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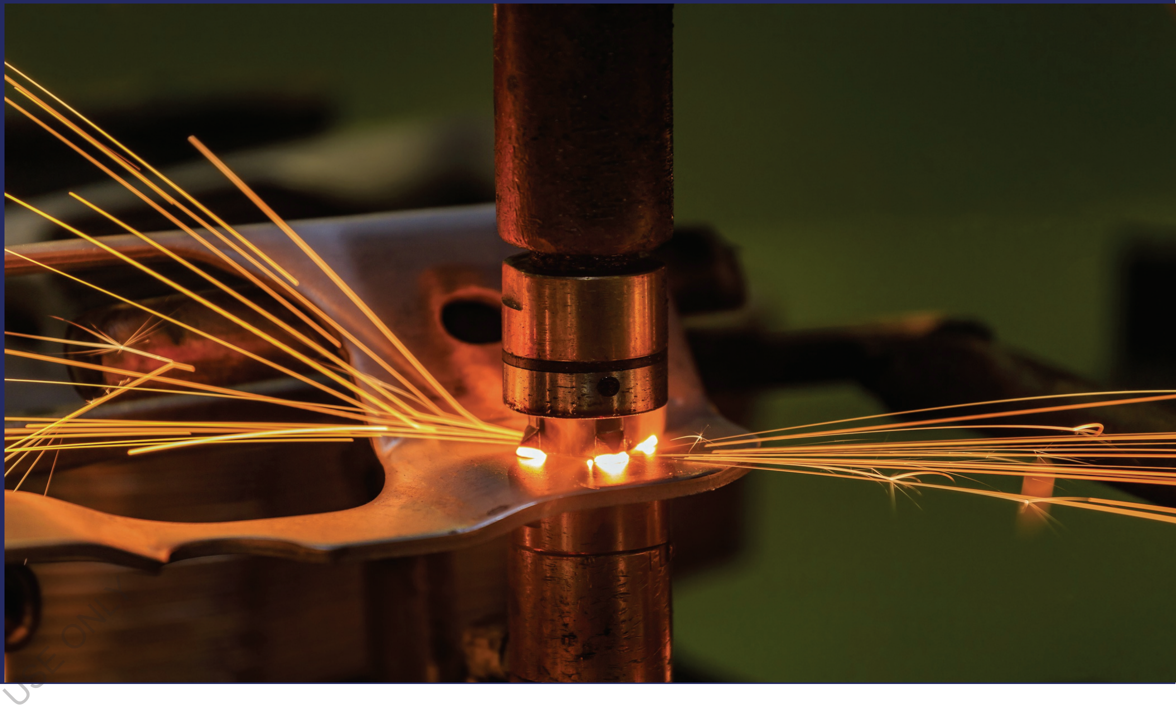

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# ABSTRACT

Mild steel also called plain-carbon steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications, Mild steel has a relatively low tensile strength and malleable; surface hardness can be increased through carburizing. This material is also electrically conductive, easily available and flexible in design. It can be machined by using many non-conventional methods like laser cutting, water jet machining and plasma arc machining. Among them Plasma arc machining is a widely used industrial process due to its high accuracy, finishing, ability of machining any hard materials and to produce intricate shape increases its demand in market. This process is considered a challenging technology compared to its main competitors: Oxy-fuel and laser cutting, in particular for cutting of mild steel for thickness 8-40 mm.

By considering literature surveys for plasma machining in context to parametric optimization and analysis to attain target and optimum results, Taguchi method and Response surface methodology is employed. For this Hypertherm plasma arc source, operating 30-400 A and output voltage between 100-200V is considered. The appropriate orthogonal array has been selected as per number of factors and their levels to perform minimum experimentation.

The first part of work targets on finding the optimal combination of parameters which gives the best performance measure. For this Taguchi techniques are applied and then ANOVA F- test is performed to check the significance.

In second part of this work is related Regression equation is generated by using Response surface methodology through central composite design scheme to obtain output value with in specified limits without further experimentation. ANOVA F-test is performed to check the significance and errors are compared.

Key Words: plasma, ANOVA, Taguchi

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# CHAPTER 1

# INTRODUCTION

## 1.0 Motivation

There are several materials that are used in vast for manufacturing in the present days but amongst them mild steels, ceramics, polymers, carbides and few other metals have found wide applications in the manufacturing industry. Mild steel also called **plain-carbon steel**, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications more so than iron, it is often used when large quantities of steel are needed. The density of mild steel is approximately 7.85 g/cm$^3$ (7850 kg/m$^3$ or 0.284 lb/in$^3$) and the Young's modulus is 210 GPa (30,000,000 psi). It contains 0.05–0.3% carbon making it malleable and ductile easily available flexible in design and fast to erect. Its inherent properties allow electrical current to flow easily through it without upsetting its structural integrity.

Mild steel is used in 85% of all steel products, This over whelming market demand makes it the cheapest form of steel available, with such a wide spread usage, the knowledge of its properties is necessary for anybody who's the manufacturing business to choose for the best machining process.

For this kind of material, Manufacturing process based on metal removal have been used for many years. The recent advancements in manufacturing technology have enabled manufacturers to make parts and products faster with better quality and more complexity. Laser, water jet, and plasma technique represent some of newly established techniques in manufacturing. Amongst other thermal machining methods, plasma arc machining (PAC) is a very important thermal machining process and has been used successfully in the machining of stainless steel, high hardness metals, high melting point metals and other difficult to machine alloys. The cost of machining by PAC method is 2 to 3 times lower, while productivity is 2.5 times higher than other process. Due to this the interest of modern industries in plasma arc machining applications have increased by comparing the capability of this process with Laser machining (higher quality but also more expensive) and Oxygen-fuel machining which is less expensive.

### 1.1 Plasma Arc Machining:

The Plasma arc machining is a Thermal method of un-conventional machining process in which the desired metal removal takes place through a constricted arc which melts the localized area of work piece and removal of molten material takes with a high velocity jet of ionized gas issuing from the constricted orifice. The plasma arc machining is a replacement of plasma arc welding, in 1941, The U.S. defense industry discovers a new welding process while researching better ways of joining metal together.

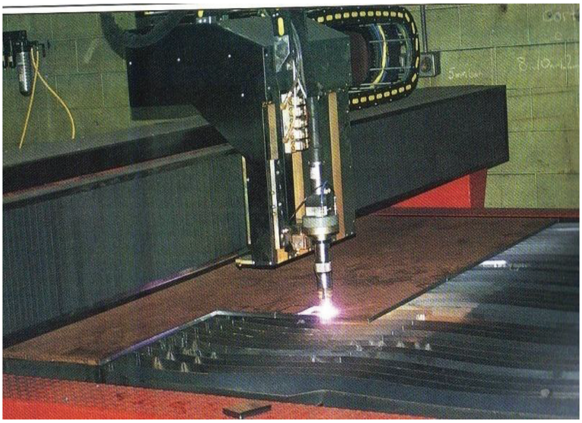


Figure 1.1 Plasma arc machining

The process commonly referred to as TIG involves feeding an inert gas through an electric arc. In 1954, Scientists learned that increasing the gas flow and reducing the opening in the gas nozzle used in TIG welding results in the formation of a plasma jet. The plasma machining is practical alternative to laser machining and abrasive water jet machining systems which is used for machining of electrically conductive metals, utilizes electrically conductive gas to transfer energy from an electrical power source through a plasma machining torch to the material being cut. It uses a high-velocity jet of electrically charged gas to cut metal at up to 50.000 degrees Kelvin.

## 1.2 Need Of Plasma:

In an economic climate that presents manufacturers with mounting pressures, it’s important to know there are options for companies of all sizes that cut metal sheet or plate for their products. Recent developments in plasma and high-definition plasma technologies have made this method cost efficient, particularly for manufacturers that have used or are considering using laser machining. Now, given the precision and quality that plasma machining can provide, manufacturers can expect to save money and time using plasma technology on parts that may in the past have required laser machining.

### What is Plasma?

The term plasma is defined as fourth state of matter. When heated to elevated temperatures, gases turns into distinctly different type of matter which is plasma. The changes that takes place when gases are heated to a few thousand degree are:

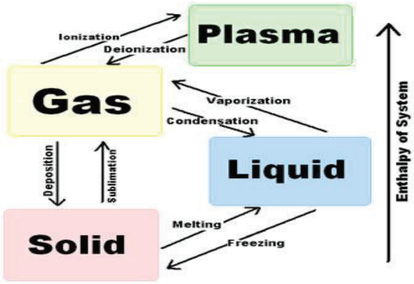


Figure 1.2 Plasma Gas

(I) The number of collisions, elastic or inelastic, between atoms increases.

(II) The gas ionizes, so that the atoms are stripped off their outer electrons, resulting in the creation of electrons and ions.

(III) The electrons thus produced, in turn, collide with atoms, heat them through relaxation processes so that their thermal kinetic energy increases, excite them so that de-excitation light is emitted from the atoms and ionize them so that more electrons and ions are produced. Thus, the new matter is characterized by its ability to conduct electricity due to the presence of free charges. At high charge densities, the matter also becomes bright due to emission from atoms.

With plasma machining, less preparation work is required. A plasma arc is hot enough to burn through most surface coatings such as paint and rust and still provides excellent machining results. With plasma machining, there is minimal heat input and distortion of the metal as there is with jigsaws or machining shears. For applications where difficult shapes are being handled or cut, such as ventilation ductwork (HVAC), tanks or vessels, plasma machining offers considerable advantage since no fixturing is required.

### 1.3 Principle Involved In Plasma Machining:

The principle involved here is, the machining system utilizes heat generated by arc discharge between the machining object material and the electrode inside the torch. Arc discharge heat forms working gas into the plasma state of high temperature. The plasma jet of high temperature and high-speed is blown out from the nozzle; and the machining object material is fused to be cut.

In this plasma arc is constricted through a nozzle. This transferred arc, which occurs when electricity flows from the non-melting electrode (cathode) to the work-piece (anode), is used to cut electrically conductive materials. This is the most commonly used form of plasma machining.

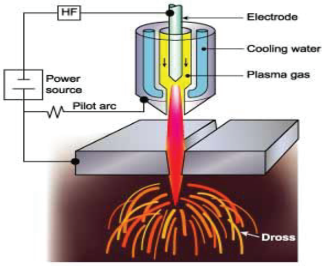


Figure 1.3 Principle of Plasma Machining

In the non-transferred mode, the arc occurs between the electrode and the nozzle. Even when using a cutting gas that contains oxygen, the heat effect of the plasma arc prevails. Thus, this method is not considered an oxy-fuel process, but rather a melt machining method. The plasma gases are partially dissociated and ionized in the arc, thereby making them electrically conductive. Owing to the high energy density and temperature, the plasma expands and moves towards the work-piece at up to three times the speed of sound.

The metal material melts and partially vaporizes due to the thermal energy of the arc and plasma gas. The melt is forced out of the kerf by the kinetic energy of the plasma gas. In contrast to oxy-fuel machining, in which about 70% of the thermal energy is produced through iron combustion, in plasma fusion machining the energy required for melting the material in the kerf is produced only electrically. Which plasma gases are used depends on the material to be cut. For example, the monatomic gas argon and/or diatomic gases, such as hydrogen, nitrogen, oxygen, and combinations thereof as well as purified air are used as the plasma gas and also as the cutting gas. Burners can either be water-cooled or gas-cooled. Plasma machining processes are broken down according to where they are used (above and on the water and under the surface of water)

## 1.4 Components of Plasma Arc Machine:

Plasma arc machine offers process flexibility that is unparalleled and enables you to cut, bevel and mark metals of up to 160 mm thick. Hypertherm Powermax series CNC plasma cutters have easy to use control interfaces.

**TECHNICAL FEATURES:**

| | |
|---|---|
| HPR Plasma | HPR260XD |
| Input current | 84A |
| Output current | 30-260A |
| Output Voltage | 175 VDC |
| Plasma gas supply | Oxygen(O2), Nitrogen(N2),F5 Gas(5%H,95%N),H35 Gas(35%H,65% Air), Compressed Air or Argon(Ar) |

| | |
|---|---|
| Shield gas supply | Nitrogen(N2), Oxygen(O2), Compressed Air or Argon(Ar) |
| Gas pressure | 8 bar |
| Cutting capacity | 32 mm |
| Pierce capacity | 38 mm |
| Severance | 64 mm |

Table 1.1 Machine Specifications

The machines have the function of automatically memorizing and restoring when the power is off; plasma arc machining requires no preheating, turnaround time is fast, the process produces a small heat-affected zone.

- With **remote control**, machining from around 40 meter radius of the machine;
- These machines also feature automatic arc voltage or mechanical floating style **torch height control**;
- the standard machining table with work piece collect drawer and the **water table**;

These machines further allow you to effectively avoid high frequency interference from plasma stream, make machining stable and safe.

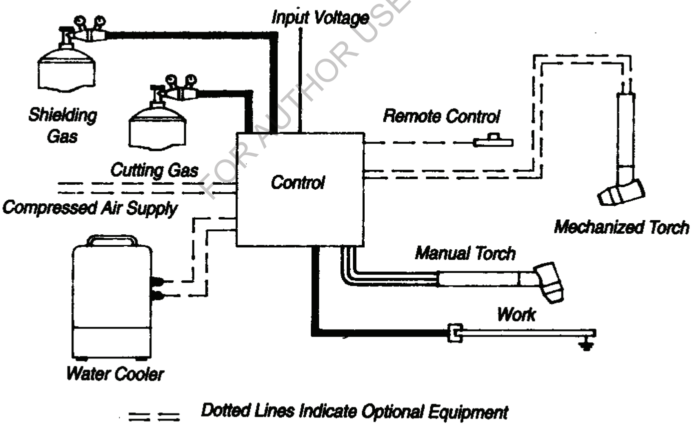


Figure 1.4 Components of plasma machine

Plasma arc machining can increase the speed and efficiency of both sheet and plate metal machining operations. Manufacturers of transportation and agricultural equipment, heavy machinery, aircraft components, air handling equipment, and many other products have discovered its benefits. Basically Plasma Arc Cutter comprises of major parts such as power supply, gas supply and plasma torch.

### 1.4.1 Power Supply:

The plasma power source supplies the operating voltage and the cutting current for the main and auxiliary arc. The no-load voltage of plasma cutting power sources ranges from between 240 and 400 V. The power source contains a pilot arc (auxiliary plasma arc) ignition system, responsible for lighting the main plasma arc. This is generally done by first lighting a non- transferred plasma arc using high-voltage pulses. This arc is responsible for ionizing the space between the nozzle and the work-piece, thus permitting the main plasma arc to be produce. Power supplies have air-cooled and an additional inductance which allows you to get a sustainable burning of plasma arc in the range of voltages from 100 to 600V.

### 1.4.2 Gas Supply:

The plasma system consists of two – three flows and their composition depends on type of material and thickness.

- Plasma gas- flows through the orifice and becomes ionized(oxygen)
- Shielding gas – flows through outer nozzle and shields the molten weld from the atmosphere.(air)
- Back – purge and trailing gas – required for certain materials and applications.

### 1.4.3 Plasma torch

The plasma torch is a device, depending on its design, which allows the creation and control of the plasma for welding or machining processes. The plasma is created in both the machining and welding torches in the same basic manner, and both torches have the same basic parts. A plasma torch supplies electrical energy to a gas to change it into the high energy state of plasma.

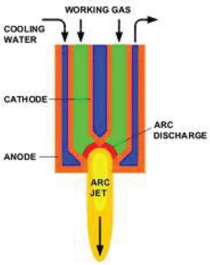


Figure 1.5 Description of plasma torch

- **Torch Body** The torch body, on a manual-type torch, is made of a special plastic that is resistant to high temperatures, ultraviolet light, and impact, The torch body is a place that provides a good grip area and protects the cable and hose connections to the head. The torch body is available in a variety of lengths and sizes.

- **Torch Head** The torch head is attached to the torch body where the cables and hoses attach to the electrode tip, nozzle tip, and nozzle. The torch and head may be connected at any angle, such as 90°, 75°, or 180° (straight), or it can be flexible. The 75° and 90° angles are popular for manual operations, and the 180° straight torch heads are most often used for machine operations.

- **Electrode Tip** The electrode tip is often made of copper with an imbedded tungsten tip. The use of a copper/ tungsten tip in the newer torches has improved the quality of work they can produce. By using copper, the heat generated at the tip can be conducted away faster. Keeping the tip as cool as possible lengthens the life of the tip and allows for better-quality cuts for a longer time.

### 1.5 Process of plasma arc machining:

**Step 1:** A start input signal is sent to the power supply. This simultaneously activates the open circuit voltage and the gas flow to the torch. Open circuit voltage can be measured from the electrode (-) to the nozzle (+). Notice that the nozzle is connected to positive in the power supply through a resistor and a relay (pilot arc relay), while the metal to be cut (work piece) is connected directly to positive. Gas flows through the nozzle and exits out the orifice. There is no arc at this time as there is no current path for the DC voltage.

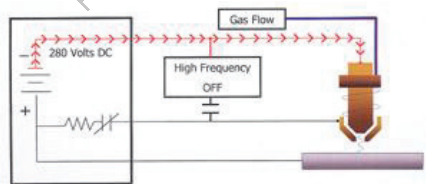


Figure 1.6 Step-1 of Plasma Machining Process

**Step 2:** After the gas flow stabilizes, the high frequency circuit is activated. The high frequency breaks down between the electrode and nozzle inside the torch in such a way that the gas must pass through this arc before exiting the nozzle. Energy transferred from the high frequency arc to the gas causes the gas to become ionized, therefore electrically conductive. This electrically conductive gas creates a current path between the electrode and the nozzle, and a resulting plasma arc is formed. The flow of the gas forces this arc through the nozzle orifice, creating a pilot arc.

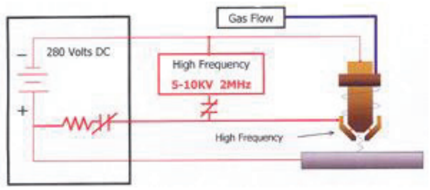


Figure 1.7 Step-2 of Plasma Machining Process

**Step 3:** Assuming that the nozzle is within close proximity to the work piece, the pilot arc will attach to the work piece, as the current path to positive (at the power supply) is not restricted by a resistance as the positive nozzle connection is. Current flow to the work piece is sensed electronically at the power supply. As this current flow is sensed, the high frequency is disabled and the pilot arc relay is opened. Gas ionization is maintained with energy from the main DC arc.

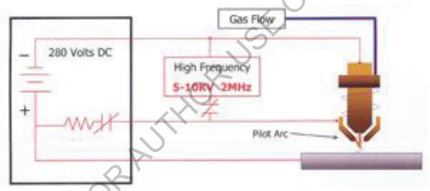


Figure 1.8 Step-3 of Plasma Machining Process

**Step 4:** The temperature of the plasma arc melts the metal, pierces through the work piece and the high velocity gas flow removes the molten material from the bottom of the cut kerf. At this time, torch motion is initiated and the machining process begins.

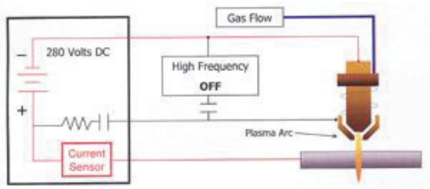


Figure 1.9 Step-4 of Plasma Machining process

## 1.6 Types of Plasma Arc Machining:

### ➢ 1.6.1 Conventional Plasma Machining

This process generally uses a single gas (usually air or nitrogen) that both cools and produces the plasma. Most of these systems are rated at under 100 Amps, for machining materials under 5/8" thick. Primarily used in hand held applications.

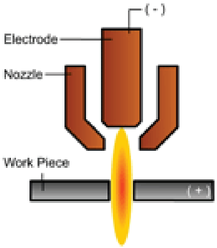


Figure 1.10 Conventional Plasma Arc Machining

### ➢ 1.6.2 Dual gas Plasma Machining

This process utilizes two gases; one for the plasma and one as a shield gas.The shield gas is used to shield the cut area from atmosphere, producing a cleaner cut edge. This is probably the most popular variation, as many different gas combinations can be used to produce the best possible cut quality on a given material.

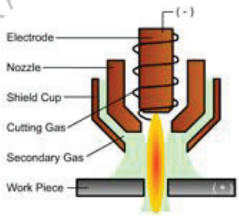


Figure 1.11 Dual Gas Plasma Machining

### ➢ 1.6.3 Water shield Plasma Machining

This is a variation of the dual gas process where water is substituted for the shield gas. It produces improved nozzle and work piece cooling along with better cut quality on stainless steel. This process is for mechanized applications only.

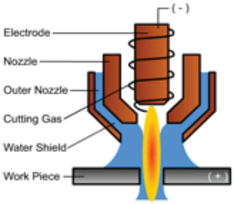


Figure 1.12 Water Shield Plasma Machining

### ➢ 1.6.4 Water injection Plasma Machining

This process uses a single gas for plasma and utilizes water either radially or swirl injected directly into the arc to greatly improve arc constriction, therefore arc density and temperatures increase. This process is used from 260 to 750 amps for high quality machining of many materials and thickness. This process is for mechanized applications only.

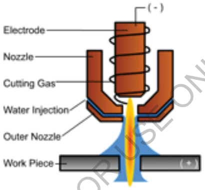


Figure 1.13 Water injection Plasma Machining

### ➢ 1.6.5 Precision Plasma Machining

This process produces superior cut quality on thinner materials, (less than 1/2") at slower speeds. This improved quality is a result of using the latest technology to super constricts the arc, dramatically increasing energy density. The slower speeds are required to allow the motion device to contour more accurately. This process is for mechanized applications only.

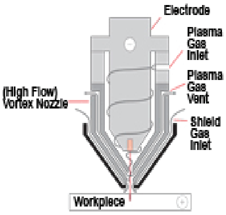


Figure 1.14 Precision Plasma Machining

## 1.7 Advantages and Limitations of Plasma Arc Machining:

### 1.7.1 Advantages

- **Cost Savings:** Reduce fabrications costs by choosing precision plasma cut parts
- **Quality Improvements:** Produce sharper inside/outside corners, sharper edges, and narrower kerf widths than conventional methods.
- **Efficient Production:** Fabricating times reduced when parts are received with +/- .20" and free of dross and burrs.
- **Economical Productivity:** Minimize scrap and reduce handling time given capacity to handle plate sizes as large as 100" x 260" which allows programmers to nest a large quantity of parts on a single sheet during plasma machining processes.
- **Operational Efficiency:** Parts continue to be produced by the High Definition Plasma system as our dual automatic pallet shuttle removes completed cut shapes while new material is simultaneously being loaded.
- **Design Flexibility:** Eliminate the need for making templates, transferring to steel parts, center punching, hand-machining and hand-grinding as the flexible table designs of our Fine Plasma Cutters are ideal for machining holes and features in tubes and structural shapes as well as sheet and plate.

### 1.7.2 Limitations

- Initial investment is more
- The cutter’s electrode and nozzle sometimes require frequent replacement which adds to the cost of operation.
- Non conductive materials such as wood or plastic cannot cut with plasma cutters
- Plasma arc typically leaves a 4-6 degree bevel on the cut edge; although this angle is almost invisible on thinner material, it is noticeable on thicker pieces.
- The dimensions in the drawings shall be taken to be the nominal dimensions being determined on the clean surfaces of the cut. The limit deviations for the cut surface quality (perpendicularity tolerance) are treated separately from the limit deviations for the dimensional deviations of the work piece in order to emphasize the different influences on work piece.

## 1.8 Process Parameters:

Process parameters are classified into three types according to their involvement in machining.

| Constant parameters | Material parameters | Variable parameters |
|---|---|---|
| ➢ **Current**<br>➢ **Gas Pressure**<br>➢ **Kerf**<br>➢ **Plasma gas** | ➢ **Material**<br>➢ **Thickness** | ➢ **Cut speed**<br>➢ **Stand-off distance**<br>➢ **Voltage** |

Table 1.2 Process parameters

### 1.8.1 Current:

Current flow rate is the value of current given during machining process. The cause of the burn-through was the increase in the cutting current or the decrease in the cutting speed. When the cutting current increases or the cutting speed decreases, the stable state of the keyhole changes accordingly. If the cutting current and the flow rate of the plasma gas are increased and/or the cutting speed is decreased, the process will withstand larger variations in the cutting parameters.

### 1.8.2 Gas Pressure:

Pressured air serves two purposes in plasma machining. The primary purpose is to supply gas to fuel the plasma reaction and the secondary purpose is to blow melted material away while cooling the tip. Pressure was determined as a variable affecting quality by the plasma CAM machine manual; a maximum pressure input of 125 psi was also listed. Operating pressure was found to be 70 psi for all cutting power levels (Thermal dynamics).A combination of operating range and experimentation determined that the discrete range used for investigation was 60 psi

### 1.8.3 Kerf:

The kerf is the space left in the work piece as the metal is removed during a cut. The width of a PAC kerf is often wider than that of an oxy-fuel cut. Several factors will affect the width of the kerf. The kerf width obtained by plasma arc machining will be greater than that achieved by oxy-fuel machining on carbon steel, but not as great as that obtained by other processes, such as abrasive machining or arc gouging. The rule of thumb for estimating the kerf in plasma machining is that the width will be approximately 1.5 to 2.5 times the tip orifice diameter.

### 1.8.4 Plasma gas:

For mild steel use oxygen plasma and air shield for the best cut quality, lowest dross levels, minimal rework, excellent weldability and highest cutting speed/productivity. Oxygen has become the industry standard for machining Carbon Steel because it provides the best cut quality and fastest cutting speed of any plasma gas. Oxygen plasma gas reacts with carbon steel to produce a finer spray of molten metal, each droplet having a lower surface tension. This molten spray is more easily ejected from the kerf.

Air is the most versatile plasma gas; it produces good cut quality and speed on mild steel, stainless, and aluminum. Air also lowers the cost of operation because it is not necessary to purchase gases. However air is not free. Shop air must be cleaned to remove contamination such as particulate, oil mist, and moisture.

### 1.8.5 Material:

The material assumed for plasma machining is Mild steel. This is also called plain-carbon steel, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications, more so than iron. Low-carbon steel contains approximately 0.05–0.3% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm$^3$ (7850 kg/m$^3$ or 0.284 lb/in$^3$) and the Young's modulus is 210 GPa (30,000,000 psi).

### 1.8.6 Thickness:

The assumed thickness is 8mm mild steel plate and this thickness is remained to be constant throughout the experimentation. By considering the data, further experimentation is carried out by assuming the constant and varying process parameters current, gas pressure, kerf and plasma gas and varying process parameters like Cut-speed, stand-off distance and voltage for the experimentation process for getting better results.

### 1.8.7 Cut speed:

The cut speed is the speed at which the torch moves in the x-y plane while the torch is machining. Cut speed varies depending on material type, material thickness and input power. The best way to judge cutting speed is to look at the arc as it exits the bottom of the work piece. Observe the angle of the cutting arc through the proper welding lens. If machining with air, the arc should be vertical straight down, or zero degrees as it exits the bottom side of the cut.

### 1.8.8 Stand-off distance:

"Torch stand-off" is the distance the outer face of the torch tip or constricting orifice nozzle is to the base metal surface. This standoff distance will be determined by the thickness of material being cut and the amperage required. Low heat build-up while machining with less than 40 amperes may allow dragging the torch tip on the material. If a high build-up of heat is expected, a standoff distance of 1/16" to 1/8" will be required.

### 1.8.9 Voltage:

The power source required for the plasma arc process must have a drooping characteristic and a high voltage. Although the operating voltage to sustain the plasma is typically 100 to 160 V, the open circuit voltage needed to initiate the arc can be up to 400V DC. On initiation, the pilot arc is formed within the body of the torch between the electrode and the nozzle.

## 1.9 Performance Measures:

### 1.9.1 Metal Removal Rate

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Material Removal Rate (MRR) is defined by:

$$\mathbf{MRR = WRW/T\ [g/min]} \qquad ..1.1$$

Where,
WRW: work-piece removal weight (g)
T: machining time(s)
WRW is the weight different between before and after work piece machining. The volume different can be calculated when information regarding material density available. The relation between WRW and WRV is given as follow:
$WRV = WRW/\rho$
Where,
$\rho$: Work piece density (g/ mm3)

### 1.9.2 .Surface Roughness

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough, if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness normally measured. Roughness plays an important role in determining how a real object will interact with its environment.

### 1.9.3 Dross (Re-solidified metal);

This phenomenon refers to the re-solidified metal that adheres to the bottom edge of the plasma cut. The concentration of dross will be heavier on the bad side of the cut. The amount of dross that fonus is a result of the type of metal being cut, the cutting speed, and the arc current. Dross can be formed from either too high or too Iowa cutting speed, but there is a "window" between these two extremes in which dross-free cuts can usually be achieved. The dross-free range is greater on stainless steel and aluminium than it is on carbon steel and copper alloys. If dross-free cuts cannot be achieved, then a minimum amount of low speed dross is more desirable, because it is more easily removed than the high-speed variety.

### 1.9.4 Heat affected zone:

This study of thermal and chemical effects in plasma-cut stainless and aluminum confirmed many of the findings of previous studies on carbon steel.

- The HAZ is small in plasma-cut pieces. Most HAZ measurements in this study were less than 0.001 inch thick.
- HAZ varies with speed and power. The extent of the HAZ in mild steel is related to process variables, such as cut speed and power, as well as material thickness.
- Faster machining produces less HAZ. Decreasing the time required to perform a cut by using high amperage and high-speed conditions reduces the HAZ.
- More heat (per square inch) can produce less HAZ. High-energy density processes (more power per unit area), such as high-precision PAC, produce less HAZ.

For some applications the HAZ must be removed mechanically before welding to prevent embrittlement and weld failure, but the HAZ of plasma-cut stainless and aluminum generally is small and can be further minimized through process controls.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction

Several researches have been carried on plasma arc machining process for machining different materials. Based on literature reviews on plasma arc machining, they are classified into three categories, such as

- Experimental model
- Optimization models and
- Analysis model

## 2.1 Experimental Model

- R.Bhuvenesh et al [2012] considered plasma arc machining process which is one of thermal removing process for machining AISI 1017 Steel of 200 mm x100 mm x 6 mm material operates on the principle of passing an electric arc through a quantity of gas through a restricted outlet. They have considered cutting current, air pressure, cutting speed, arc gap as input parameters and performance measures metal removal rates and surface roughness. It was found that experiment 8 produces lowest surface roughness and experiment 6 gives highest metal removal rate

## 2.2 Optimization Model

- M.I.S.Ismail et al [2011] assumed plasma arc machining for ASSAB 618 steel to find out surface hardening with the help of Taguchi techniques. Here, L8 orthogonal array is assumed then after ANOVA F-test is performed. The results obtained are for hardened depth optimum parameter values are current 60A, low scanning velocity 0.1m/s and low carbon content 0.38wt% For surface roughness the values are low arc current 30A, high scanning velocity 0.3m/s and high carbon content 0.9wt%.It was also observed that increase of hardened depth of 1.34 times and improvement in surface roughness value by 1.77 times.

- R.Bhuvenesh et al [2012] considered plasma arc machining AISI 1017 Steel of 200 mm x100 mm x 6 mm material and conducted taguchi techniques for optimization process by considering L9 orthogonal array for 3 parameters and 3 levels. The observed optimization is that experiment 8 with input values 6.5 air pressure, 75 amps current, 600 machining speed, 5.0 arc gap and experiment with input values 60 air pressure, 80 current, 600 cut speed, 4.0 arc gap produce lowest surface roughness and highest MRR.

- Joseph c.chen et al [2009] studied Taguchi parameter design to optimize the roundness of holes made by an aging plasma-machining machine for . L9 array is used in Taguchi experiment design consisting of four controllable factors, each with three levels, with two non controllable factors included in the setting. The Taguchi experiments gave the optimal combination A1B2C1D3 (small for tip size, 93 in/min for feed rate, 100v for voltage and 63 a for amperage).

- John Kechagias et al [2010] considered optimization of the machining parameters for CNC plasma-arc machining of St37 mild steel plates is attempted using robust design. An orthogonal matrix experiment [L18 ($2^1 \times 3^7$)] was conducted and the right bevel angle was measured and optimized according to the process parameters using an analysis of means and an analysis of variances. The results show that the arc ampere has an effect mainly on the bevel angle (50.89%), while the plate thickness and torch standoff distance also have an influence of 6.22 and 15.9% respectively.

- S Ramakrishnan et al [2000] , reported the results on influence of oxygen for plasma gas used in the plasma arc machining process for machining 6mm mild steel plates. A comparison of the melting rates for oxygen with those of air reveals that although oxygen can produce more exothermal energy by oxidation, oxygen is not a superior to air in melting near the bottom of the kerf formed at high machining speeds.

- Wei-long Liu et al [2009] used L18 Taguchi method to obtain the optimum electro deposition parameters for the synthesis of CuInSe2 thin film for solar cells. The experiments were carried out according An X-ray diffract meter(XRD) and a scanning electron microscope (SEM) were respectively used to analyze the phases and observe the micro structure and the grain size of the CuInSe2 film before and after annealing treatment. The results showed that the CuInSe2 phase was deposited with a preferred plane (112) parallel to the substrate surface. The optimum parameters are as follows: current density 7mA/$cm^2$ ; CuCl2 concentration 10 mm; FeCl3 concentration 50mm; H2SeO3 concentration 15mm; TEA amount 0ml; pH value 1.65 deposition time 10 min, annealing temperature $500^oC$.

## 2.3 Analysis Model

- Pedro Ferreira et al [2006] considered plasma cutting for QstE-380 material of 15 mm thick plate. The input parameters are current, voltage, cutting gas pressure and Protection gas pressure where as response is cutting cost per unit length. The procedure is carried out by considering Response surface methodology through Central composite design scheme. A regression equation is generated and ANOVA-F test is performed to check the significance. The result obtained is an increase of 65% of cutting speed which in turn decrease in 29% of cutting cost

- Madic et al [2012] considered $CO_2$ laser cutting process on stainless steel and analysis is performed by using the Box-Behnken type of RSM method. The input parameters are laser power, cutting speed, assist gas pressure and focus position where as the response is perpendicularity. A regression equation is obtained for the response then ANOVA-F test is applied to test the developed mathematical model in which the F value of lack of fit and regression is compared. The observation is that F value of lack of fit 1.35 is lower than the F value of regression 4.30. Hence the developed RSM model is adequate at 99% confidence level. The perpendicularity increases as the laser power and focus position increase, and it decreases as the cutting speed and assist gas pressure increase. However, the focus position is the main factor affecting the perpendicularity.

- Myers, Khuriet al [1995], assumed orthogonal design which was motivated by Box and Wilson (1951) in the case of the first-order model. For the second-order models, many subject- matter scientists and engineers have a working knowledge of the central composite designs (CCDs) and three-level designs by Box and Behnken (1960). Also, the same research states that another important contribution came from Hartley (1959), who made an effort to create a more economical or small composite design. There exist many papers in the literatures about the response surface models. In contrast, 3-level fractional design has limited works. Thus, 3- level fractional design is an open research subject. Fractional Factorial Experiment Design for Factor at 3-Levels (Connor and Zelen 1959) is a helpful resource conducting this kind of design. Many three- level fractional factorial designs and more importantly their alias tables can be found in their study.

- Sharma et al [2012] optimized the process parameters of WEDM for multi-response using response surface methodology. Mathematical model is developed for the solution of this length provided the functions to generate central composite design for analysis of resulting data, the package provides for estimating the response surface, testing its lack of fit, displaying ensemble such as steepest ascent, canonical obtained using the Kienzle-victor Surface Model.

- Latkar et al. [2006] assessed the effect of machining on tool wear and surface roughness with graphite based grease mixed with base oil in varying proportions applied in MQL and compared the results with dry machining using response surface methodology while medium alloy steel was machined with tungsten carbide tool. Graphite and MoS assisted end milling process has reported considerable improvement in the process performance as compared to that of machining with cutting fluid in terms of cutting forces, surface quality and specific energy.

## 2.4 Fish Bone Diagram:

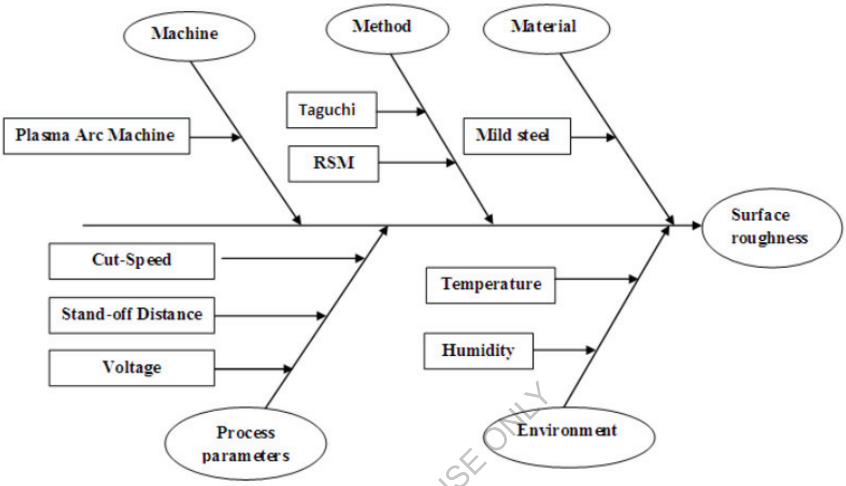


Figure 2.1 Fish Bone Diagram

## 2.5 Scope:

- By studying the above literatures it was observed that many machining processes are carried on steel. R.Bhuvenesh et al [2012] considered machining on mild steel with parameters air pressure, current, machining speed and arc gap. By considering this literature, a combination of Cut-speed, stand-off distance and voltage are considered as a set of process parameters in this work for machining mild steel with thickness of 8mm.

## 2.6 Objective of present work:

- The objective of this research work is to study the influence of process parameters on mild steel and to improve the surface finish by finding out the optimal conditions for process parameters by using Taguchi Approach through L9 Orthogonal array and performing Analysis of variance to find the significance of process parameters.

- Response surface methodology is considered to investigate the relationships and parametric interactions between the three controllable parameters on surface roughness and to generate regression equation.

- To study the proposed second-order polynomial model for surface roughness, by using central composite experimental design to estimation the model coefficients of the three factors, which are believed to influence the surface roughness in plasma arc cutting process.

# CHAPTER 3

# METHODOLOGY

## 3.1 Taguchi Methodology:

### 3.1.1 Taguchi Principle:

Taguchi methods are statistical methods which are not only used to improve quality but also reduces the variation of a process for manufactured goods. This technique was developed by Dr. Genichi Taguchi, in this the principle behind the Taguchi approach is that as an engineering task, it is considerably easier to adjust the mean level of some response variable to a target value than it is to reduce the variation of the response variable. Consequently, Taguchi techniques focus priority on the reduction of variation by paying considerable attention to how the variability of the response changes as the factor levels change.

### 3.1.2 Development of orthogonal design:

Dr.Genichi Taguchi suggested the use of orthogonal array (OAS) for designing the experiments. He has also developed the concept of linear graph which simplifies the design of orthogonal array (OA) experiments. These designs can be applied by engineers/ scientists without acquiring advanced statistical knowledge. The main advantage of these design lies in there simplicity. Easy adaptability to more compels experiments involving number factors with different number of levels. They provide the desired information with the least possible number trails. These methods are usually employed to study main effects and applied in screening of experiments.

This method follows a step by step procedure to attain the required quality for manufactured goods. The following 8 steps gives the detailed procedure for the Taguchi methods.

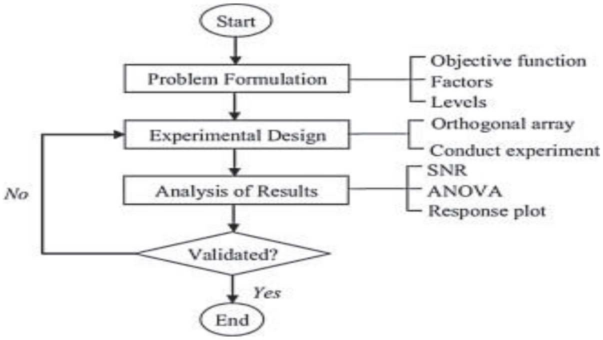


Figure 3.1 Steps involved in Taguchi Process

### 3.1.3 Steps involved:

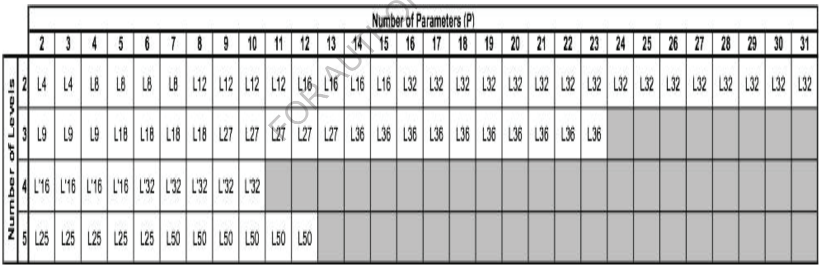
**Step1**: Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example it may be maximizing material removal rate or minimizing surface roughness. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

**Step2**: Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measures that can be easily controlled. The number of levels that the parameter should be varied at must be specified.

**Step3**: Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.

To define an orthogonal array, one must identify:

1. Number of factors to be studied
2. Levels for each factor
3. The specific 2-factor interactions to be estimated
4. The special difficulties that would be encountered in running the experiment



| | | Number of Parameters (P) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Number of Levels | 2 | L4 | L4 | L8 | L8 | L8 | L8 | L12 | L12 | L12 | L12 | L16 | L16 | L16 | L16 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 |
| | 3 | L9 | L9 | L9 | L18 | L18 | L18 | L18 | L27 | L27 | L27 | L27 | L27 | L36 | L36 | L36 | L36 | L36 | L36 | L36 | L36 | L36 | L36 | | | | | | | | |
| | 4 | L'16 | L'16 | L'16 | L'16 | L'32 | L'32 | L'32 | L'32 | L'32 | | | | | | | | | | | | | | | | | | | | | |
| | 5 | L25 | L25 | L25 | L25 | L25 | L50 | L50 | L50 | L50 | L50 | L50 | | | | | | | | | | | | | | | | | | | |

Table 3.1 Array selector table

**Step4**: Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

For example, considering L9 orthogonal array

| Experiment | Parameter1 | Parameter2 | Parameter3 |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |

|  |  |  |  |
|---|---|---|---|
| 9 | 3 | 3 | 2 |

Table 3.2 L9 Orthogonal array table

**Step 5**: **Signal to noise ratio:**

Signal-to-noise ratio is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal).Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. Depending upon the type of response, the following three types of S/N ratios are employed in practice.

### a. Larger-the-better-type

Here the quality characteristic is continuous and non-negative. The ideal value would like to be as large as possible. It does not have any adjustment factor. Example of this type is the mechanical strength of a wire per unit cross-section area, the miles driven per gallon of fuel for an automobile carrying a certain amount of load. This problem can be transformed into smaller the better type problem by considering the reciprocal of the quality characteristic.

$$\eta = -10 \log_{10} [(1/n) \sum_{i=1}^{n} (1/y_i^2)] \qquad ..3.1.1$$

where,

n : no. of tests in the trial (no. of repetitions regardless of noise levels)

$y_i$ : is the $i^{th}$ observation of the quality characteristic

### b. Smaller-the-better-type

Here the quality characteristic is continuous and non-negative that is it can take any value from 0 to α. Its most desired value is zero. Examples of this type are the surface defect count, pollution from a power plant, electromagnetic radiation from telecommunication systems and corrosion of metals.

$$\eta = -10 \log_{10} [(1/n) \sum_{i=1}^{n} y_i^2 ] \qquad ..3.1.2$$

where

n : no. of tests in the trial (no. of repetitions regardless of noise levels)

$y_i$ : is the $i^{th}$ observation of the quality characteristic

### c. Nominal-the-best-type

In this type the quality characteristic is continuous and non-negative and it can take any value from 0 to ∞, but its target value is non-zero and finite. For this type of problems when the mean becomes zero the variances also become zero. This type of problems occurs frequently in engineering designs. Then find the scaling factor that can serve as an adjustment factor to the mean and target. Example for this type is to achieve target thickness on the surface.

$$\eta = -10 \log_{10} (\mu^2 / \sigma^2) \qquad ..3.1.3$$

$$\mu = (1/n) \sum_{i=1}^{n} y_i \quad \text{and}$$

$$\sigma^2 = (1/n-1) \sum_{i=1}^{n} (y_i - \mu)^2$$

**Step 6: Analysis of variance**

Analysis is carried out through ANOVA-F Test which includes

(a) Consider the average of output value for better result.

(b) Perform ANOVA test

| Source of variation | Sum of squares | Degrees of freedom | Mean square | $F_o$ | $F_{tab}$ | C(%) | Rank |
|---|---|---|---|---|---|---|---|
| P1<br>P2<br>:<br>:<br>Pn | $\sum_{i=n}^{n} y_i{}^2 - \text{CF}$<br>(for each) | (k-1) | $\frac{SS_i}{DOF}$ | $\frac{M.S}{Error\ value}$ | $F_{0.05,N,K}$ | $\frac{SS}{Total} * 100$ | Ranking is done in descending order |
| Error | $SS_T - \sum SS_{i=1..n}$ | N-k | | | | | |
| Total | $\sum SS_i$ | N | | | | | |

Table 3.3 ANOVA table for Taguchi

## VARIOUS FORMULAE IN ANOVA

- **Degrees of freedom:** Indicates the number of independent elements in the sum of squares. The degrees of freedom for each component of the model are:

  DF (Factor) = K-1 ..3.1.4

  DF (Error) = N – K ..3.1.5

  Total = N – 1 ..3.1.6

  Where N = the total number of observations and

  K = the number of factor levels.

- **Sum of squares (SS):** SS Total is the total variation in the data. SS (Factor)is the deviation of the estimated factor level mean around the overall mean. It is also known as the sum of squares between treatments. SS Error is the deviation of an observation from its corresponding factor level mean. It is also known as error within treatments. The calculations are:

$$\text{SS(FACTOR)} = \sum_{i=n}^{n} y_i{}^2 - \text{CF} \quad ..3.1.7$$

$$\text{SS(ERROR)} = SS_T - \sum SS_{i=1..n} \quad ..3.1.8$$

$$\text{SS(TOTAL)} = \sum SS_i \quad ..3.1.9$$

Where yi.= mean of the observations at the ith factor level,
CF = mean of all observations

- **Mean square (MS):** The calculations for the mean square for the factor and error are:

  MS (Factor) = SS (Factor)/ DF (Factor) ..3.1.10

  MS (Error) = SS (Error)/ DF (Error) ..3.1.11

- **F Value:** A test to determine whether the factor means are equal or not. The formula is:

  F = MS (Factor)/ MS (Error) ..3.1.12

  The degrees of freedom for the numerator are k - 1 and for the denominator are N-K Larger values of F support rejecting the null hypothesis that the means are equal.

Finally F tabulated value and F calculated values are checked, If F calculated is greater than F tabulated than the assumed parameters are in optimal condition for the assumed process.

## 3.2 Response surface methodology:

### 3.2.1 Response surface method:

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables. In RSM a sequential experimental strategy is followed. This involves two types of experiments such as the

1) First order experiment and
2) Second order experiment

**First order equation:**

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots + \beta_k X_k + e \qquad ..3.2.1$$

**Second order equation is:**

$$Y = \beta_0 + \sum^{k}_{i=1} \beta_i X_i + \sum^{k}_{i=1} \beta_{ii} X_i^2 + \sum\sum_{i<j} \beta_{ij} X_i X_j + e \qquad ..3.2.2$$

The method of least squares is used to estimate the parameters. The objective of response surface methodology is to determine the optimum operating conditions. This analysis is generally performed using computer software.

The parameters can be estimated effectively if proper experimental designs are used to collect the data. Such designs are called response surface designs. Some of the effective designs used in second order experiment are the central composite design (CCD) and Box-Behnken design. The number of experimental trails N, needed to be at least equal to the number of terms of the equations of the model:

$$N \geq C^{k}_{k+2} = \frac{(k+2)!}{k!2!} = \frac{(k+1)(k+2)}{2} \qquad ..3.2.3$$

$$N = n_F + 2k + 1$$

$k$ = number of factors
$n_F$ = number of factorial points
$2k$ = number of star points
$\frac{(k+1)(k+2)}{2}$ = smallest number of points required for second order model to be estimated.

**Standard deviation:**

Standared deviation ($\alpha$) makes the design rotatable. The value of $\alpha$ is selected between 1 and $\sqrt{k}$ and it is found out by:

$$\alpha = (n_F)^{1/4} \qquad ..3.2.4$$

By selecting the $\alpha$ value the design provides good predictions throughout the region of interest.

### 3.2.2 Analysis of first-order design:

Let us consider $2^3$ factorial design to describe the general approach, where the three factors are A, B, C.
The first order model to be fitted is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \qquad ..3.2.5$$

$X_1, X_2, X_3$ are the coded variables with -1 and +1 as the low and high levels of factors A,B,C respectively.

The relation between the coded and the natural variables is given by

$$X = \frac{V-(h+l)/2}{(h-l)/2} \qquad ..3.2.6$$

V = natural variable
h = value of high level of the factor
*l* = value of low level of the factor

Data for fitting first order model:

| Run | $X_0$ | $X_1$ | $X_2$ | $X_3$ | Y |
|---|---|---|---|---|---|
| (1) | 1 | -1 | -1 | -1 | $Y_1$ |
| A | 1 | 1 | -1 | -1 | $Y_2$ |
| B | 1 | -1 | 1 | -1 | $Y_3$ |
| AB | 1 | 1 | 1 | -1 | $Y_4$ |
| C | 1 | -1 | -1 | 1 | $Y_5$ |
| AC | 1 | 1 | -1 | 1 | $Y_6$ |
| BC | 1 | -1 | 1 | 1 | $Y_7$ |
| ABC | 1 | 1 | 1 | 1 | $Y_8$ |

Table 3.4 Data fitting for first order

Obtain sum of the each column with response Y.

$$0Y = \sum X_0 Y$$
$$C_A = 1Y = \sum X_1 Y$$
$$C_B = 2Y = \sum X_2 Y$$
$$C_C = 3Y = \sum X_3 Y$$

The regression coefficients can be estimated as follows:

$$\beta_0 = \frac{0Y}{N} \qquad ..3.2.7$$

$$\beta_m = \frac{1}{2}\frac{C_A}{n2^{k-1}} \qquad ..3.2.8$$

where, m = 1,2,3

Finally the regression equation is obtained and then the ANOVA-F test is conducted which is explained further.

### 3.2.3 Analysis of second-order design:

The general form of a second-order polynomial with three variables is:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3$ ..3.2.9

$X_1, X_2, X_3$ are the coded variables with -1 and +1 as the low and high levels of factors A,B,C respectively.

The relation between the coded and the natural variables is given by

$$X = \frac{\mu - (h+l)/2}{(h-l)/2} \qquad ..3.2.10$$

μ = natural variable
h = value of high level of the factor
l = value of low level of the factor

Standard deviation for this model:

$$\sqrt[4]{2^k} = \sqrt[4]{2^3} = 1.682$$

### 3.2.4 Fitting the model:

**Step 1:** To the CCD add column $X_0$ to the left and $X_1^2, X_2^2, X_3^2, X_1X_2, X_1X_3, X_2X_3$, Y(response)to the right hand side.

**Step 2:** Obtain sum of product of each column with Y.

$0Y = \sum X_0 Y$
$1Y = \sum X_1 Y$
$2Y = \sum X_2 Y$
$3Y = \sum X_3 Y$
$11Y = \sum X_1^2 Y$
$22Y = \sum X_2^2 Y$
$33Y = \sum X_3^2 Y$
$12Y = \sum X_1 X_2 Y$
$13Y = \sum X_1 X_3 Y$
$23Y = \sum X_2 X_3 Y$

Data for fitting second order model:

| $X_0$ | $X_1$ | $X_2$ | $X_3$ | $X_1^2$ | $X_2^2$ | $X_3^2$ | $X_1X_2$ | $X_1X_3$ | $X_2X_3$ | Y |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 | $Y_1$ |
| 1 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 | $Y_2$ |
| 1 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | $Y_3$ |
| 1 | 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 | $Y_4$ |
| 1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | $Y_5$ |
| 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | 1 | -1 | $Y_6$ |
| 1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 1 | $Y_7$ |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | $Y_8$ |
| 1 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 0 | $Y_9$ |
| 1 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 0 | $Y_{10}$ |
| 1 | 0 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | $Y_{11}$ |
| 1 | 0 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | $Y_{12}$ |
| 1 | 0 | 0 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | $Y_{13}$ |
| 1 | 0 | 0 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | $Y_{14}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{15}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{16}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{17}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{18}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{19}$ |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $Y_{20}$ |

Table 3.5 data fitting table for second order

**Step 3:** Obtaining regression coefficients

The regression coefficients are obtained by using the design expert software by giving the units of the input and output parameters also the surface roughness values. The regression equation is obtained.

**Step 4:** Finally conducting ANOVA-F test.

Analysis of variance (ANOVA) is a method for decomposing variance in a measured out-come in to variance that can be explained, such as by a regression model or an experimental treatment assignment, and variance which cannot be explained, which is often attribute able to random error. Using this decomposition into component sums of squares, certain test statistics can be calculated that can be used to describe the data or even justify model selection. There will first be a discussion of how to decompose the variance into explained and unexplained components under both a regression and experimental context, followed by a discussion of how to use analysis of variance to explore and justify regression model selection.

In the familiar regression context, the “sum of squares" can be decomposed as follows, noting that $Y_i$ is individual i's outcome, $\bar{Y}$is the mean of the outcomes, $\hat{Y}_i$ is individuali's fitted value based on the OLS estimates, and $e_i$ is the resulting residual:

$$\sum_{i=1}^{N}(Y_i - \bar{Y})^2 = \sum_{i=1}^{N}(\hat{Y}i - \bar{Y})^2 + \sum_{i=1}^{N} e_i^2 \qquad ..3.2.11$$

Where $SS_{total} = \sum_{i=1}^{N}(Y_i - \bar{Y})^2$ is the total sum of squares.

$SS_{regression} = \sum_{i=1}^{N}(\hat{Y}i - \bar{Y})^2$ refers to the variance explained by the regression, and

$SS_{error} = \sum_{i=1}^{N} e_i^2$ is the variance due to the error term, also known as the unexplained variance. Commonly, we would write this decomposition as:

$$SS_{total} = SS_{regression} + SS_{error} \quad ..3.2.12$$

The equations above show how the total variance in the observations can be decomposed into that variance which can be explained by the regression equation and that variance which can be attributed to the random error term in the regression model.

Typically, using the above decompositions, an analysis of variance table is constructed.
In the regression context, where p is defined as the number of independent repressor and is the number of observations, the ANOVA table typically looks like:

| Source | Df | SS | MS | F |
|---|---|---|---|---|
| Regression | P | $SS_{regression}$ | $SS_{regression}/p$ | $\frac{SS_{regression}/p}{SS_{total}/n-1}$ |
| Error | n-p-1 | $SS_{error}$ | $SS_{error}/n-p-1$ | |
| Total | n-1 | $SS_{total}$ | | |

Table 3.6 ANOVA table for RSM

df = degrees of freedom
SS = sum of squares
MS = mean squared error

The above table also contains a column called F which refers to the F-test. F-test is a way of using the analysis of variance to determine if all of the regressors in a regression equation are jointly zero. In a one-way experimental analysis, the F-test determines if the means of the treatment groups are significantly different. If we have more than one treatment and one control group, then the F-test is a test to see if any treatments are significantly different from zero. The null for an F-test is that all coefficients in our model are jointly not statistically distinguishable from 0. The F-test is defined as:

$$F = \frac{explained\ variance}{unexplained\ variance} \quad ..3.2.13$$

$$= \frac{SS_{regression}/p}{SS_{error}/\mathrm{n-p-1}}$$

Finally the F- value of regression and the lack of fit is compared. If the F-value of lack of fit is lower the F-value of regression then the developed second-order RSM model is adequate at 99% confidence level.

# CHAPTER 4

# OPTIMIZATION THROUGH TAGUCHI APPROACH

## 4.0 Taguchi method

A Taguchi design requires only a fraction of full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all factors, so the effect of one factor does not influence the estimation of another factor in robust parameter design.

## 4.1Selection of process parameters

In parameter design we first choose control factors and their levels. According to assumed data there are three factors and three levels for each.

| Control factors | Units | Level1 | Level2 | Level3 |
|---|---|---|---|---|
| Cut speed | mm/min | 1500 | 2000 | 2500 |
| Stand-off distance | Mm | 2.5 | 3 | 3.5 |
| voltage | Volts | 120 | 125 | 130 |

Table 4.1 Parameters and levels

## 4.2 Selection of orthogonal array

Experiments were designed by the Taguchi method using an L9 orthogonal array that was composed of three columns and 9 rows. This design was selected based on three machining parameters with three levels each. The selected machining parameters for this study are: Cut-speed, Stand-off distance, voltage

| Experiment no. | Cutting speed (mm/min) | Stand-off distance (mm) | Voltage (volts) |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

Table 4.2 Experimental lay out with coded values

## 4.3 Conducting the matrix experiment:

### 4.3.1 Experimentation:

Now experimentation is carried out according to L9 orthogonal array on plasma arc cutting machine with each set of parameters according to assumed dimensions $30*30\ mm^2$ for thickness of 8mm mild steel plate.

Figure 4.1 work piece after machining

### 4.3.2 Surface roughness calculation:

After this machining process the work pieces are collected and their out parameter surface roughness is calculated. The surface roughness analysis was carried out using Mitutoyo SJ-201 machine in the area of the machining surface to observe the irregularities of the surface based on the applied parameters. The surface is assumed rough when the deviations of a real surface from its ideal form are large and vice versa.

Figure 4.2 Surface roughness Tester (Mitutoyo SJ-201)

The surface roughness is calculated for 3 positions on machined surface to obtain better results for calculation and then S/N ratio is calculated.

| Experiment no. | Cut-speed | Stand-off distance | voltage | Measured surface roughness | | |
|---|---|---|---|---|---|---|
| **units** | **(mm/min)** | **(mm)** | **(volts)** | **Ra1** | **Ra2** | **Ra3** |
| 1 | 1500 | 2.5 | 120 | 2.92 | 2.11 | 2.89 |
| 2 | 1500 | 3 | 125 | 2.38 | 2.84 | 2.28 |
| 3 | 1500 | 3.5 | 130 | 3.14 | 3.84 | 3.43 |
| 4 | 2000 | 2.5 | 125 | 3.73 | 3.91 | 4.03 |
| 5 | 2000 | 3 | 130 | 5.12 | 4.84 | 4.97 |
| 6 | 2000 | 3.5 | 120 | 3.86 | 3.94 | 5.21 |
| 7 | 2500 | 2.5 | 130 | 2.96 | 2.82 | 3.18 |
| 8 | 2500 | 3 | 120 | 5.12 | 3.86 | 3.62 |
| 9 | 2500 | 3.5 | 125 | 3.12 | 4.73 | 3.92 |

Table 4.3 Surface roughness values

## 4.4: Signal-to-Noise ratio (S/N Ratio)

S/N ratio(η) is calculated by considering smaller the better value.

$$\eta = -10 \log_{10} [(1/n) \sum_{i=1}^{n} y_i^2 ] \qquad ..4.1$$

- $\eta_1$=-10log[$\frac{1}{3}$($2.92^2 + 2.71^2 + 2.89^2$)] =-8.1903

The S/N values for remaining experiments are calculated similarly,

| Exp no. | Measured surface roughness | | | S/N ratio |
|---|---|---|---|---|
| **Units** | **Ra1** | **Ra2** | **Ra3** | |
| 1 | 2.92 | 2.11 | 2.89 | -8.1903 |
| 2 | 2.38 | 2.84 | 2.28 | -7.999 |

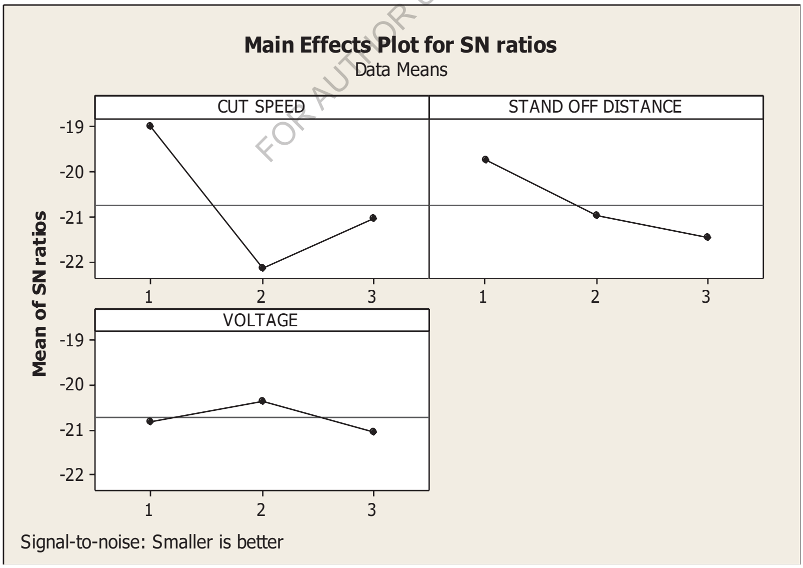
| | | | | |
|---|---|---|---|---|
| 3 | 3.14 | 3.84 | 3.43 | -10.836 |
| 4 | 3.73 | 3.91 | 4.03 | -11.803 |
| 5 | 5.12 | 4.84 | 4.97 | -13.94 |
| 6 | 3.86 | 3.94 | 5.21 | -12.83 |
| 7 | 2.96 | 2.82 | 3.18 | -9.514 |
| 8 | 5.12 | 3.86 | 3.62 | -12.57 |
| 9 | 3.12 | 4.73 | 3.92 | -11.993 |

Table 4.4 S/N ratio values

## 4.5 Experimental results for surface roughness

After experimental results have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis is done by MINITAB, shows interactions of all parameters.

By using Minitab software we acquire graphs which shows that cut speed has the main effect on surface roughness and decreases with increase in the Cutting Speed and Arc Gap.



Graph 4.1: Main effects versus S/N ratio of surface roughness.

## 4.6 Analysis of variance:

Then ANOVA of the experimental data has been done to calculate the contribution of each factor in each response. Then we calculated S/N ratio for surface roughness of specimens. Then we obtain optimal conditions has been calculated surface roughness of specimen. The following table shows readings of surface roughness at each experiment, it also shows S/N ratio for surface roughness at each experiments.

Analysis of variance helps us to identify which parameter is important for us after literature review following ANOVA table is obtained for Surface roughness.

The procedure for construction of ANOVA is described as below.

1) The S/N value calculated for each experiment

- $S/N_1$= -10 log $[\frac{1}{3}(2.92^2 + 2.71^2 + 2.89^2)]$ = -8.1903 ..4.2

The remaining S/N values for each experiments are calculate similarly

2) The sum of S/N values for experimental average:

- $S/N_{total}$=[8.1903+7.999+10.836+11.803+13.94+12.83+9.514+12.57+11.993]
  =99.6753 ..4.3

3) Calculation of correction factor

- $C.F = \frac{T^2}{N} = \frac{99.675^2}{9}$ =1103.907 ..4.4

4) The total sum of squares:

- $SS_{Total} = \sum_{i=1}^{n} y_i^2 - C.F$

$$= [(8.1903^2 + 7.999^2 + 10.836^2 + 11.803^2 + 13.94^2 + 12.83^2 + 9.514^2 + 12.57^2 + 11.993^2) - 1103.997]$$

= [1137.573-1103.997]

=33.576 ..4.5

5) The total sum of squares due to factors:

The sum of squares of factors involves the squaring the sum of individual factors according to their levels. The response average table is given below for factors with their levels.

| LEVELS | Cut-Speed (mm/min) | Stand-off distance (mm) | Voltage (volts) |
|---|---|---|---|
| 1 | Y1+Y2+Y3 | Y1+Y4+Y7 | Y1+Y6+Y8 |
| 2 | Y4+Y5+Y6 | Y2+Y5+Y8 | Y2+Y4+Y9 |
| 3 | Y7+Y8+Y9 | Y3+Y6+Y9 | Y3+Y5+Y7 |

Table 4.5 Average response table for factors

From above data the average response table :

| Factors/ Levels | Cut-speed (mm/min) | Stand-off distance (mm) | Voltage(volts) |
|---|---|---|---|
| 1 | 8.1903+7.999+10.836 | 8.1903+11.803+9.514 | 8.1903+12.83+12.57 |
| 2 | 11.803+13.94+12.83 | 7.999+13.94+12.57 | 7.999+11.803+11.993 |
| 3 | 9.514+12.57+11.993 | 10.836+12.83+11.993 | 10.836+13.94+9.514 |

Table 4.6 Values for average responses for factors

- $SS_A = [\frac{1}{n}\sum_{i=1}^{n} A_i^2] = [\frac{1}{3}(27.0253^2 + 38.573^2 + 34.077^2)] = 22.49$ ..4.6
- $SS_B = [\frac{1}{n}\sum_{i=1}^{n} B_i^2] = [\frac{1}{3}(29.5073^2 + 34.509^2 + 35.659^2)] = 7.04$ ..4.7
- $SS_C = [\frac{1}{n}\sum_{i=1}^{n} C_i^2] = [\frac{1}{3}(33.5903^2 + 31.795^2 + 34.29^2)] = 1.0144$ ..4.8

6) Sum of squares due to error:

- $SS_e = SS_{Total} - (SS_A + SS_B + SS_C)$ ..4.9
- $SS_e = 33.576 - (22.49 + 7.04 + 1.0144) = 3.03154$

7) Mean of Sum of Squares:

- $M.SS_A = \frac{SS_A}{D.f} = \frac{22.49}{2} = 11.245$ ..4.10
- $M.SS_B = \frac{SS_B}{D.f} = \frac{7.04}{2} = 3.52$ ..4.11
- $M.SS_C = \frac{SS_C}{D.f} = \frac{1.0144}{2} = 0.5072$ ..4.12
- $M.SS_e = \frac{SS_e}{D.f} = \frac{3.03154}{6} = 0.5052$ ..4.13

8) Calculation of F-value (data):

- For Factor A = F $_{A(Calculated)}$ = $\frac{MSS_A}{MSS_e}$ = $\frac{11.245}{0.5052}$ =22.25 ..4.14

- For Factor B = F $_{B(Calculated)}$ = $\frac{MSS_B}{MSS_e}$ = $\frac{6.9675}{0.5052}$ =6.9675 ..4.15

- For Factor C = F $_{C(Calculated)}$ = $\frac{MSS_C}{MSS_e}$ = $\frac{0.5072}{0.5052}$ =1.003 ..4.16

9) The F-ratio Test:

Comparing the values of F-ratio, the calculated F$_{calculated}$ greater than the tabulated F-value. F-tabulated remains the same for all three parameters, according to F-Distribution with 95% confidence interval with 9 experiments.

- F-Tabulated value = 5.12

10) Calculation of percent of contribution:

In order to calculate the percent contribution of the various sources in an analysis of variants, calculate the pure sum of squares and divide by the total sum of squares.

- For Factor A: $C_{Cut-Speed} = \frac{SS_A}{SS_{Total}} * 100 = \frac{22.49}{33.576} * 100 = 66.982\%$ ..4.17

- For Factor B: $C_{Stand-off\ distance} = \frac{SS_B}{SS_{Total}} * 100 = \frac{7.04}{33.576} * 100 = 20.96$ ..4.18

- For Factor C: $C_{Voltage} = \frac{SS_C}{SS_{Total}} * 100 = \frac{1.0144}{33.576} * 100 = 3.0212\%$ ..4.19

All the above results are shown in the following table.

**Analysis of variance**

| Factors | SS | df | MS | F | F-tabulated | Contribution (%) |
|---|---|---|---|---|---|---|
| Cut speed | 22.49 | 2 | 11.245 | 22.25 | 5.14 | 66.982 % (1) |
| Stand-off distance | 7.04 | 2 | 3.52 | 6.9675 | 5.14 | 20.96 % (2) |
| Voltage | 1.0144 | 2 | 0.5072 | 1.003 | 5.14 | 3.0212 % (3) |
| Error | 3.031 | 6 | 0.5052 | | | 9.037 % |
| Total | 33.576 | 8 | | | | 100 % |

Table 4.7 ANOVA table for Taguchi

The Optimum levels of parameters for **Minimizing Surface roughness** observed from experimental results are A1B1C2 i.e.,
Cut-speed: 1500 mm/min Bar

Stan-off distance: 2.5 mm

Voltage: 125 volts

Above table shows that cut-speed has main effect on machining process which possess about 66.98% , Stand-off distance possess 20.96%and voltage possess about 3.02 %.

# CHAPTER 5
# ANALYSIS THROUGH RESPONSE SURFACE METHODOLOGY

## 5.0 Response Surface Methodology:

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which responses are influenced by several variables and the goal is to find the correlation between the response and the variables by assuming CCD (central composite Design) scheme.

The mathematical model is then developed that illustrate the relationship between the process variable and response. The behavior of the system is explained by the following empirical

$$Y = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + \sum_{i=1}^{K} \beta_{ii} X_{ii}^2 + \sum_{i=1}^{K-1} \sum_{j=2}^{K} \beta_{ij} X_i X_j \qquad ..5.1$$

## 5.1Selection of Process Parameters:

The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. The Cut-speed, Stand-off distance, Voltage are assumed as machining variables, selected for our investigation.

We select $\alpha$ value for three parameters and three levels as,

$$\alpha = \sqrt[4]{2^3} \qquad ..5.2$$

$$\alpha = 1.682$$

| Parameter/coded value | -1.682 | -1 | 0 | 1 | 1.682 |
|---|---|---|---|---|---|
| Cut speed(mm/min) | 1500 | 1700 | 2000 | 2300 | 2500 |
| Stand-off distance (mm) | 2.5 | 2.7 | 3 | 3.3 | 3.5 |
| Voltage(volts) | 120 | 122 | 125 | 128 | 130 |

Table 5.1 Parameters and their levels

## 5.2 Design of Experiments:

As there are three parameters with five levels. The matrix experiment table with generated coded values are shown in below table.

| EXP NO. | CUT SPEED (mm/min) | STAND-OFF DISTANCE (mm) | VOLTAGE (volts) |
|---|---|---|---|
| 1 | -1 | -1 | -1 |
| 2 | 1 | -1 | -1 |
| 3 | -1 | 1 | -1 |
| 4 | 1 | 1 | -1 |
| 5 | -1 | -1 | 1 |
| 6 | 1 | -1 | 1 |
| 7 | -1 | 1 | 1 |
| 8 | 1 | 1 | 1 |
| 9 | -1.68 | 0 | 0 |
| 10 | +1.68 | 0 | 0 |
| 11 | 0 | -1.68 | 0 |
| 12 | 0 | +1.68 | 0 |
| 13 | 0 | 0 | -1.68 |
| 14 | 0 | 0 | +1.68 |
| 15 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 |

Table 5.2 Coded values for factors

## 5.3 Conducting Experimentation:

### 5.3.1 Experimentation:

In the next step, the experimentation is carried out with each set of parameters by plasma arc machining source for mild steel plate of 8mm thickness to cut with dimensions 30*30 $mm^2$. A total of 20 experiments are conducted as assumed through given data.Theplanning to accomplish the experiments by means of response surface methodology (RSM) using a Central Composite Design (CCD) with three variables, eight cube points, four central points, six axial points and two centre point in axial, in total 20 runs.

Figure 5.1 Work-piece after experimentation

For conducting experiment, the coded values are converted into natural variables, using following relation.

$$X_i = \frac{\xi-(A_H+A_L)/2}{(A_H-A_L)/2} \quad ..5.3$$

Where,

$\xi$=natural variable

$A_H$=value of high level of factor A

$A_L$=value of low level of factor A

### 5.3.2 Surface Roughness Calculation:

Figure 5.2 Surface roughness Tester

The calculation of surface roughness is carried through Mitutoyo SJ-201 series in the area of the machining surface to observe the irregularities of the surface based on the applied parameters. The surface is assumed rough when the deviations of a real surface from its ideal form are large and vice versa.

| EXP NO. | CUT SPEED (mm/min) | TORCH HEIGHT (mm) | VOLTAGE (volts) | SURFACE ROUGHNESS $(\mu m)$ |
|---|---|---|---|---|
| 1 | 1700 | 2.7 | 122 | 4.11 |
| 2 | 2300 | 2.7 | 122 | 4.31 |
| 3 | 1700 | 3.3 | 122 | 6.11 |
| 4 | 2300 | 3.3 | 122 | 5.47 |
| 5 | 1700 | 2.7 | 128 | 3.58 |
| 6 | 2300 | 2.7 | 128 | 4.93 |
| 7 | 1700 | 3.3 | 128 | 5.11 |
| 8 | 2300 | 3.3 | 128 | 4.97 |
| 9 | 1500 | 3 | 125 | 4.85 |
| 10 | 2500 | 3 | 125 | 4.76 |
| 11 | 2000 | 2.5 | 125 | 3.01 |
| 12 | 2000 | 3.5 | 125 | 4.79 |
| 13 | 2000 | 3 | 120 | 4.00 |
| 14 | 2000 | 3 | 130 | 2.92 |
| 15 | 2000 | 3 | 125 | 2.10 |
| 16 | 2000 | 3 | 125 | 3.01 |
| 17 | 2000 | 3 | 125 | 2.96 |
| 18 | 2000 | 3 | 125 | 3.00 |

| | | | | |
|---|---|---|---|---|
| 19 | 2000 | 3 | 125 | 2.93 |
| 20 | 2000 | 3 | 125 | 3.08 |

Table 5.3 surface roughness for input values

The surface roughness obtained by assuming each set of parameters is mentioned in the last column above. We assume these values for generating Regression equation.

## 5.4: Data for CCD

Central composite Design with three factors is given in below table, from this values we use software for solution of these models which will give the fitted model including ANOVA and other related statistics and generate contour and response surface plots.

| $X_O$ | $X_1$ | $X_2$ | $X_3$ | $X_1^2$ | $X_2^2$ | $X_3^2$ | $X_1X_2$ | $X_1X_3$ | $X_2X_3$ | SURFACE ROUGHNESS $(\mu m)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 4.11 |
| 1 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 | 4.31 |
| 1 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | 6.11 |
| 1 | 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 | 5.47 |
| 1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 3.58 |
| 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | 1 | -1 | 4.93 |
| 1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 1 | 5.11 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | 1 | 4.97 |
| 1 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 0 | 4.85 |
| 1 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 0 | 4.76 |
| 1 | 0 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 3.01 |
| 1 | 0 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 0 | 4.79 |
| 1 | 0 | 0 | -1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 4.00 |
| 1 | 0 | 0 | 1.682 | 0 | 0 | 2.828 | 0 | 0 | 0 | 2.92 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.10 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.01 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.96 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.00 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.93 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.08 |

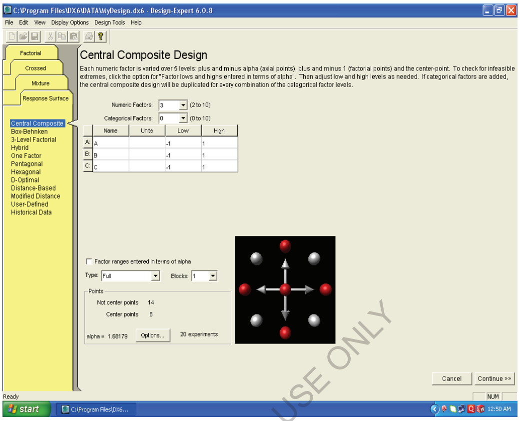
Table 5.4: Data for central composite design with three factors

## 5.5 Use of Software

Steps involved in design expert software:

File→New design→Response surface→Central composite

→Select Numeric factors=3 Click continue



Central Composite Design

Each numeric factor is varied over 5 levels: plus and minus alpha (axial points), plus and minus 1 (factorial points) and the center-point. To check for infeasible extremes, click the option for "Factor lows and highs entered in terms of alpha". Then adjust low and high levels as needed. If categorical factors are added, the central composite design will be duplicated for every combination of the categorical factor levels.

Numeric Factors: 3 (2 to 10)

Categorical Factors: 0 (0 to 10)

|  | Name | Units | Low | High |
|---|---|---|---|---|
| A: | A |  | -1 | 1 |
| B: | B |  | -1 | 1 |
| C: | C |  | -1 | 1 |

☐ Factor ranges entered in terms of alpha

Type: Full Blocks: 1

Points

Not center points 14

Center points 6

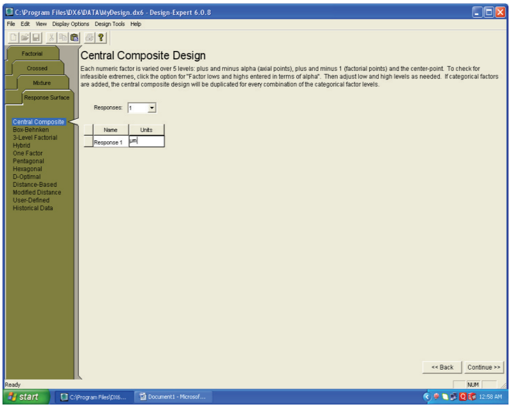
alpha = 1.68179 Options... 20 experiments

Figure 5.3 Three factor level design for CCD

**Step 2: Select Response**

Click on Responses=1

Specify number of Responses



Central Composite Design

Each numeric factor is varied over 5 levels: plus and minus alpha (axial points), plus and minus 1 (factorial points) and the center-point. To check for infeasible extremes, click the option for "Factor lows and highs entered in terms of alpha". Then adjust low and high levels as needed. If categorical factors are added, the central composite design will be duplicated for every combination of the categorical factor levels.

Responses: 1

|  | Name | Units |
|---|---|---|
|  | Response 1 | μm |

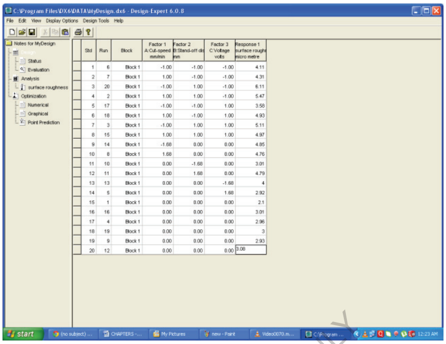
Figure 5.4 Response for CCD

**Step 3:Notes for My Design**

Select Standard order→ Modify it as standard order by right click and select standard order

Select Type→ Modify it as Display point type by right click on Type

Select Factors and Rename them as Factor1: Cut speed(mm/min), Factor2:Stand-off distance(mm), Factor3:voltage(volts), Response: Surface roughness(μm).



| Std | Run | Block | Factor 1 A:Cut-speed mm/min | Factor 2 B:Stand-off dis mm | Factor 3 C:Voltage volts | Response 1 surface rough micro metre |
|---|---|---|---|---|---|---|
| 1 | 6 | Block 1 | -1.00 | -1.00 | -1.00 | 4.11 |
| 2 | 7 | Block 1 | 1.00 | -1.00 | -1.00 | 4.31 |
| 3 | 20 | Block 1 | -1.00 | 1.00 | -1.00 | 6.11 |
| 4 | 2 | Block 1 | 1.00 | 1.00 | -1.00 | 5.47 |
| 5 | 17 | Block 1 | -1.00 | -1.00 | 1.00 | 3.58 |
| 6 | 18 | Block 1 | 1.00 | -1.00 | 1.00 | 4.93 |
| 7 | 3 | Block 1 | -1.00 | 1.00 | 1.00 | 5.11 |
| 8 | 15 | Block 1 | 1.00 | 1.00 | 1.00 | 4.97 |
| 9 | 14 | Block 1 | -1.68 | 0.00 | 0.00 | 4.85 |
| 10 | 8 | Block 1 | 1.68 | 0.00 | 0.00 | 4.76 |
| 11 | 10 | Block 1 | 0.00 | -1.68 | 0.00 | 3.01 |
| 12 | 11 | Block 1 | 0.00 | 1.68 | 0.00 | 4.79 |
| 13 | 13 | Block 1 | 0.00 | 0.00 | -1.68 | 4 |
| 14 | 5 | Block 1 | 0.00 | 0.00 | 1.68 | 2.92 |
| 15 | 1 | Block 1 | 0.00 | 0.00 | 0.00 | 2.1 |
| 16 | 16 | Block 1 | 0.00 | 0.00 | 0.00 | 3.01 |
| 17 | 4 | Block 1 | 0.00 | 0.00 | 0.00 | 2.96 |
| 18 | 19 | Block 1 | 0.00 | 0.00 | 0.00 | 3 |
| 19 | 9 | Block 1 | 0.00 | 0.00 | 0.00 | 2.93 |
| 20 | 12 | Block 1 | 0.00 | 0.00 | 0.00 | 3.08 |

Figure 5.5 Input values for CCD deign

**Step 4: Analysis**

Select Analysis

→Surface roughness→ Fit summary

**a. Sequential model Sum of squares**

| Source | Sum of squares | DF | Mean Square | F Value | Prob>F | |
|---|---|---|---|---|---|---|
| Mean | 326.43 | 1 | 326.43 | | | |
| Linear | 5.16 | 3 | 1.72 | 1.82 | 0.1833 | |
| 2FI | 1.33 | 3 | 0.44 | 0.42 | 0.7411 | |
| Quadratic | 11.96 | 3 | 3.99 | 22.31 | <0.0001 | suggested |
| Cubic | 0.19 | 4 | 0.046 | 0.17 | 0.9441 | Aliased |
| Residual | 1.6 | 6 | 0.27 | | | |
| Total | 346.67 | 20 | 17.33 | | | |

Table 5.5 Sequential model table

**b. Lack of Fit test**

| Source | Sum of squares | DF | Mean Square | F Value | Prob>F | |
|---|---|---|---|---|---|---|
| Linear | 15.06 | 11 | 1.37 | 332.27 | <0.0001 | |
| 2FI | 13.72 | 8 | 1.72 | 416.36 | <0.0001 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Quadratic | 1.77 | 5 | 0.35 | 85.73 | <0.0001 | Suggested |
| Cubic | 1.58 | 1 | 1.58 | 383.69 | <0.0001 | |
| Pure error | 0.021 | 5 | 4.120E-003 | | | |

Table 5.6 Lack of fit table

**c. Model summary Statistics**

| Source | Std.Dev | R-Squared | Adjusted R-Squared | Predicted R-Squared | PRESS | |
|---|---|---|---|---|---|---|
| Linear | 0.97 | 0.2549 | 0.1152 | -0.1346 | 22.96 | |
| 2FI | 1.03 | 0.3209 | 0.0074 | -1.5111 | 50.82 | |
| Quadratic | 0.42 | 0.9117 | 0.8323 | 0.3354 | 13.45 | Suggested |
| Cubic | 0.52 | 0.9209 | 0.7494 | -16.2204 | 348.49 | Aliased |

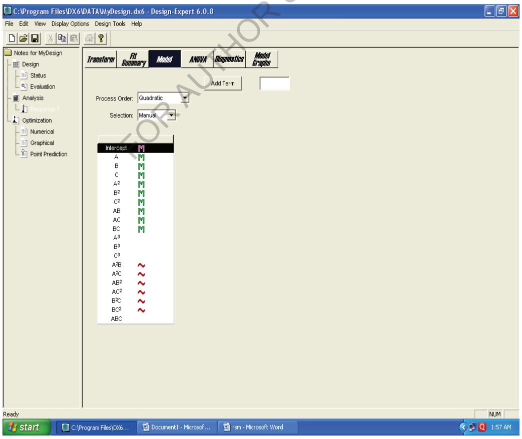
Table 5.6 Model summary table

**Step 5:**

Select Model

→Process order→Quadratic

→Selection: Manual



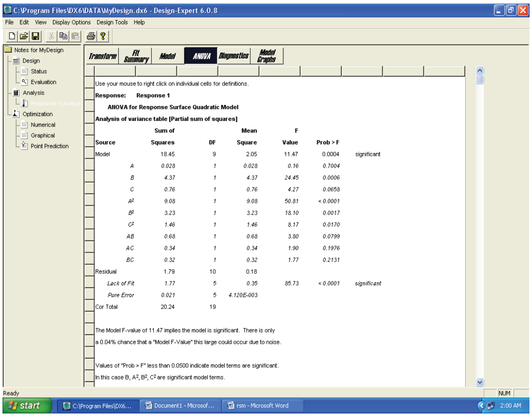
Process Order: Quadratic

Selection: Manual

Figure 5.6 Selection of Quadratic model

**Step 6:** Anova

Select Anova



```
Use your mouse to right click on individual cells for definitions.
Response:     Response 1
     ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares]
                 Sum of               Mean          F
Source          Squares     DF      Square      Value     Prob > F
Model             18.45      9        2.05      11.47       0.0004    significant
           A      0.028      1       0.028       0.16       0.7004
           B       4.37      1        4.37      24.45       0.0006
           C       0.76      1        0.76       4.27       0.0658
          A²       9.08      1        9.08      50.81     < 0.0001
          B²       3.23      1        3.23      18.10       0.0017
          C²       1.46      1        1.46       8.17       0.0170
          AB       0.68      1        0.68       3.80       0.0799
          AC       0.34      1        0.34       1.90       0.1976
          BC       0.32      1        0.32       1.77       0.2131
Residual           1.79     10        0.18
 Lack of Fit       1.77      5        0.35      85.73     < 0.0001    significant
  Pure Error      0.021      5   4.120E-003
Cor Total         20.24     19

The Model F-value of 11.47 implies the model is significant.  There is only
a 0.04% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.
In this case B, A², B², C² are significant model terms.
```

Figure 5.7 ANOVA-F test

## 5.6 Regression equation:

**The regression equation generated from above values is:**

$R_a$=2.95728+0.045299*A+0.56555*B-.23624*C+0.7937*$A^2$+0.47373*$B^2$+0.31817*$C^2$-0.29125*A*B+0.20625*A*C-0.19875*B*C ..5.4

## 5.7 Comparison of Actual values and Regression values

| EXP NO. | ACTUAL VALUE | REGRESSION EQUATION VALUE | ERROR | PERCENTAGE OF ERROR |
|---|---|---|---|---|
| 1 | 4.11 | 3.88 | 0.22 | 5.66 |
| 2 | 3.1 | 4.15 | 0.16 | 3.977 |
| 3 | 6.11 | 4.86 | 1.245 | 25.6 |
| 4 | 5.47 | 5.09 | 0.378 | 7.438 |
| 5 | 3.58 | 3.397 | 0.182 | 5.38 |
| 6 | 4.93 | 4.482 | 0.447 | 9.97 |
| 7 | 5.11 | 4.71 | 0.396 | 8.42 |
| 8 | 4.97 | 4.633 | 0.336 | 7.256 |
| 9 | 4.85 | 5.121 | 0.271 | 5.297 |
| 10 | 4.76 | 5.273 | 0.5135 | 9.73 |
| 11 | 3.01 | 3.344 | 0.334 | 9.99 |
| 12 | 4.79 | 5.244 | 0.4544 | 8.66 |

|  |  |  |  |  |
|---|---|---|---|---|
| 13 | 4 | 4.252 | 0.252 | 5.93 |
| 14 | 2.92 | 3.458 | 0.538 | 15.57 |
| 15 | 2.9 | 2.957 | 0.057 | 1.935 |
| 16 | 3.01 | 2.957 | 0.052 | 1.78 |
| 17 | 2.96 | 2.957 | 0.0027 | 0.272 |
| 18 | 3 | 2.957 | 0.042 | 1.44 |
| 19 | 2.93 | 2.957 | 0.0272 | 0.922 |
| 20 | 3.08 | 2.957 | 0.122 | 4.14 |

Table 5.8 percentage of error

- Calculation of error= Actual value- Regression value ..5.5
- Calculation of percentage of error= (error value/Regression value)* 100 ..5.6

## 5.8 Analysis of variance:

| Source | Sum of squares | D.O.F | Mean Squares | F-value | Prob>F |  |
|---|---|---|---|---|---|---|
| Model | 18.45 | 9 | 2.05 | 11.47 | 0.0004 | *Significant* |
| A | 0.028 | 1 | 0.028 | 0.16 | 0.7004 |  |
| B | 4.37 | 1 | 4.37 | 24.45 | 0.0006 |  |
| C | 0.76 | 1 | 0.76 | 4.27 | 0.0658 |  |
| $A^2$ | 9.08 | 1 | 9.08 | 50.81 | 0.0001 |  |
| $B^2$ | 3.23 | 1 | 3.23 | 18.10 | 0.0017 |  |
| $C^2$ | 1.46 | 1 | 1.46 | 8.17 | 0.017 |  |
| AB | 0.68 | 1 | 0.68 | 3.80 | 0.0799 |  |
| AC | 0.34 | 1 | 0.34 | 1.90 | 0.1976 |  |
| BC | 0.32 | 1 | 0.32 | 1.77 | 0.2131 |  |
| Residual | 1.79 | 10 | 0.18 |  |  |  |
| Lack of fit | 1.77 | 5 | 0.35 | 85.73 | 0.0001 | *Significant* |
| Pure Error | 0.021 | 5 | *4.120E-003* |  |  |  |
| Cor Total | 20.24 | 19 |  |  |  |  |

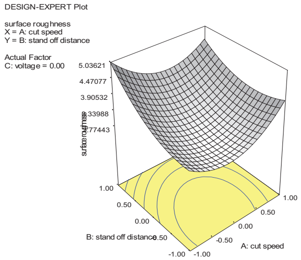
Table 5.9 Analysis of variance

- Mean square= Sum of square/ D.O.F ..5.7
- F-value= Mean Square/Residual error ..5.8

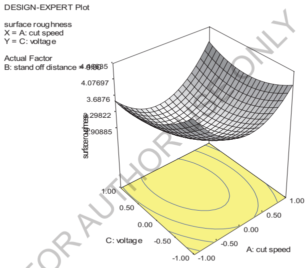
The Model F-value of 11.47 implies the model is significant. There is only a 0.04% chance that a "Model F-Value" this large could occur due to noise.
Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, $A^2$, $B^2$, $C^2$ are significant model terms.

## 5.9 Generated Graphs:

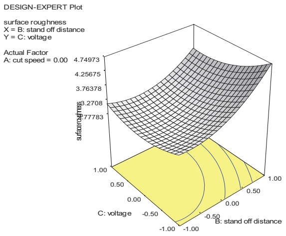
The graphs are generated using Design expert 6.0.8 software by giving the input surface roughness values.



Graph 5.1 Cut-speed on X-axis, Stand-off distance on Y-axis, Surface roughness on Z-axis



Graph 5.2 Cut-speed on X-axis, Voltage on Y-axis, Surface roughness on Z-axis



Graph 5.3 Stand-off distance on X-axis, Voltage on Y-axis, Surface roughness on Z-axis

# CHAPTER 6

# RESULTS AND DISCUSSIONS

In this work Plasma arc machining of Mild Steel is considered for study. For this, parameters like Cut-Speed, Stand-off distance and Voltage are considered as variables and Current, Gas pressure, Plasma gas, Material, thickness of material are considered to be constant. Performance Measure is assumed as Surface roughness. Using Taguchi method, the above considered parameters were optimized and optimal combination is found. ANOVA-F test is used to determine the significance of each parameter for considered performance measure. Further regression equation is generated between parameters by using Response Surface Methodology and ANOVA-F test is done to check significance of model.

As per Taguchi method, each considered parameter is taken for three levels and corresponding orthogonal array L9 is determined. Table 4.2 represents L9 orthogonal array. According to this array, experimentation is carried out and surface roughness is measured for each set three times and S/N values are calculated according to smaller–better value. Table 4.4 represents S/N ratio values. The Graph 4.1 shows the relation between considered parameters to S/N ratios, from the Graph 4.1 it was observed that the optimum parameter combination for Cut-speed with 1500 mm/min, Stand-off distance with 2.5 mm and Voltage with 125 volts gives the optimal value.

ANOVA-F test is been conducted, Table 4.7 represents ANOVA – F test, from this table it was observed that Cut-speed and stand-off distance are significant parameters. The contribution of each parameter as Cut-speed possess 66.98%, Stand-off distance possess 20.96% Voltage possess 3.02% and experimentation error is 9.03% which is in permissible limit.

Regression equation developed between parameters for surface roughness using Response Surface Methodology, Table 5.2 represents experimental coded values for RSM. Equation 5.4 represents the developed regression equation between factors.

ANOVA test is used for analysis. Table 5.9 Represents ANOVA table for response surface methodology, from table F value for the model is greater than F-tabulated value this indicates that the model is significant.

**The effect of parameters on surface roughness**

The effect of various parameters on surface roughness are studied. Figure 4.1 represents the effect of each parameter on surface roughness. The figures show the graph between S/N ratios to parameters. It can be observed that if the S/N value is high at that point minimum surface roughness will be generated. If S/N ratio value is low at that point maximum surface roughness will be generated.

**Effect of Cut-speed:**

The below figure shows the effect of Cut-speed on surface roughness. From level-1 to level-2 as the Cut-speed value is increasing, the surface roughness is increasing, and from level 2 to level 3 further increasing Cut-speed, the surface roughness is decreasing, by observing the graph, level-1 gives the minimum surface roughness and it also shows that increase in Cut-speed results in increase of surface roughness.

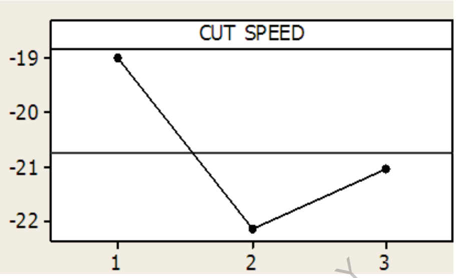


Figure 6.1 Effect of Cut-speed on Surface roughness

**Effect of Stand-off distance:**

The below figure shows the effect of Stand-off distance on surface roughness. From the level-1 to level-3, as the Stand-off distance is increasing, the surface roughness value is increasing. It results that minimum Stand-off distance gives minimum surface roughness value.

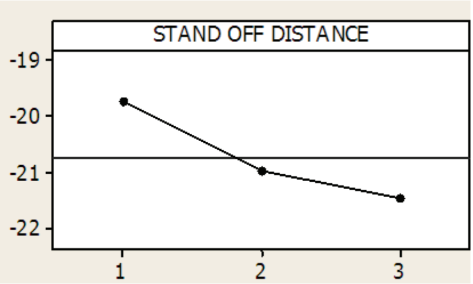


Figure 6.2 Effect of Stand-off distance on Surface roughness

**Effect of Voltage:**

The below figure shows the effect of voltage on surface roughness. From level-1 to level-3 as the voltage is increased the surface roughness value is not varying. It shows that the Voltage has very less effect on surface roughness and also from ANOVA test it was found that the contribution percentage of voltage is very low. So the surface roughness will not be affected with voltage in considerable amount.

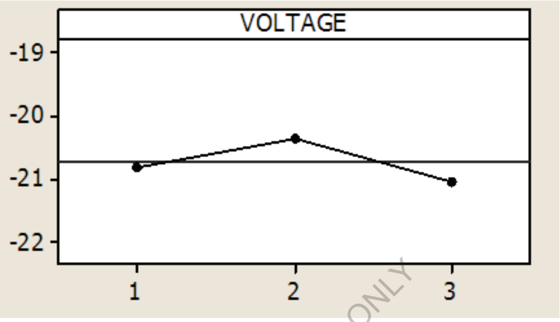


Figure 6.3 Effect of Voltage on Surface roughness

# CHAPTER 7

# CONCLUSION

In this Thesis through Taguchi approach the optimal value for the parameters Cut-speed, Stand-off distance and Voltage for minimum surface roughness are found,

Cut-speed= 1500 mm/min

Stand-off distance= 2.5 mm

Voltage= 125 volts

Cut-speed and Stand-off distance has major impact and Voltage has minor impact on surface roughness. By performing ANOVA-F test the significance of Parameters are found as Cut-speed with 66.98% , Stand-off distance has 20.96% and Voltage has least with 3.02%.

The regression equation generated between parameters Cut-speed, Stand-off distance and Voltage by Reponse Surface Methodology. Error analysis and ANOVA-F test confirms the accuracy of the equation.

# CHAPTER 8

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