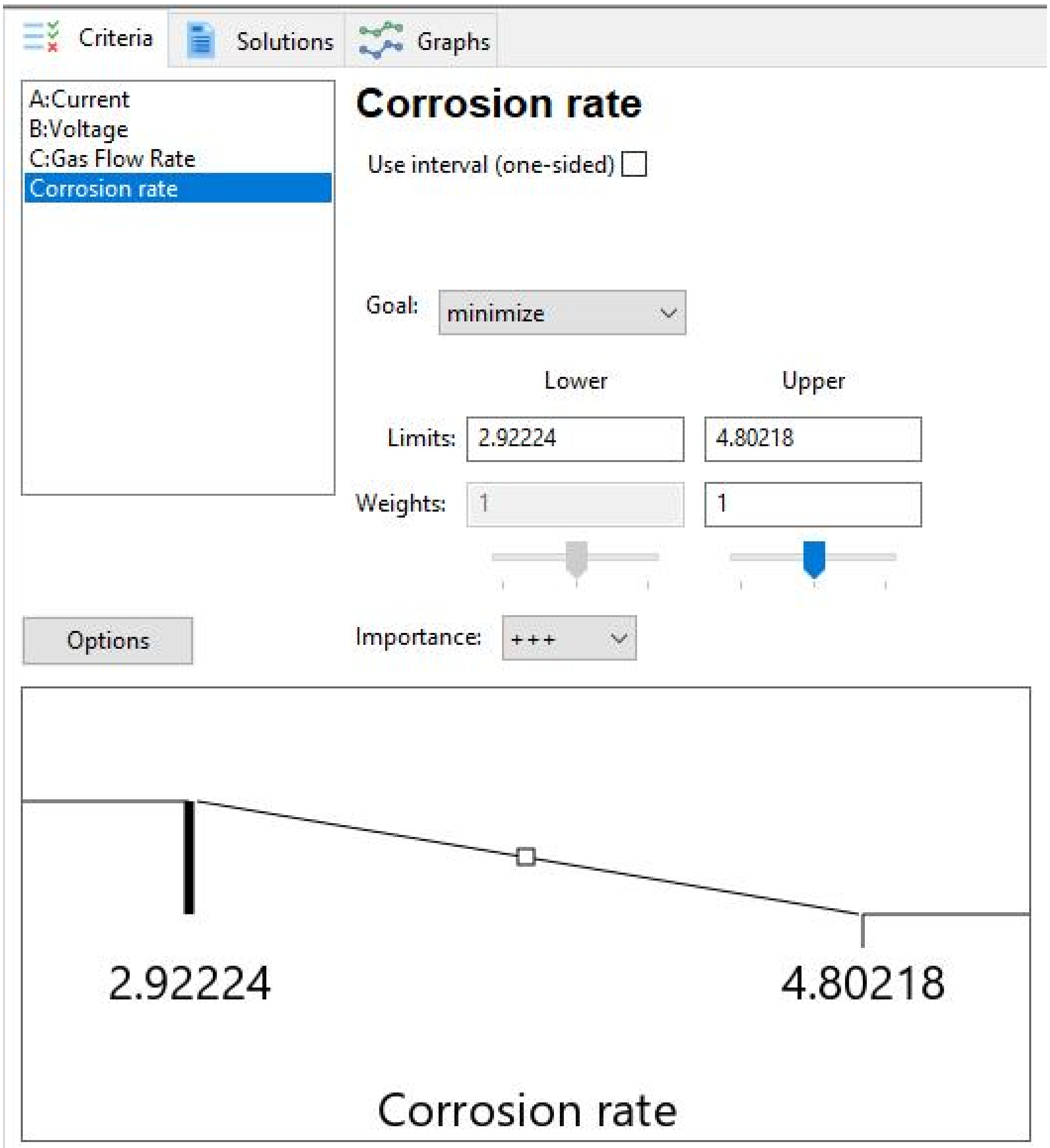


Figure 4.13: Interphase of numerical optimization model for minimizing rate of corrosion

Numerical optimization was performed to ascertain the desirability of the overall model. In the numerical optimization phase, we ask design expert to;determine the optimum current (Amp), voltage (volts) and gas flow rate (L/min) that will minimize the rate of corrosion. The interphase of the numerical optimization showing the objective function is presented in Figure.

Start the optimization by clicking the **Solutions** tab. It defaults to the Ramps view so you get a good visual on the best factor settings and the desirability of the predicted responses.

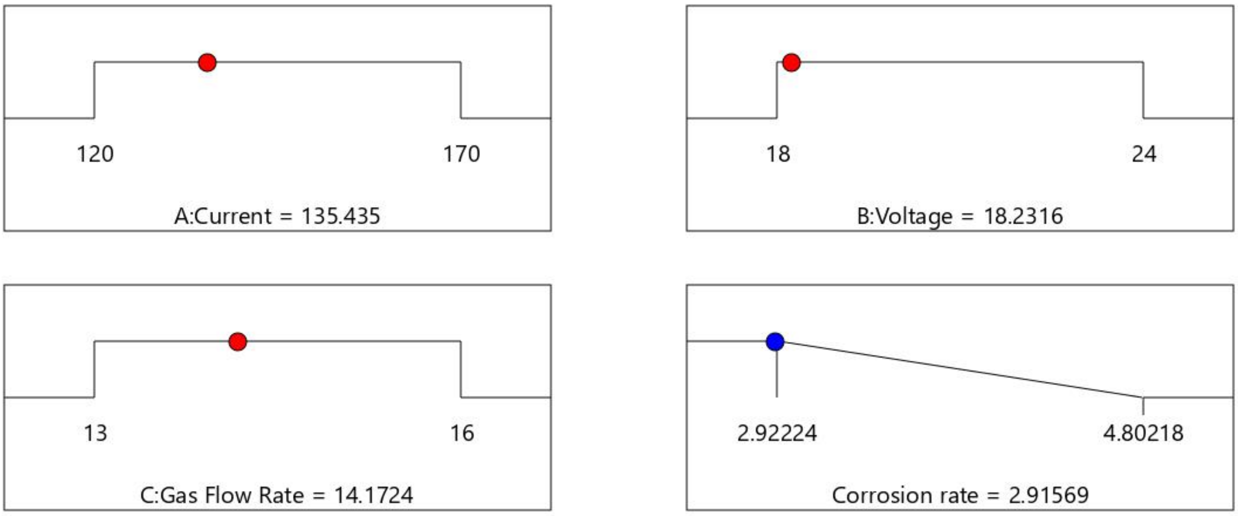


Figure 4.14: Numerical Optimization Ramps view for Solutions (Your results may differ)

Table 4.18: Report on numerical optimization

Number	Current	Voltage	Gas Flow Rate	Corrosion rate	Desirability	
1	**144.851**	**18.220**	**13.866**	**2.883**	**1.000**	**Selected**
2	144.124	18.472	13.691	2.907	1.000	
3	127.810	18.017	13.823	2.922	1.000	
4	142.421	18.234	14.133	2.904	1.000	
5	133.509	18.181	13.834	2.908	1.000	
6	127.654	18.005	13.888	2.920	1.000	
7	143.110	18.368	14.145	2.913	1.000	
8	129.594	18.064	13.930	2.915	1.000	
9	167.183	18.163	13.926	2.852	1.000	
10	131.545	18.267	13.833	2.917	1.000	
11	136.939	18.433	14.106	2.919	1.000	
12	136.657	18.103	13.887	2.896	1.000	
13	131.744	18.013	14.241	2.922	1.000	
14	140.001	18.484	14.066	2.917	1.000	
15	148.081	18.088	13.843	2.865	1.000	
16	127.379	18.051	14.032	2.922	1.000	
17	156.232	18.063	13.275	2.843	1.000	
18	128.121	18.098	13.900	2.920	1.000	

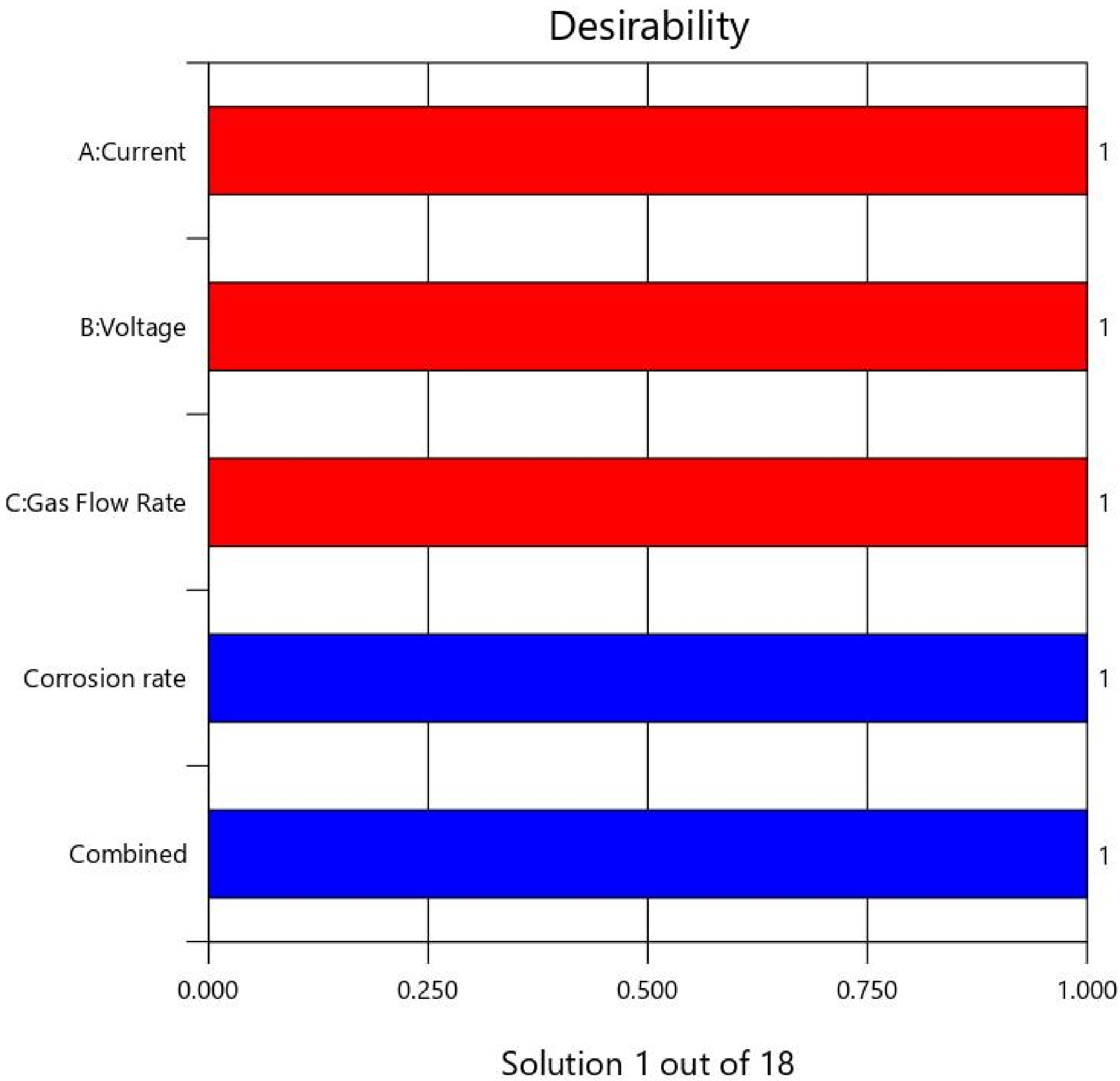


Figure 4.15: Solution to single response optimization — desirability bar graph

The desirability bar graph which shows the accuracy with which the model is able to predict the values of the selected input variables and the corresponding response.

It can be deduce from the result of Figure 4.16 that the model developed based on response surface methodology and optimized using numerical optimization method, predicted rate of corrosion with an accuracy level of 100%.

Optimization Graphs

We Selected the Graphs tab to view a contour graph in the figure below of the overall desirability and all of our responses. Desirability = 1.00 and rate of corrosion (mpy) = 2.91766

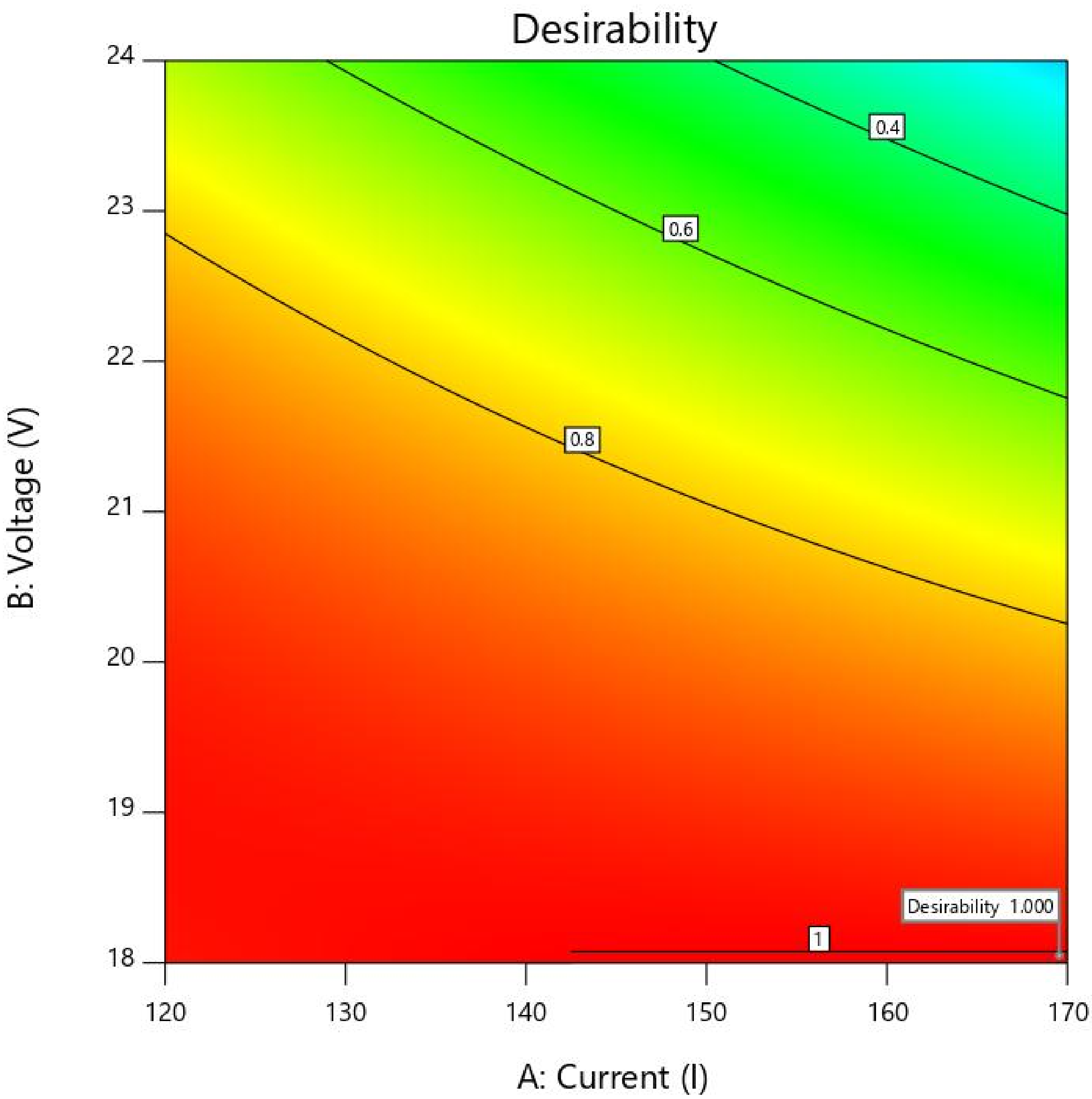


Figure 4.16: Desirability plot

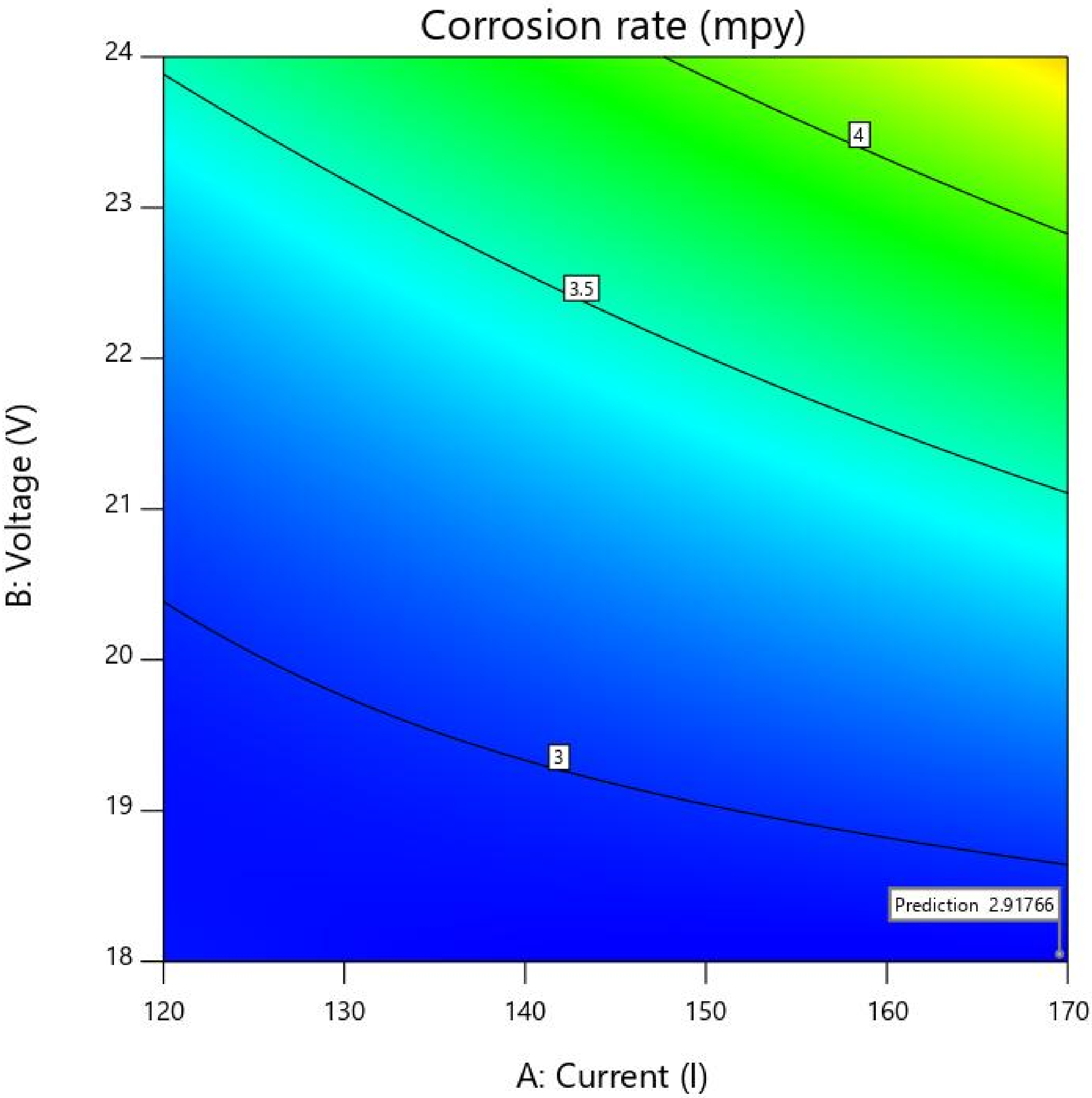


Figure 4.17: Rate of corrosion contour plot

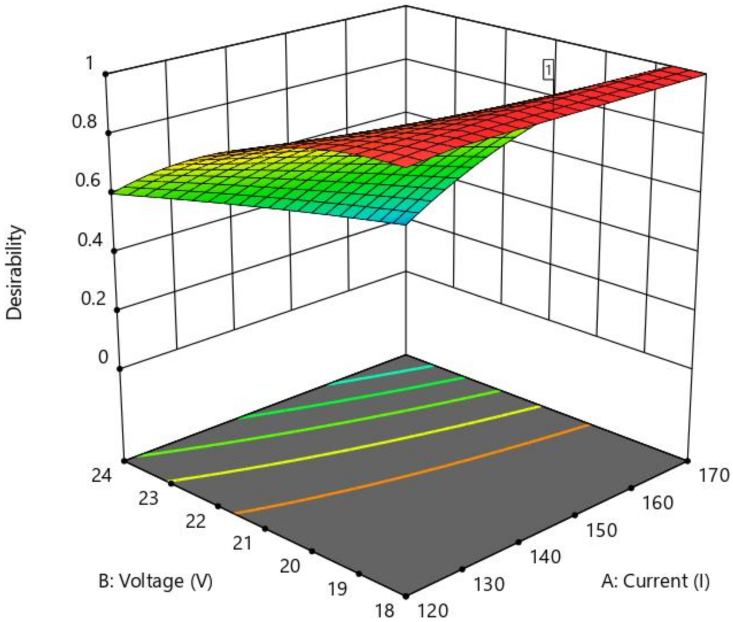


Figure 4.18: 3D desirability Plot

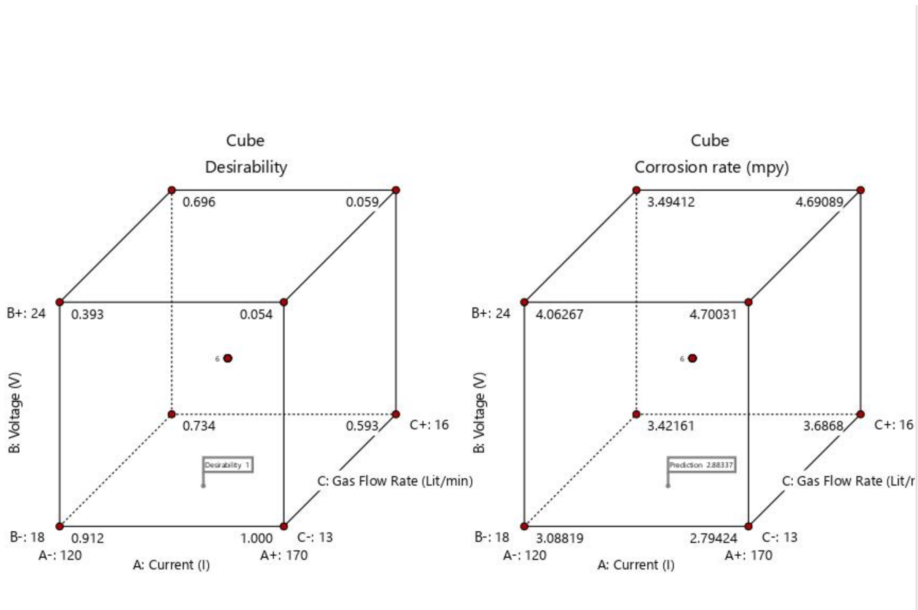


Figure 4.19: cube plot for optimization by CCD

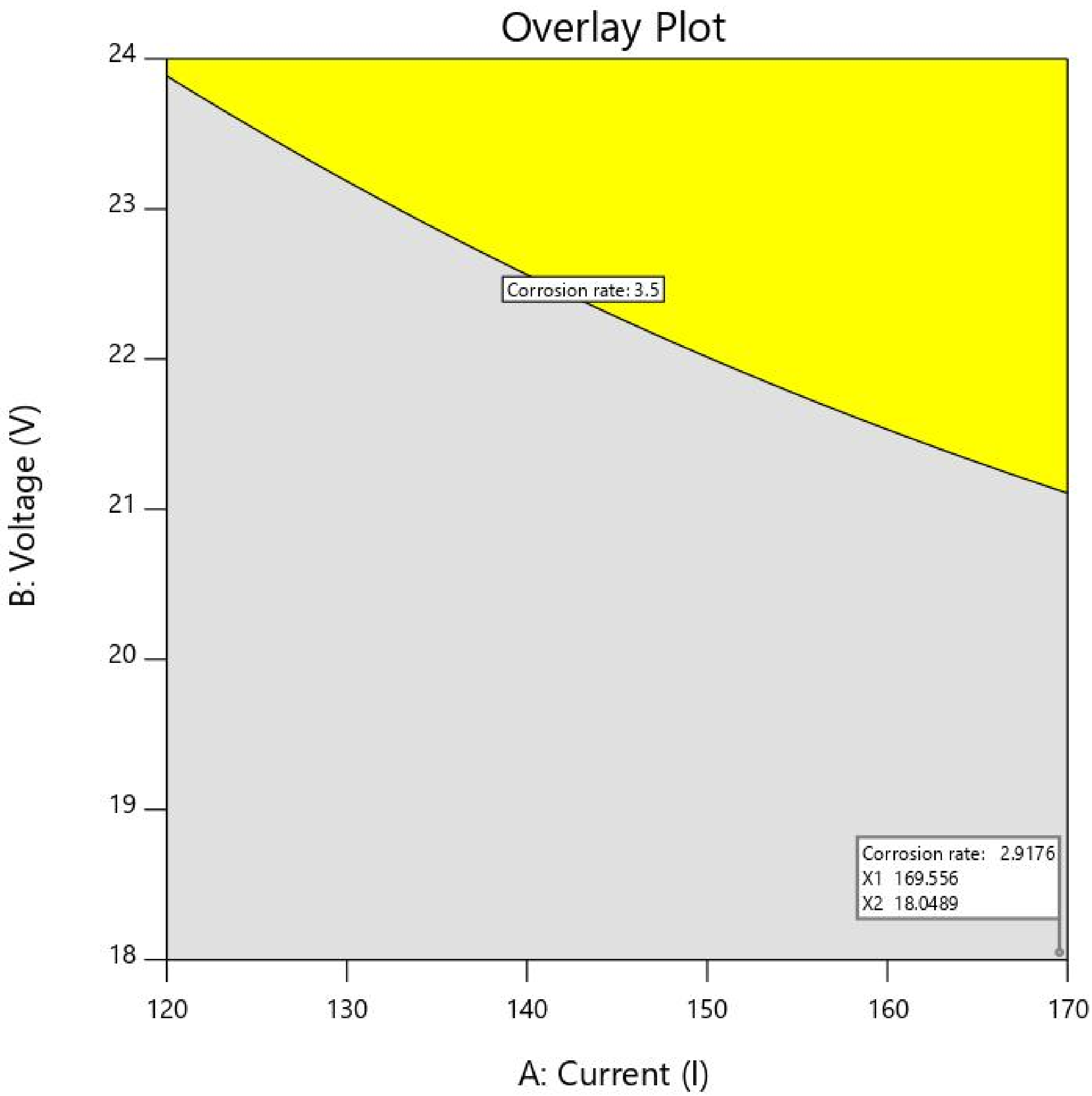


Figure 4.20: overlay plot

Figure 4.20 shows an overlay plot generated from the model. The coloured area represents the region of rate of corrosion above 3.5mpy. hence, the optimal rate of corrosion falls within the unshaded region.

Table 4.19: factors prediction

Factors | Point Prediction

Factors

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Current	144.85	120.00	170.00	0.0000	Actual
B	Voltage	18.22	18.00	24.00	0.0000	Actual
C	Gas Flow Rate	13.87	13.00	16.00	0.0000	Actual

Factors | Point Prediction

Point Prediction

Two-sided Confidence = 95% Population = 99%

Solution 1 of 18 Response	Predicted Mean	Predicted Median	Observed	Std Dev	SE Mean	95% CI low for Mean	95% CI high for Mean	95% TI low for 99% Pop	95% TI high for 99% Pop
Corrosion rate	2.88337	2.88337		0.141258	0.0630533	2.74288	3.02386	2.18944	3.5773

Confirmation Location #1 | Factors | Confirmation

Confirmation Location #1

Current	Voltage	Gas Flow Rate
150.124	18.2733	13.9156

Response data

Runs: 3

Corrosion rate
2.8099
2.9001
2.8514

Confirmation Location #1 | Factors | Confirmation

Factors

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Current	144.85	120.00	170.00	0.0000	Actual
B	Voltage	18.22	18.00	24.00	0.0000	Actual
C	Gas Flow Rate	13.87	13.00	16.00	0.0000	Actual

Confirmation

Two-sided Confidence = 95%

Response	Predicted Mean	Predicted Median	Observed	Std Dev	n	SE Pred	95% PI low	Data Mean	95% PI high
Corrosion rate	2.8816	2.8816		0.141258	3	0.102913	2.6523	2.8538	3.11091

Coefficients Table

p-value colors: **p < 0.05** 0.05 ≤ p < 0.1 p ≥ 0.1

	Intercept	A	B	C	AB	AC	BC	A^2	B^2	C^2
Corrosion rate	3.2501	**0.225707**	**0.494647**	0.0810004	**0.232896**	**0.139784**	**-0.225494**	0.0168756	**0.189697**	**0.285683**
p-values		**0.0002**	**< 0.0001**	0.0599	**0.0009**	**0.0188**	**0.0011**	0.6600	**0.0005**	**< 0.0001**

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND CONTRIBUTION TO KNOWLEDGE

5.1 Conclusion

In this study, an attempt was made to determine the effects of combined welding input parameters such as gas flow rate, voltage and current using response surface methodology to optimize and predict the rate of corrosion.The butt joint specimens were performed based on varying the welding input parameters. The result obtained in this study shows that the current has a very strong influence on the rate of corrosion.Based onthe findings, it is summarized that the corrosion rate is minimum when a weldingvoltage of V = 18V, current = 120A and gas flow rate = 13lit/min

5.2 Recommendation

It isrecommended that welding and fabrication industries should endeavor to use the optimum welding process parameters achieved in this study to produce high quality welds in Tungsten inert gas welding process.

5.13 Contribution to Knowledge

In this study the application Response Surface Methodologyto optimize and predict the rate of corrosion of a mild steel pipe weldment join has been successfully established.

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