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# THE EFFECT OF PLASMA ARC CUTTING PARAMETERS ON STAINLESS STEEL (304)

A Thesis Submitted in Partial Fulfilment Of The Requirements
For The Degree Of Master in Mechanical Engineering

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# DEDICATION

**I would like to dedicate this small piece of work to my mother, my father's pure soul, my wife, my son, my brother and sisters.**

## ACKNOWLEDGEMENTS

**I give my full thanking and appreciation to doctor (Salem sultan) and all people whom helped me to complete this work.**

## الملخص

في ا لأربعين سنة الماضية كانت هناك عدة بحوت في الآلات والتطور التكنولوجي ومع زيادة التنافس في السوق والانجاز بدقة عالية في هذه الأيام من أهم الطرق الآلية هي الطرق الغير تقليدية حيث أصبحت شريان الحياة لأي صناعة . من أحدى أهم الطرق الآلية هي طريقة القطع بقوس البلازما وذلك لدقتها العالية والوصول إلي نهاية تصنيع دقيقة والقدرة علي تصنيع أي مادة و إنتاج أي شكل معقد ولهذا يزداد الطلب علي هده الطريقة.وفي هذه الأطروحة درست عملية إدخال المتغيرات لآلة البلازما لكي نحصل علي منتج بدقة عالية ومن أجل الوصول إلى هذا الهدف والنتائج الأمثل ثم استخدام طريقة تيقوتشي.واستخدمت طريقة الصفوف المتعامدة لقلة المتغيرات و المستويات المستخدمة لإنجاز أقل عدد من التجارب . ومشغولة العمل المستخدمة هو الحديد المقاوم للصدأ نوع(304) لغرض التجربة فقط . وثم الوصول إلي القيمة الأمثل بمساعدة جدول (الأنوفان) ومعادلة الانحدار لمعدل المادة المزالة (MRR)وخشونة السطح (Ra)وطورت بمساعدة نظام (minitabsoftwear 15) . وثم استعمال متغيرات (6.0) بار ضغط الغاز و(150) أمبير لمعدل تدفق التيار و(500)ملم/الدقيقة سرعة القطع و(3.0)ملم مسافة إلكترود عن المشغولة لتأكيد معدل إزالة المعدن (MRR).وإن مستوي العوامل المثالية لخشونة السطح تكون علي النحو التالي (5.0)بار ضغط الغاز و(175) أمبير معدل تدفق التيار الكهربائي و(600) ملم /الدقيقة سرعة القطع (2.0)ملم مسافة إلكترود عن المشغولة.

النتائج التجريبية استخدمت لتأكيد فاعلية هذا البحث ,بعد التأكد أصبحت قيمة معدل إزالة المعدن (0.1836)جرام لكل ثانية و خشونة السطح (0.34156) ميكرو متر.

**النسبة العالية من الغازات ثنائية الذرة تزيد من عمق الطبقة في العينة B ,A من 5 الي 180ميكرو متر وتخفف من نسبة طبقة الأكسجين الي حوالي 1ملم التي تتشكل دائما علي السطح وهي مسئولة عن اللون المميز للسطح .ولسمك 1.2ملم من الصفيحة حيث تكون سرعة القطع ثابته و يكون تحليل العينة A (H35) و B (%70 N2- %30 H35) و التي توضح كمية الأكسجين علي خطوط سطح القطع حيث يخفف بشكل ملحوظ من غاز القطع N2 المستخدم ومن العوائق و المتمثلة في ذرات النيتروجين الموجودة علي السطح .**

# ABSTRACT

In the last forty years there is tremendous research in machining and development in technology. With increase in competition in market and to attain high accuracy now a days the nonconventional machining are becoming lifeline of any industry. One of the most important non conventional machining methods is Plasma Arc Machining. Its high accuracy, finishing, ability of machining any hard materials and to produce intricate shape increases its demand in market. In thesis work has been studied in context to parametric optimization of Plasma Arc Cutting Machine. In order to attain target and optimum results, Taguchi method employed. The appropriate orthogonal array has been selected as per number of factors and there levels to perform minimum experimentation. The work pieces of Stainless Steel (304) materials were used for experiment purpose. The optimum value has been determined with the help of main effect ANOVA table. The Regression equation for MRR and Surface Roughness (Ra) has been developed with the help of Minitab 15 Software.

Confirmation test have done to confirm the value estimated through the software. The Confirmation for MRR run was done by using the setting of 6.0 bar (Gas pressure), 150 A (Current flow rate), 500 mm/min (cutting speed) and 3.0 mm (Arc gap). The optimum parameters level for Surface Roughness are 5.0 Bar (Gas Pressure), 175 A (Current), 600 mm/min

(Cutting Speed) and 2 mm (Arc Gap). Experimental results are provided to confirm the effectiveness of this approach. After the confirmation the MRR value was 0.1836 g/sec and Ra o.34156µm.

A higher percentage of diatomic species ($N_2$ and $H_2$) increases the deepness of the layer for samples A and B, from 5 to180 **µm**. A thin oxygen rich layer of about 1m is always formed on the kerf surface and it is responsible of the characteristic colour of the surface. For 1.2 mm plate thickness and fixed cutting speed, micro structural analysis of samples A (H35), B (H35 30% - $N_2$ 70%) showed that the amount of atomic oxygen on the kerf surface can be significantly reduced if a plasma cutting gas very rich in $N_2$ is used, with the drawbacks of a thicker remelted layer and the presence of atomic nitrogen on the surface.

## Abbreviations and Symbols

(CNC ) Computer numerical control

(SR ) Surface Roughness

(Ra ) Surface Roughness

(MRR) material removal rate

(EDM) Electrical discharge machining

(CM) Chemical machining

(ECM) Electrochemical machining

(USM) Ultrasonic machining

(LBM) Laser–beam machining

(PAC) plasma Arc cutting

(DOE) design of experiments

**(OA)** orthogonal array

(S/N) signal to noise ratio

(HAZ) heat affect zone

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# CHAPTER ONE

## INTRODUCTON

## 1.1 Introduction:

Plasma arc cutting is one of thermal removing process which operates on the principle of passing an electric arc through a quantity of gas through a restricted outlet [1]. This process has been used in cutting applications of stainless steel, hardened and high melting-point metal and hardened alloys [2]. The interest of modern industries in plasma arc cutting applications have increased due to the capability of this process to compete with Laser cutting (higher quality but also more expensive) and Oxygen-fuel cutting which is less expensive but lower cutting quality. Most of plasma arc cutting process was supported by the CNC attachment which benefits wide industries. There is several numbers of researches on the plasma arc cutting machining [ 6 ]. concludes that the different cutting speed produces the same effects on microstructure at the deformation of the structure that occurred at the area of the cutting process. Whilst, according to the maximize depth of the hardened zone in steel specimens is significant with the optimization of plasma arc cutting process[ 7]. Higher quality of plasma arc cutting can be achieved by manipulating the speed and the cutting current However in this work, the cutting process was performed manually which could benefit to small manufacturing industries. Therefore, plasma outputs and parameters of the study which is suited for manual and capability of plasma arc cutting machine are not entirely similar to the conventional automated plasma arc cutting machine.

Qualities of thermal cutting processing can be evaluated based on many aspects. In this work, the surface area of the materials cut by plasma arc cutting process and the rate of removed material were considered. SR is the measurement of the surface texture based on the vertical deviation (Ra) of a real surface from its ideal form. The surface roughness test is conducted to determine the irregularities of the cutting surface after the cutting process. These irregularities in which manufacturing industries considered could lead part to easily being crack when used as mechanical components [5]. MRR is the capability measurement of plasma arc cutting process to remove the specific volume of material in a specific time ($mm^3$/min). The weight of the specimens were measured before and after the cutting process to determine the material removal rate of the plasma arc cutting based on the chosen parameters. There were several methods available for the design of experiments to optimize the plasma cutting parameters. The Taguchi method approach was utilized since it requires a fewer number of tests and the information extracted more efficiently compare to full factorial and fractional factorial design of experiments method [7].

## 1.2 Literature Review:

Plasma cutting is a process that is used to cut steel and other metals (or sometimes other materials) using a plasma torch. In this process, an inert gas (Argon) is blown at high speed out of a nozzle and at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and moves sufficiently fast to blow molten metal away from the cut. Plasma can also be used for plasma arc welding and other applications. Plasma is typically an ionized gas. Plasma is considered to be a distinct state of matter, apart from gases, because of its unique properties [2]. Ionized refers to presence of one or more free electrons, which are not bound to an atom or molecule. The free electric charges make the plasma electrically conductive so that it responds strongly to electromagnetic fields.

The arc type uses a two cycle approach to producing plasma. First, a high-voltage, low current circuit is used to initialize a very small high intensity spark within the torch body, thereby generating a small pocket ofplasma gas. This is referred to as the pilot arc. The pilot arc has a return electrical path built into the torch head. The pilot arc will maintain until it is brought into proximity of the work piece where it ignites the main plasma cutting arc. Plasma arcs are extremely hot and are in the range of 15,000 degrees Celsius.

Oxy fuel cuts by burning, or oxidizing, the metal it is severing. It is therefore limited to steel and other ferrous metals which support the oxidizing process. Metals like aluminum and stainless steel form an oxide that inhibits further oxidization, making conventional ox fuel cutting impossible. Plasma cutting, however, does not rely on oxidation to work, and thus it can cut aluminum, stainless and any other conductive material. While different gasses can be used for plasma cutting, most people today use compressed air for the plasma gas. In most shops, compressed air is readily available, and thus plasma does not require fuel gas and compressed oxygen for operation.

Plasma cutting is typically easier for the novice to master, and on thinner materials, plasma cutting is much faster than ox fuel cutting. However, for heavy sections of steel (1inch and greater), ox fuel is still preferred since ox fuel is typically faster and, for heavier plate applications, very high capacity power supplies are required for plasma cutting applications [3].

## 1.3 Aim of the Study:

The aim of the research is to investigate the four plasma arc cutting parameters ,Gas Pressure, cutting speed, arc gap and plasma current in coregent on stainless steels (304) permanent source of electromagnetic radiations with large spectrum (infrared, visible, ultraviolet).

# CHAPTER TWO
# STAINLESS STEEL
# ( 304)

## 2.1 Stainless Steel Grade (304):

most versatile and widely used stainless steel. It is still sometimes referred to by its old name 18/8 which is derived from the nominal composition of type 304 being 18% chromium and 8% nickel. Type 304 stainless steel is an austenitic grade that can be severely deep drawn. This property has resulted in 304 being the dominant grade used in applications like sinks and saucepans. Type 304 is the low carbon version of 304. It is used in heavy gauge components for improved weld ability. Some products such as plate and pipe may be available as "dual certified" material that meets the criteria for both 304 and 304L. 304H, a high carbon content variant, is also available for use at high temperatures. Property data given in this document is typical for flat rolled products covered by ASTM A240/A240M. ASTM, EN or other standards may cover products sold by Alco. It is reasonable to expect specifications in these standards to be similar but not necessarily identical to those given in this datasheet [8].

**Table 2.1 typical chemical composition**

| C | Mn | Si | P | S | Cr | C i | N |
|---|---|---|---|---|---|---|---|
| 0.08 | 2.0 | 0.75 | 0.045 | 0.03 | 18 | 10 | 0.1 |

**Table 2.2 typical mechanical properties**

| Tensile Strength (MPa) | Compression Strength (MPa) | Proof Stress 0.2% (MPa) | Elongation A5 (%) | Hardness Rockwell B |
|---|---|---|---|---|
| 520 | 210 | 210 | 45 | 92 |

**Table 2.3 typical physical properties**

| Density | Melting Point | Modulus of Elasticity | Electrical Resistivity | Thermal Conductivit | Thermal Expansion |
|---|---|---|---|---|---|
| 8.00 g/cm3 | 1400-1450°C | 193 GPa | 0.072x10-6 Ω.m | 16.2 W/m.K at 100°C | 17.2x10-6 /K at 100°C |

## 2.2 Heat Resistance:

304 has good resistance to oxidation in intermittent service up to 870°C and in continuous service to 925°C. However, continuous use at 425-860°C is not recommended if corrosion resistance in water is required. In this instance 304 is recommended due to its resistance to carbide precipitation. Where high strength is required at temperatures above 500°C and up to 800°C, grade 304H is recommended. This material will retain aqueous corrosion Resistance [4].

## 2.3 Fabrication:

Fabrication of all stainless steels should be done only with tools dedicated to stainless steel materials. Tooling and work surfaces must be thoroughly cleaned before use. these precautions are necessary to avoid cross contamination of stainless steel by easily corroded metals that may discolor the surface of the fabricated product.

## 2.4 Cold Working:

304 stainless steel readily work hardens. Fabrication methods involving cold working may require an intermediate annealing stage to alleviate work hardening and avoid tearing or cracking. At the completion of fabrication a full annealing operation should be employed to reduce internal stresses and optimize corrosion resistance.

## 2.5 Hot Working:

Fabrication methods, like forging, that involve hot working should occur after uniform heating to 1149-1260°C. The fabricated components should then be rapidly cooled to ensure maximum corrosion resistance.

## 2.6 Heat Treatment:

304 stainless steel cannot be hardened by heat treatment. Solution treatment or annealing can be done by rapid cooling after heating to 1010-1120°C.

## 2.7 Machinability:

304 has good machinability. Machining can be enhanced by using the following rules:

- Cutting edges must be kept sharp. Dull edges cause excess work hardening.
- Cuts should be light but deep enough to prevent work hardening by riding on the surface of the material.
- Chip breakers should be employed to assist in ensuring sward remains clear of the work.
- Low thermal conductivity of austenitic alloys results in heat concentrating at the cutting edges. This means coolants and lubricants are necessary and must be used in large quantities[10].

# CHAPTER THREE

# MANUFACTURING PROCESSESCUTTING

## 3-1 Traditional Manufacturing Processes cutting

### 3.1.1 Turning:

Turning is a machining operation for all types of metallic and non-metallic materials and is capable of producing circular parts with straight or various profiles. The cutting tools may be single-point or form tools. The most common machine tool used is a **lathe;** modern lathes are computer-controlled and can achieve high production rates with little labour. The basic operation is shown in ( Fig3.1), where the work piece is held in a chuck and rotates at $N$ r/min; a cutting tool moves along the length of the piece at a feed $f$ (in/r or mm/r) and removes material at a radial depth $d$, reducing the diameter from $D0$ to $D f$.

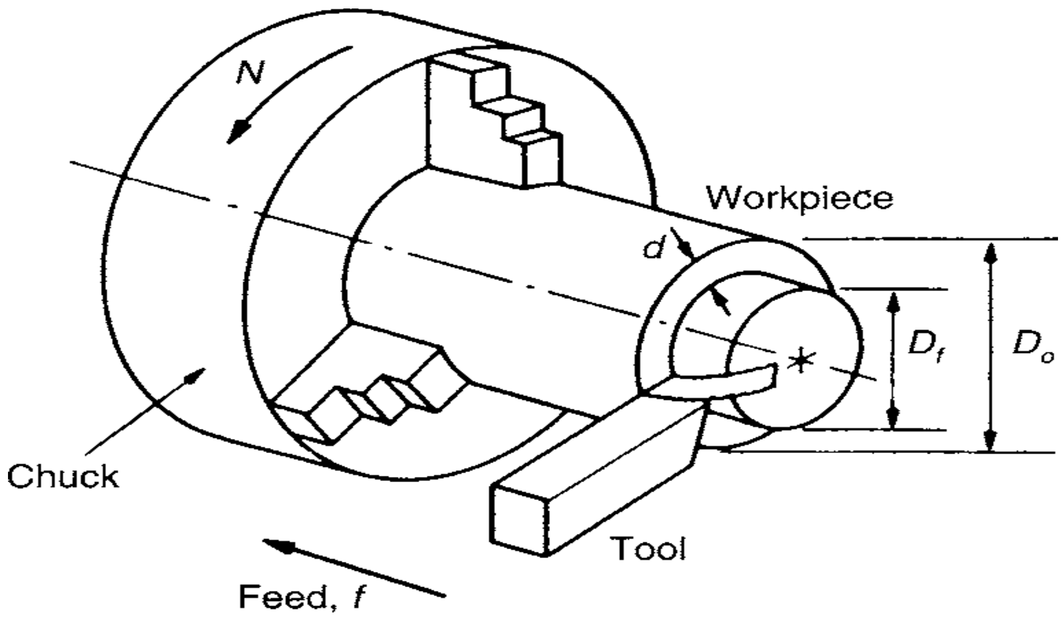



**Figure (3.1) Turning**

### 3.1.2 Milling:

Milling is one of the most versatile machining processes and is capable of producing a variety of shapes involving flat surfaces, slots, and contours (Fig.3.2 ). Milling machine suse cutters with multiple teeth in contrast with the single-point tools of the lathe and planer. Milling-machine classification is based on design, operation, or purpose.

Knee-and-column type milling machines have the table and saddle supported on the vertically adjustable knee gibed to the face of the column. The table is fed longitudinally on the saddle, and the latter transverse lay on the knee to give three feeding motions. Knee-type machines are made with horizontal or vertical spindles. The **horizontal** universal machines have a swiveling table for cutting helices. The plain machines are used for jobbing or production work, the universal for tool room work. **Vertical** milling machines with fixed or sliding heads are otherwise similar to the horizontal type. They are used for face or end milling and are frequently provided with a rotary table for making cylindrical surfaces. The **fixed-bed** machines have a spindle mounted in a head dovetailed to and sliding on the face of the column. The table rests directly on the bed. They are simple and rigidly built and are used primarily for high-production work. These machines are usually provided with work-holding fixtures and may be constructed as plain or multiple-spindle machines, simple or duplex [16].

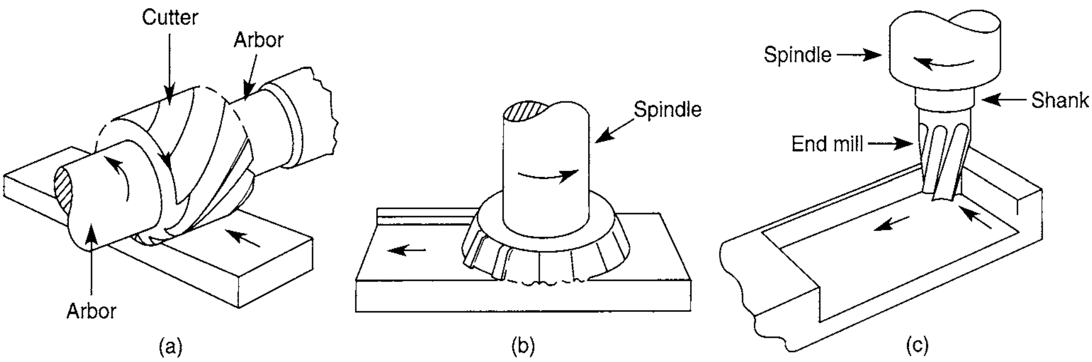



**Figure (3.2) Milling**

## 3.1.3 Sawing:

Sawing machines are classified according to basic machine design, i.e. band saw, gang saw, chain saw, circular saw. Saws are designated as **ripsaws** if they are designed to cut along the grain or **crosscut** saws if they are designed to cut across the grain. A **combination** saw is designed to cut reasonably well along the grain, across the grain, or along a direction at an angle to the grain (mitre**).** Sawing machines are often further classified according to the specific operation for which they are used, e.g., **head saw** (the primary log-breakdown saw in a sawmill), **re saw** (saw for ripping cants into boards), **edger** (saw for edging boards in a sawmill), **variety saw** (general-purpose saw for use in furniture plants), **scroll saw** (general-purpose narrow-band saw for use in furniture plants).

### 3.1.4 Planning and Melding:

Machinery Planning and melding machines employ a rotating cutter head to generate a smooth, defect-free surface by cutting in a direction approximately along the grain. A **surface r** (or **planer)** is designed to machine boards or panels to uniform thickness. A **facer (**or **facing planer)** is designed to generate a flat (plane) surface on the wide faces ofboards. The **edge jointer** is intended to perform the same task on the edges of boards in preparation for edge-gluing into panels. A **planer matcher** is a heavy-duty machine designed to plane rough boards to uniform width and thickness in one operation. This machine is commonly used for dressing dimension lumber and producing millwork. The **milder** is a high-production machine for use in furniture plants to generate parts of uniform cross-sectional shape [23].

## 3. 2 Non Traditional Manufacturing Processes cutting:

Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non Traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below:

- Very hard fragile materials difficult to clamp for traditional machining.
- When the work piece is too flexible or slender.
- When the shape of the part is too complex.

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes. The common non-traditional machining processes are described in this section.

### 3.2.1 Electrical discharge machining (EDM):

Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilises thermoelectric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the work piece and the electrode. A picture of EDM machine in operation is shown in Figure(3.3).

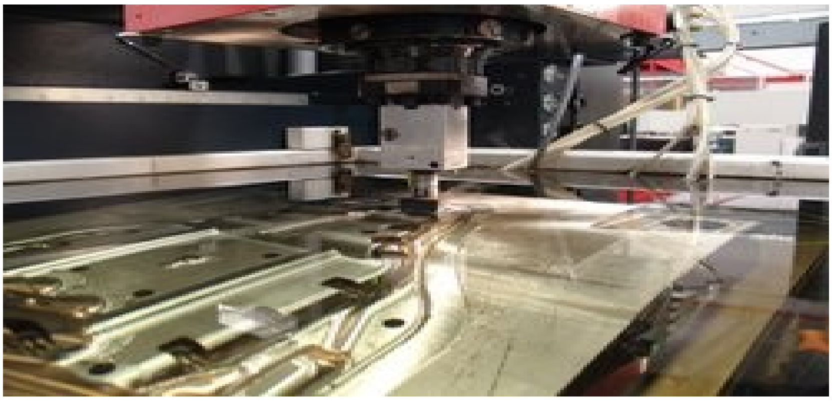


**Fig (3.3) Electrical discharge machine**

The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. so the hardness of the material is no longer a dominating factor for EDM process. A schematic of an EDM process is shown in Fig(3.4) where the tool and the work piece are immersed in a dielectric fluid [22].

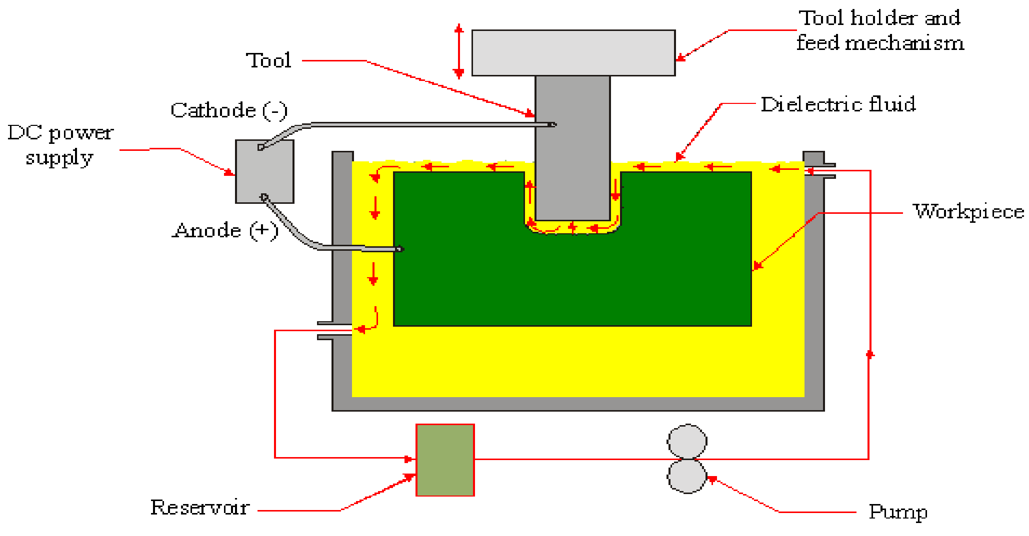
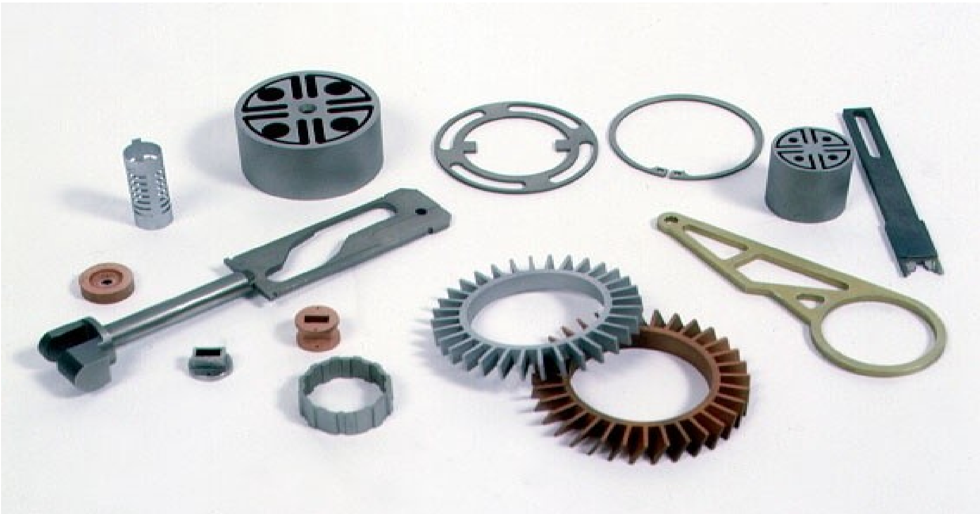



**Fig (3.4) Schematic of EDM process**

EDM removes material by discharging an electrical current, normally stored in a capacitor bank, across a small gap between the tool (cathode) and the work piece (anode) typically in the order of 50 volts/10amps.

**Application of EDM:**

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown in Figure ( 3.5).

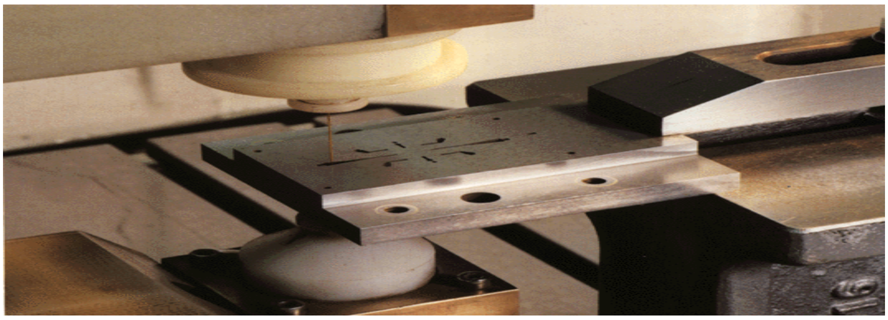


**Fig(3.5) Difficult internal parts made by EDM process**

## 3.2.2 Wire EDM

EDM, primarily, exists commercially in the form of die-sinking machines and wire-cutting machines (Wire EDM). The concept of wire EDM is shown in Figure(3.5). In this process, a slowly moving wire travels along a prescribed path and removes material from the work piece. Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the work piece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids.

The wire EDM process can cut intricate components for the electric and aerospace industries. This non-traditional machining process is widely used to pattern tool steel for die manufacturing.



**Fig( 3.6) Wire erosion of an extrusion die**

The wires for wire EDM is made of brass, copper, tungsten, molybdenum. Zinc or brass coated wires are also used extensively in this process. The wire used in this process should posses high tensile strength and good electrical conductivity. Wire EDM can also employ to cut cylindrical objects with high precision. The sparked eroded extrusion dies are presented in Figure (3.7).

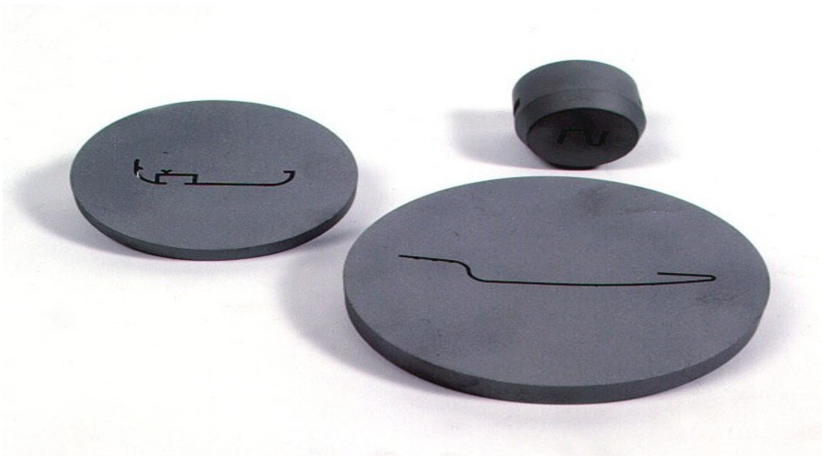


Figure (3.7) Sparked eroded extrusion dies

This process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. The surface quality and MRR of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, and wire materials.

### 3.2.3 Chemical machining (CM):

Chemical machining (CM) is the controlled dissolution of work piece material (etching) by means of a strong chemical reagent (etchant). In CM material is removed from selected areas of work piece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min. The basic process takes many forms: chemical milling of pockets, contours, overall metal removal, chemical blanking for etching through thin sheets; photochemical machining (pcm) for etching by using of photosensitive resists in microelectronics; chemical or electrochemical polishing where weak chemical reagents are used (sometimes with remote electric assist) for polishing or debarring and chemical jet machining where a single chemically active jet is used. A schematic of chemical machining process is shown in Figure(3.8).

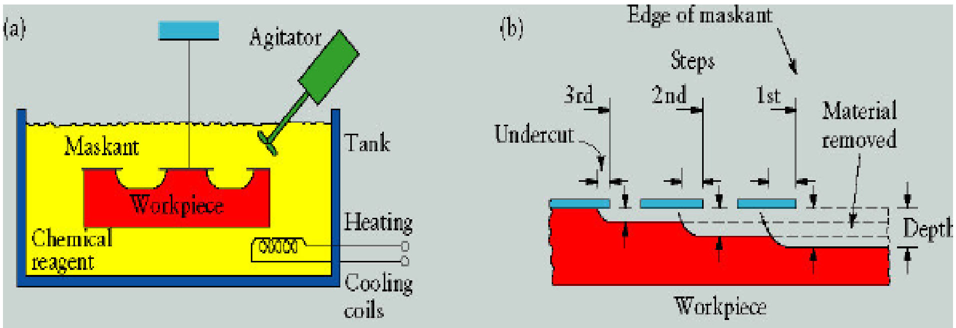



**Figure 3.8 (a) Schematic of chemical machining process (b) Stages in producing a profiled cavity by chemical machining (Kalpakjain& Schmidt) [9].**

## 3.2.3.1 Chemical milling:

In chemical milling, shallow cavities are produced on plates, sheets, forgings and extrusions. The two key materials used in chemical milling process are etchant and mask ant. Etchants are acid or alkaline solutions maintained within controlled ranges of chemical composition and temperature. Mask ants are specially designed elastomeric products that are hand strippable and chemically resistant to the harsh etchants.

**Steps in chemical milling:**

- Residual stress relieving: If the part to be machined has residual stresses from the previous processing, these stresses first should be relieved in order to prevent warping after chemical milling.
- Preparing: The surfaces are degreased and cleaned thoroughly to ensure both good adhesion of the masking material and the uniform material removal.
- Masking: Masking material is applied (coating or protecting areas not to be etched).
- Etching: The exposed surfaces are machined chemically with etchants.
- Damasking: After machining, the parts should be washed thoroughly to prevent further reactions with or exposure to any etchant residues. Then the rest of the masking material is removed and the part is cleaned and inspected.

**Applications:**

Chemical milling is used in the aerospace industry to remove shallow layers of material from large aircraft components missile skin panels (Figure 3.8), extruded parts for airframes.

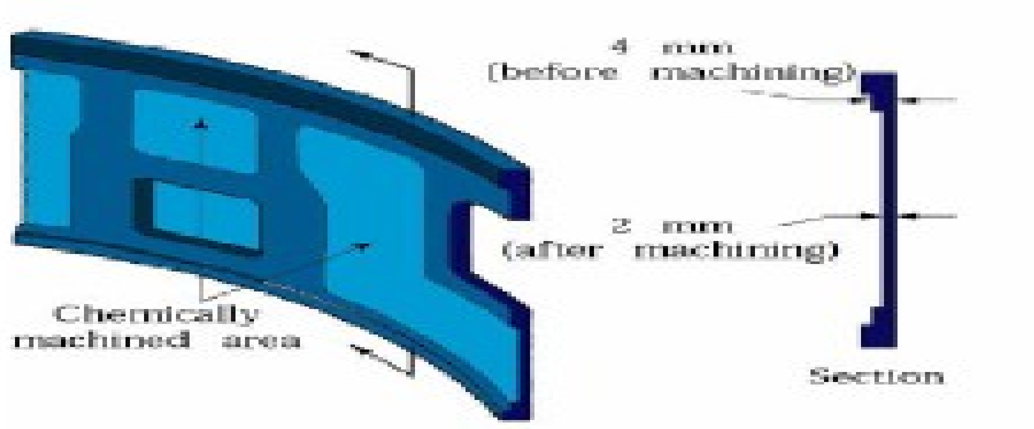
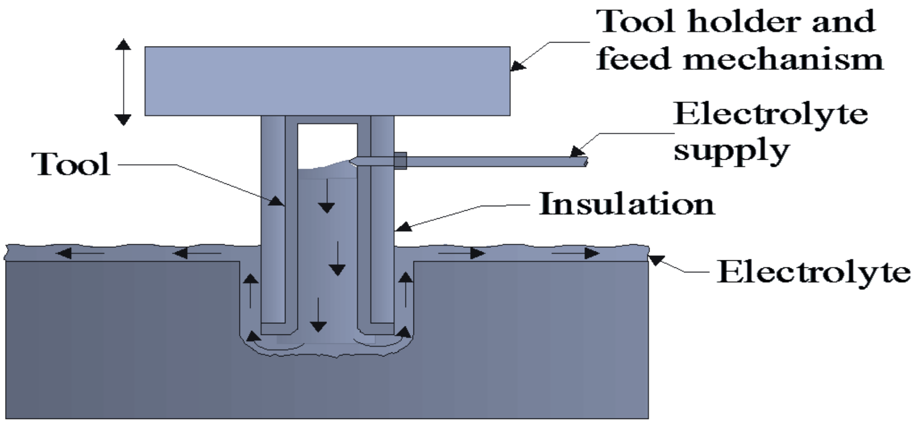



**Figure 3.9 Missile skin-panel section contoured by chemical milling to improve the stiffness- to- weight ratio of the part (Kalpakjain& Schmidt) [12].**

## 3.2.4 Electrochemical machining (ECM)

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating. In this process, particles travel from the anodic material (work piece) toward the catholic material (machining tool). A current of electrolyte fluid carries away the depleted material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape.




**Fig(3.10) ECM process**

Similar to EDM, the work piece hardness is not a factor, making ECM suitable for machining difficult-to –machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. A schematic representation of ECM process is shown in (Figure 3.10.) The ECM tool is positioned very close to the work piece and a low voltage, high amperage DC current is passed between the work piece and electrode. Some of the shapes made by ECM process is shown in Fig( 3.11).

**Figure 3.11 Parts made by ECM**

## 3.2.5 Ultrasonic machining (USM):

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle work piece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and work piece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes. The hard particles in slurry are accelerated toward the surface of the work piece by a tool oscillating at a frequency up to 100 KHz - through repeated abrasions, the tool machines a cavity of a cross section identical to its own. A schematic representation of USM is shown in Fig(3.11).

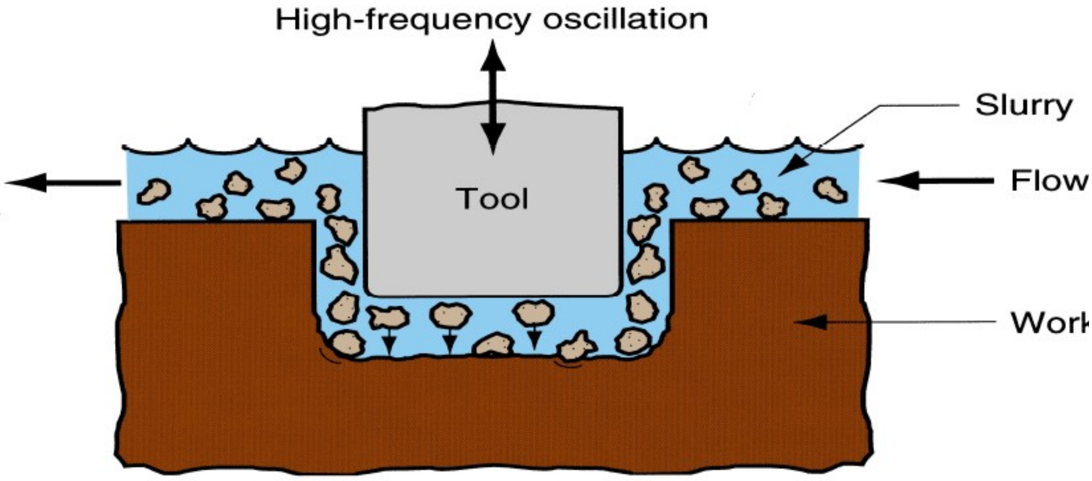



**Figure (3.12) Schematic of ultrasonic machine tool**

USM is primarily targeted for the machining of hard and brittle materials(dielectric or conductive) such as boron carbide, ceramics, titanium carbides, rubies, quartz etc. USM is a versatile machining process as far as properties of materials are concerned. This process is able to effectively machine all materials whether they are electrically conductive or insulator [6]. For an effective cutting operation, the following parameters need to be carefully considered:

- The machining tool must be selected to be highly wear resistant, such as high-carbon steels.
- The abrasives (25-60 μm in dia.) in the (water-based, up to 40% solid volume) slurry includes: Boron carbide, silicon carbide and aluminum oxide.

**Applications:**

The beauty of USM is that it can make non round shapes in hard and brittle materials. Ultrasonically machined non round-hole part is shown in (Figure3.13).

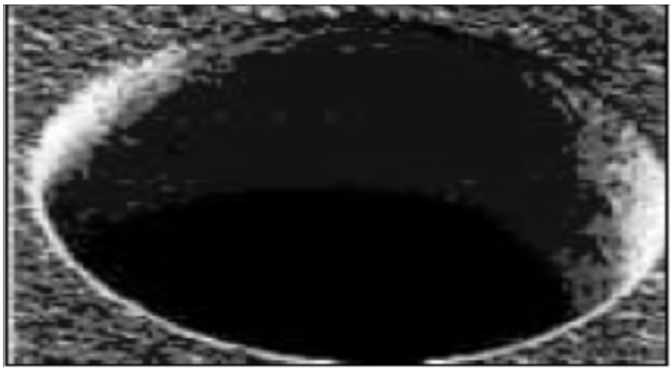


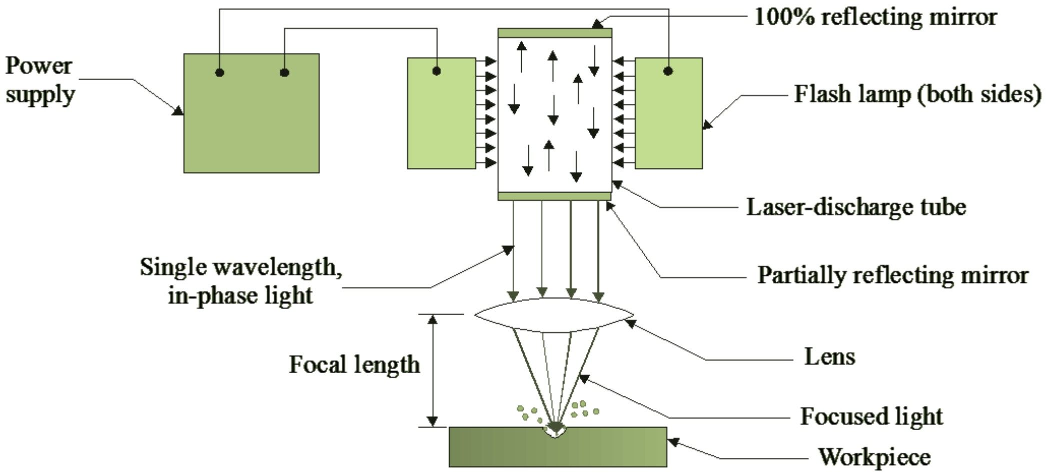
**Figure (3.13)A non-round hole made by USM**

## 3.2.6 Laser–Beam Machining (LBM):

Laser-beam machining is a thermal material-removal process that utilizes a high-energy, coherent light beam to melt and vaporize particles on the surface of metallic and non-metallic work pieces. Lasers can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes. A schematic of laser beam machining is shown in Fig( 3.14).

Different types of lasers are available for manufacturing operations which are as follows:

- $CO_2$ (pulsed or continuous wave): It is a gas laser that emits light in the infrared region. It can provide up to 25 kW in continuous-wave mode.
- Nd:YAG: Neodymium-doped Yttrium-Aluminum-Garnet ($Y_3Al_5O_{12}$) laser is a solid-state laser which can deliver light through a fibre-optic cable. It can provide up to 50 kW power in pulsed mode and 1 kW in continuous-wave mode.




**Fig(3.14): Laser beam machining schematic**

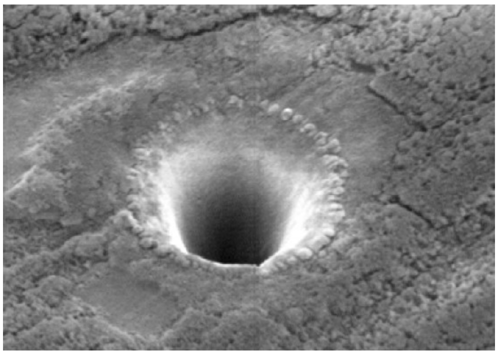
## Applications:

- LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the work pieces. This process is used widely for drilling and cutting of metallic and non-metallic materials. Laser beam machining is being used extensively in the electronic and automotive industries. In drilling, energy transferred (e.g., via a

Nd:YAG laser) into the work piece melts the material at the point of contact, which subsequently changes into a plasma and leaves the region.

- A gas jet (typically, oxygen) can further facilitate this phase transformation and departure of material removed.
- Laser drilling should be targeted for hard materials and hole geometries that are difficult to achieve with other methods.

A typical SEM micrograph hole drilled by laser beam machining process employed in making a hole is shown in Figure ( 3.15)

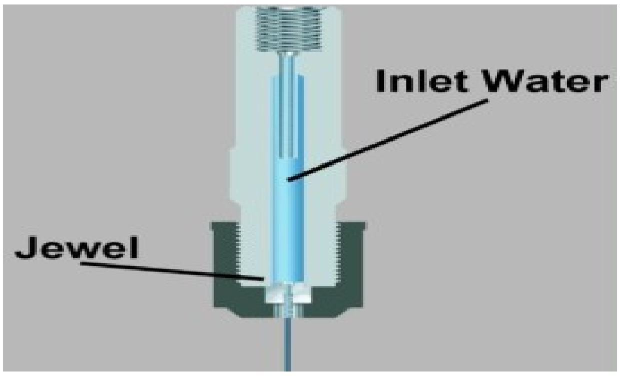


**Fig(3.15) SEM micrograph hole drilled in 250 micro meter thick Silicon Nitride with 3rd harmonic Nd: YAG laser**

### 3.2.7 Water Jet Cutting:

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallisation, hardening, reduced weald ability and mach inability are reduced in this process.

Water jet technology uses the principle of pressure sing water to extremely high pressures, and allowing the water to escape through a very small opening called “orifice” or “jewel”. Water jet cutting uses the beam of water exiting the orifice to cut soft materials. This method is not suitable for cutting hard materials. The inlet water is typically pressure sed between 1300 – 4000 bars. This high pressure is forced through a tiny hole in the jewel, which is typically o.18 to 0.4 mm in diameter. A picture of water jet machining process is shown in( Figure 3.16)




**Fig(3.16) Water jet cutting**

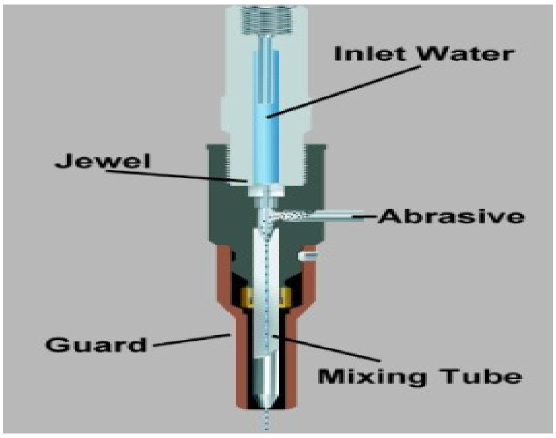
**Applications:**

Water jet cutting is mostly used to cut lower strength materials such as wood, plastics and aluminium. When abrasives are added, (abrasive water jet cutting) stronger materials such as steel and tool steel can be cut.

## 3.2.8 Abrasive water-Jet cutting:

Abrasive water jet cutting is an extended version of water jet cutting; in which the water jet contains abrasive particles such as silicon carbide or aluminium oxide in order to increase the material removal rate above that of water jet machining. Almost any type of material ranging from hard brittle materials such as ceramics, metals and glass to extremely soft materials such as foam and rubbers can be cut by abrasive water jet cutting. The narrow cutting stream and computer controlled movement enables this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be cut by laser or thermal cut. Metallic, non-metallic and advanced composite materials of various thicknesses can be cut by this process. This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining.

The schematic of abrasive water jet cutting is shown in Figure 15 which is similar to water jet cutting apart from some more features underneath the jewel; namely abrasive, guard and mixing tube. In this process, high velocity water exiting the jewel creates a vacuum which sucks abrasive from the abrasive line, which mixes with the water in the mixing tube to form a high velocity beam of abrasives.




**Fig(3.17) Abrasive water jet machining**

**Applications:**

Abrasive water jet cutting is highly used in aerospace, automotive and electronics industries. In aerospace industries, parts such as titanium bodies for military aircrafts, engine components (aluminium, titanium, heat resistant alloys), aluminium body parts and interior cabin parts are made using abrasive water jet cutting. In automotive industries, parts like interior trim (head liners, trunk liners, door panels) and fibre glass body components and bumpers are made by this process. Similarly, in electronics industries, circuit boards and cable stripping are made by abrasive water jet cutting [23].

**Fig(3.18) Abrasive water jet cutting**

**Fig(3.19) Steel gear and rack cut with an abrasive water jet**

Plasma cutting is a process that is used to cut steel and other metals (or sometimes other materials) using a plasma torch. In this process, an inert gas (Argon) is blown at high speed out of a nozzle and at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and moves sufficiently fast to blow molten metal away from the cut. Plasma can also be used for plasma arc welding and other applications [24].

CHAPTER FOUR

# PLASMA ARC CUTTING

## 4.1 Principle of Plasma arc Cutting:

Ess has always been seen as an alternative to the oxy-fuel process. In this part of the series the process fundamentals are described with emphasis being placed on the operating features and the advantages of the many process variants. Fig( 4.1) he principle of the plasma cutting .The plasma is additionally tied up by a water-cooled nozzle. With this energy densities up to 2x106 W/cm2 inside of the plasma beam can be achieved. Because of the high temperature the plasma expands and flows with supersonic velocity speed to the work piece (anode). Inside the plasma arc temperatures of 30 000oC can arise, that realize in connection with the high kinetic energy of the plasma beam and depending on the material thickness very high cutting speeds on all electrically conductive materials. The term for advisable state of plasma arc is called stability of arc too. The stability of arc is keeping the plasma jet in desired form. It is possible to be provided by [18]:

a) Shape of Plasma Torch,

b) Streaming Jet,

c) Water.

**These parameters must monitored :**

1- Temperature and electrical conducting.

2- Density of plasma jet.

3- Diameter of plasma beam.

4- Degree of the plasma beam focusing in output from nozzle.

For the cutting process first of all a pilot arc ignition by high voltage between nozzle and cathode takes place. This low- energy pilot arc prepares by ionization in parts the way between plasma torch and work piece. When the pilot arc touches the work piece (flying cutting, flying piercing), the main arc will start by an automatic increase in power The basic principle is that the arc formed between the electrode and the work piece is constricted by a fine bore, copper nozzle. This increases the temperature and velocity of the plasma emanating from the nozzle. The temperature of the plasma is in excess of 20 000°C and the velocity can approach the speed of sound. When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material and molten material is removed in the efflux plasma. The process differs from the oxy-fuel process in that the plasma process operates by using the arc to melt the metal whereas in the oxy-fuel process, the oxygen oxidizes the metal and the heat from the exothermic reaction melts the metal. Thus, unlike the oxy-fuel process, the plasma process can be applied to cutting metals which form refractory oxides such as stainless steel, aluminum, cast iron and non-ferrous alloys. 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 160V, 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. For cutting, the arc must be transferred to the work piece in the so-called 'transferred' arc mode. The electrode has a negative polarity and the work piece a positive polarity so that the majority of the arc energy (approximately two thirds) is used for cutting. In the conventional system using a tungsten electrode, the plasma is inert, formed using either argon, argon-H2 or nitrogen. However, as described in Process variants, oxidizing gases, such as air or oxygen can be used but the electrode must be copper with hafnium. The plasma gas flow is critical and must be set according to the current level and the nozzle bore diameter. If the gas flow is too low for the current level, or the current level too high for the nozzle bore diameter, the arc will break down forming two arcs in series, electrode to nozzle and nozzle to work piece. The effect of ‘double arcing’ is usually catastrophic with the nozzle melting. The quality of the plasma cut edge is similar to that achieved with the oxy fuel process.

However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge. As these limitations are associated with the degree of constriction of the arc, several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut. The process variants have principally been designed to improve cut quality and arc stability, reduce the noise and fume or to increase cutting speed. The inert or uncreative plasma forming gas (argon or nitrogen) can be replaced with air but this requires a special electrode of hafnium or zirconium mounted in a copper holder, by shearing . The air can also replace water for cooling the torch. The advantage of an air plasma torch is that it uses air instead of expensive gases. It should be noted that although the electrode and nozzle are the only consumables, hafnium tipped electrodes can be expensive compared with tungsten electrodes. This relatively new process differs from conventional, dry plasma cutting in that water is injected around the arc. The net result is greatly improved cut quality on virtually all metals, including mild steel. Today, because of advances in equipment design and improvement in cut quality, previously unheard of applications, such as multiple torches cutting of mild steel, are becoming common place [20].

### 4.1.1 Shielding and cutting gases for plasma cutting:

Inert gases such as argon, helium, and nitrogen (except at elevated temperatures) are used with tungsten electrodes. Air may be used for the cutting gas when special electrodes made from water-cooled copper with inserts of metals such as hafnium are used. Recently, PAC units shielded by compressed air have been developed to cut thin-gauge materials. Almost all plasma cutting of mild steel is done with one of three gas types:

1. Nitrogen with carbon dioxide shielding or water injection (mechanized).
2. Nitrogen-oxygen or air.
3. Argon-hydrogen and nitrogen-hydrogen mixtures.

The first two have become standard for high-speed mechanized applications. Argon hydrogen and nitrogen-hydrogen (20 to 35 percent hydrogen) are occasionally used for manual cutting, but the formation of dross, a tenacious deposit of res olidified metal attached at the bottom of the cut, is a problem with the argon blend. A possible explanation for the heavier, more tenacious dross formed with argon is the greater surface tension of the molten metal. The surface tension of liquid steel is 30 percent higher in an argon atmosphere than in one of nitrogen. Air cutting gives a dross similar to that formed in a nitrogen atmosphere. The plasma jet tends to remove more metal from the upper part of the work piece than from the lower part. This results in nonparallel cut surfaces that are generally wider at the top than at the bottom. The use of argon-hydrogen, because of its uniform heat pattern or the injection of water into the torch nozzle (mechanized only), can produce cuts that are square on one side and beveled on the other side. For base metal over 3 inches thick, argon-hydrogen is frequently used without water injection [17].

## 4.1.2 Plasma Gas Selection:

**Air Plasma:**

1- Mostly used on ferrous or carbon based materials to obtain good quality a faster cutting speeds.

2- Only clan, dry air is recommended to use as plasma gas. Any oil or moisture in the air supply will substantially reduce torch parts life.

3- Air Plasma is normally used with air secondary.

**Nitrogen Plasma:**

1- Can be used in place of air plasma with air secondary.

2- Provides much better parts life than air.

3- Provides better cut quality on non-ferrous materials such as stainless steel and aluminum.

4- A good clean welding grade nitrogen should be used.

**Argon/Hydrogen Plasma:**

1- A 65% argon/35% hydrogen mixture should be used.

2- Provides faster cutting speeds and high cut quality on thicker material to offset the higher cost of the gas.

3- Poor quality on ferrous materials.

**Oxygen Plasma:**

1- Oxygen is recommended for cutting ferrous metals.

2- Provides faster cutting speeds.

3- Provides very smooth finishes and minimizes nitride build-up on cut surface(nitride build-up can cause difficulties in producing high quality welds if not removed).

## 4.1.3 Secondary Gas Selection for Plasma Cutting:

**A -Air Secondary:**

1- Air secondary is normally used when operating with air plasma and occasionally with nitrogen plasma.

2- Inexpensive - reduces operating costs

3- Improves cut quality on some ferrous materials.

**B- CO2 Secondary:**

1- CO2 secondary is used with nitrogen or Ar/H2 plasma.

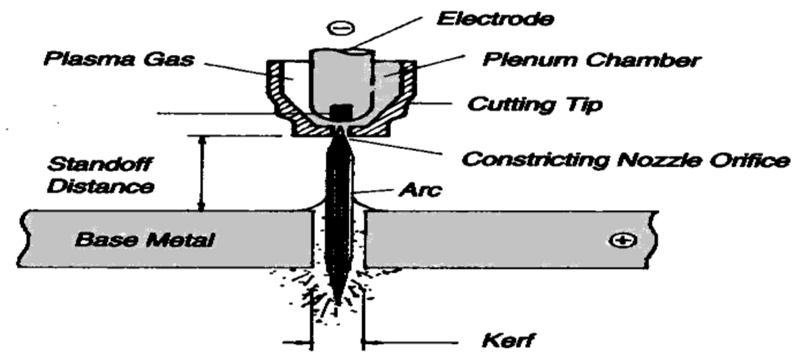
2- Provides good cooling and maximizes torch parts life.

3- Usable on any ferrous or non-ferrous material.

4- May reduce smoke when used with Ar/H2 plasma.

## 4.2 Plasma Cutting Capability:

Plasma is an effective means of cutting thin and thick materials alike. Hand held torches can usually cut up to 2 in (48 mm) thick steel plate, and stronger computer controlled torches can pierce and cut steel up to 12 inches (300 mm) thick. Formerly, plasma cutters could only work on conductive materials, however new technologies allow the plasma ignition arc to be enclosed within the nozzle thus allowing the cutter to be used for non-conductive work pieces. Since plasma cutters produce a very hot and much localized cone to cut with they are extremely useful for cutting sheet metal in curved or angled shapes.




'Fig (4.2) Plasma Cutting Capability

In this work, Plasma Arc Cutter was utilized to perform Stainless Steel (3O4) material cutting. The system and the process are the important elements when utilizing plasma arc cutting. It is important to know current plasma arc cutting research areas to plan the direction of this work so that this work would contribute information that will be useful in future [13].

# CHAPTER FIEVE

# EXEPREMENTAL WORK

## 5.1. SPECIMEN PREPARATION: .

9 test specimens having dimension 30mm x 30mm x 1.2 mm were prepared for the experimental work. The material for test specimen was Stainless Steel

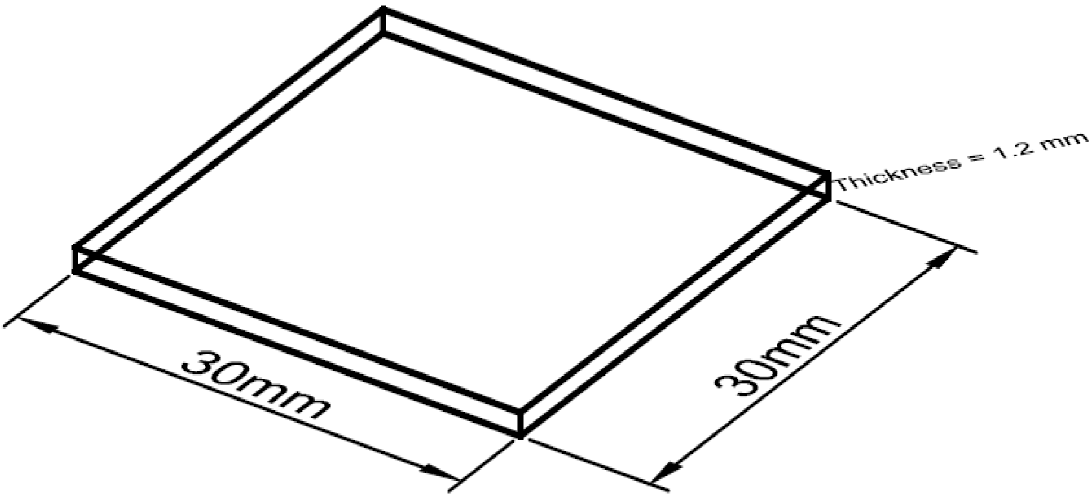



**Figure 5.1 (b) illustrate the drawing of test specimen and its dimension**

## 5.2 MATERIAL:

Stainless Steel is essentially a low carbon steel which contains chromium at 10% or more by weight. It is this addition of chromium that gives steel its unique stainless, corrosion resisting properties. The chromium content allows the formation of a tough, adherent, invisible, corrosion resisting chromium oxide film on the steel surface. Generally pipe flanges are manufactured from the Stainless Steel of grade 304 Low Carbon Content.

## 5.3: Equipment

Equipment for the experiment use is:

1- Plasma arc cutting (PRECISION GENERATOR ) pp260 a.
2- Digital weight balancer equipment(SARTORIUS).
3- The surface roughness tester (Form Taly Surf) Taylor Hobson (U.K).

### 5.3.1 Plasma Arc Cutting System:

Plasma Arc Cutter used in this work is Silvering Make with Sharp line Bombay make Burney 10 LCD. Before cutting, worker always know plasma arc cuts all electrically conductive metals (Ox fuel is usually limited to steel), plasma arc cutting requires no preheating, turnaround time is fast, the process produces a small heat-affected zone.


**Figure 5.2 (a) plasma arc cutting machine**

**Figure 5.2 (b) DC Power Supply Source**

### 5.3.2 Power Supply:

The power supply required depends on the material thickness and cutting speeds desired. Increasing the power increases the cutting speed or enables thicker metals to be cut without slow down. Power ratings are commonly between 20 and 200 KW.

**Table 5.1 Technical Features**

| **Technical Features** | **Machine** |
|---|---|
| Machine Type | Pp260 a |
| Serial number | G13008 |
| Construction years | 2013 |
| Max power consumption | 52 kw |
| Short circuit | 5 kw |

### 5.3.3 Digital weight balancer equipment:

The weight of the work pieces (specimens) before and after the cutting process need to be measured in order to obtain the amount of Material Remove Rate(MRR)

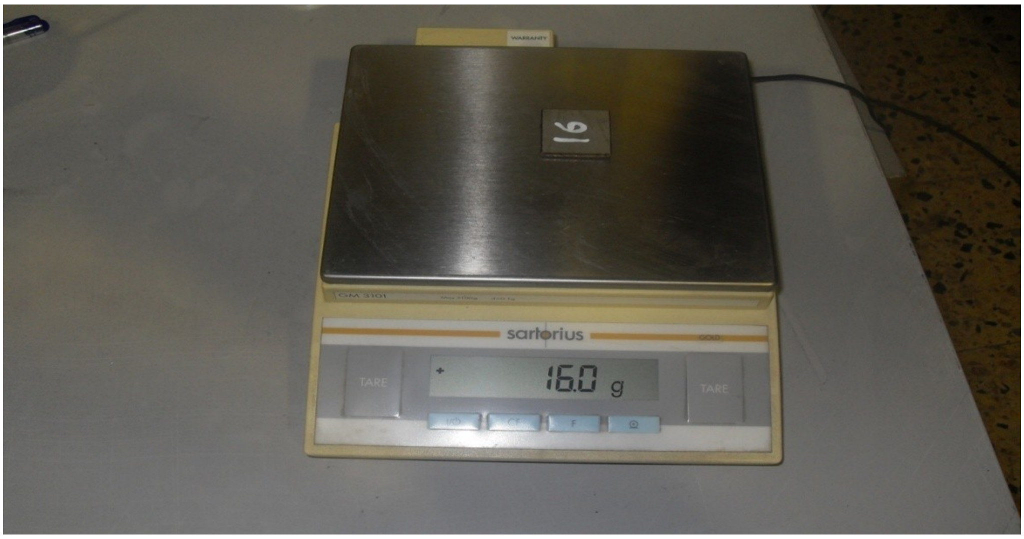



**Figure 5.3 Digital weight balancer equipment**

### 5.3.4 Surface Roughness Tester:

There are five steps to measure the surface roughness of specimens. Firstly, clamp the work piece of project use a clamping in the machine. And then, setting a prop of axis likes up and down, right or left direction. After finish setting, can start measured a work piece. Lastly, a data value for roughness can print out after finish measured. The surface roughness tester (FORM TALY SURF) used in this work, with the following specifications:

Manufacturer: Taylor Hobson, U.K.

Travelling length: 01mm-50mm.

Force: 4N/m.

Stylus: Diamond 2µm tip radius.

Resolution: 16nm/1.0mm.

Software: Form ultra software.


**Figure 5.4 Surface Roughness Tester**

## 5.4 Surface Preparation for Metallographic Investigations

### 5. 4.1 Grinding

Mechanical grinding by means of abrasive silicon carbide (SiC) grit papers fixed to electrically rotating Metaserv grinder was carried out until a uniform smooth surface finish was attained. The grinding was performed in successive steps using; 220, 400, 600, 800, 1000, 2500 and finished by 4000grit SiC papers. Tap water was used as the lubricant media for all the grinding stages.


**Figure 5.5Grinding Equipment**

### 5.4.2 Polishing

Mechanical polishing was carried out with polishing nap cloths fixed on rotating Metaserv-polisher. Pastes containing fine diamond particles of 6 μm, 3 μm and 1 μm sizes were subsequently used as polishing media, while a sprayed solution of alcohol and propylene glycol was employed as lubricant. The polished samples were then rinsed in deionized water and sprayed with ethanol after which the clean samples were dried using a stream of compressed cool air.


**Figure 5.6 polishing Equipment**

### 5.4.3 Chemical etching

The ground and polished samples were chemically etched to reveal their microstructures. This was achieved by aroom temperature immersion for 15-20 secondsin 2 % Nital solution (98% ethanol + 2% nitric acid). The etched samples were then rinsed in deionised water, sprayed with ethanol and air dried.

### 5.4.4 Optical Microscopy (OM)

Metallographic observations were performed on an Olympus BHM optical microscope connected to C-35AD-2 Olympus camera. Images from the areas of interest were captured at different magnifications on black and white films. The captured images were then processed using image J software.

**Figure5.7 Optical Microscopy**

### 5.4.5 Scanning Electron Microscopy (SEM)

In this work, a Zeiss scanning electron microscope connected to a personal computer were employed for high resolution imaging. Both secondary electrons and backscattered electrons modes were utilized to analyse the metallurgical features of interest within of the various heat treated microstructures of the stainless steel (304). The captured images were then processed using image software.

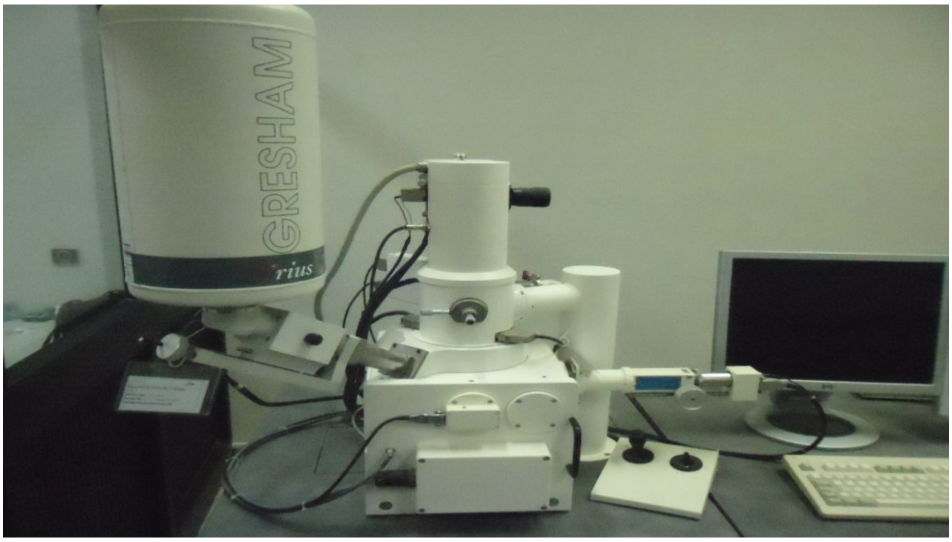



**Figure 5.8 Scanning Electron Microscopy**

### 5.4.6 Hardness testing

The Vickers hardness values for each of the sample were then measured at the center of the top side of the cylindrical samples using a digital Mitutoyo hardness tester model MVK-HVL equipped with VL-101 video line micrometer. All hardness measurements were conducted at room temperature under a static load of 1 kg, which was maintained for 15 seconds.


**Figure 5.9 Vickers hardness machine**

## 5.5 Design Factors:

Design of Experiments technique has been utilized to obtain the best combination of design factors to achieve optimum performance measures. Plasma Arc Cutting involves several input parameters to be considered during machining process. In this thesis, the combination factors such as Gas Pressure [bar], Current Flow Rate [A], Cutting Speed [mm/min] and Arc Gap [mm] are considered. These factors are the most important to have the best value for Material Removal Rate (MRR) and Surface Roughness (Ra) when cutting material like Stainless Steel or Nickel Base Alloy etc.

### 5.5.1 Gas Pressure:

According to Larry Jeff us[9] Sixth Addition, almost any gas or gas mixture can be used today for the PAC process. Normally Nitrogen or Argon with 0-35% Hydrogen is used for cutting Stainless Steel material. We used Argon with[35%] Hydrogen for our experiment purpose. It is important to have the correct gas for the size tip, metal type and thickness. Too low a gas flow will result in a cut having excessive dross and sharply beveled sides. Too high a gas will produce a poor cut because of turbulence in the plasma stream and waste gas. Controlling the pressure is one way of controlling gas flow.

### 5.5.2 Current:

Current flow rate is the value of current given during cutting 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 of the plasma gas are increased and the cutting speed is decreased, the process will withstand larger variations in the cutting parameters.

### 5.5.3 Cutting Speed:

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 cutting with air, the arc should be vertical straight down, or zero degrees as it exits the bottom side of the cut. If cutting with nitrogen or argon/hydrogen, then the correct cutting speed will produce a trailing arc (that is, an exit arc that is opposite to the direction of torch travel).

The torch speed needs to be adjusted to get a good-quality cut. A cutting speed that is too slow or too fast will cause cut quality problems. In most metals there is a window between these two extremes that will give straight, clean, dross free cuts.

### 5.5.4 Arc Gap:

Arc gap is the gap between the plasma arc cutter torch and welding electrodes with the work piece.

## 5.6 Plasma Arc Cutting Response:

There are two Plasma Arc Cutting responses measured in this study, known as:

i. Material Removal Rate (MRR).

ii. Surface Roughness (Ra).

### 5.6.1 Material 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:

$$MRR = WRW/T \text{ [g/min]}.$$

Where,

WRW: work piece removal (g).

T: cutting time(s).

WRW is the weight different between before and after work piece cutting. The optimum 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).

The density of the Nickel-Base Alloys is 8 g/cm3 or 0.008g/cm3.

### 5.6.2 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. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces (see teratology). Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

In this thesis, the average surface roughness is measured and calculated. The average surface roughness is the integral of the absolute value of the roughness profile height over the evaluation length and is denoted by the following equation.

## 5.7 Background of Taguchi design:

The method which presented in this study is an experimental design process called the Taguchi design method. The employing design of experiments (DOE), described by Dr Taguchi, is one of the most important statistical technique of Total quality management (TQM) for designing high

quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost. Fundamentally, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of the process parameter increases. To solve this problem, the Taguchi method has used to the entire parameter space with only a small number of experiments. Taguchi methods has been widely utilized in engineering analysis and consists of a plan of experiments with the objective of acquiring data in a controlled way and in order to obtain information about the behavior of a given processes. The greatest advantage of this method is to save the effort in cost by finding out significant factors fast . Taguchi parameter design offers a simple, systematic approach and reduce number experiment to optimize design for performance ,quality and cost. Taguchi method offers the quality of produce is measured by quality characteristics such as: nominal is the best, smaller is better and larger is better

.

## 5.8 Analysis Software:

MINITAB statistical software is used in this study selecting the types of design to be used for running the experiments, to display all possible combination of controllable factors and analyzing data representing main

and interaction relationship between the this software provides a wide rang of basic and advanced data analysis capabilities.

### 5.8.1 Minitab advantages:

- Comprehensive statistics capabilities, including exploratory data analysis, and simulations and distributions.
- High –resolution graphics.
- A design experiments capability allows the user to generate and analyze full and fractional design.

-

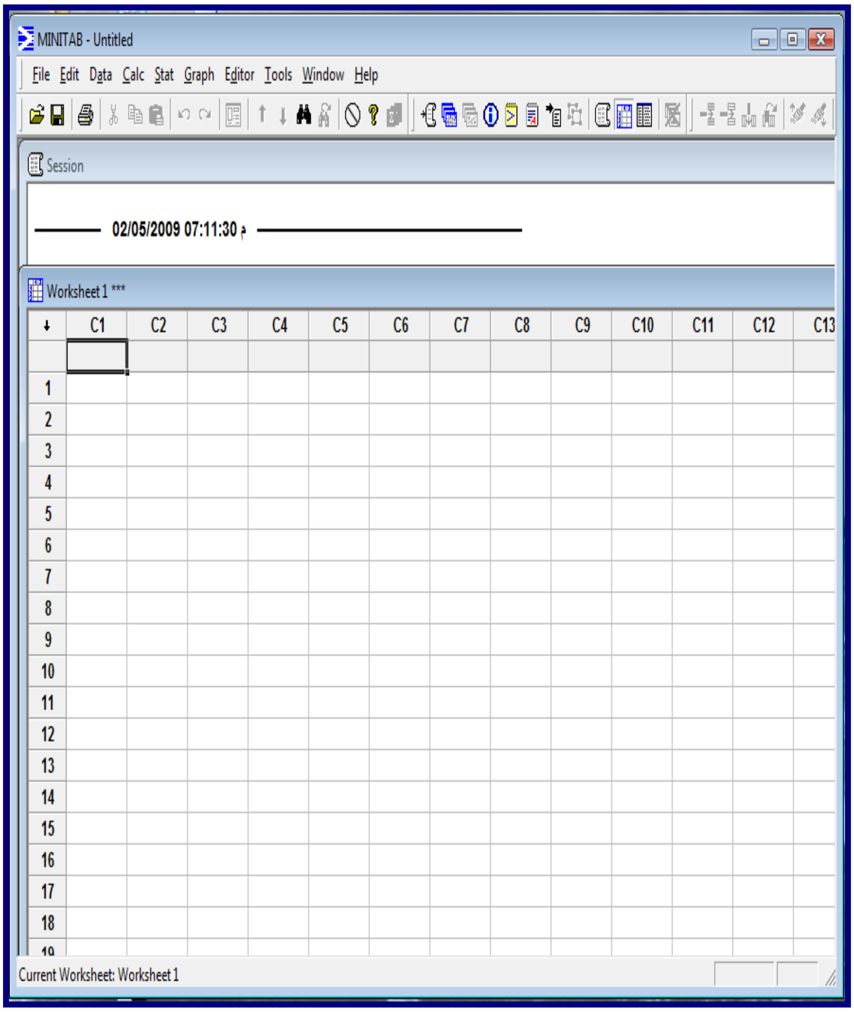



**Figure 5.10 Analysis Software**

# CHAPTER SIX

# RESULTS AND DISCUSSION

## 6 .1 Procedure and steps of Taguchi parameter Design:

The procedure of the Taguchi design is described in ( figure 6.1) The procedure of Taguchi design method can be divided into seven steps . The steps of Taguchi optimization are presented in as following:

1- Select the Quality characteristic.

2- Select noise factors and control factors.

3- Select Orthogonal Array.

4- Conduct the experiments.

5- Analyze results: determine optimum factor –level combination.

6- Predict optimum performance.

7- Confirm Experimental Design.

**Figure 6.1 procedure and steps of Taguchi parameter design.**

## 6.2 Outline Of Thesis Work:

It is found already many work has been done in MRR and Surface finish but very little work has been done on optimization of Plasma Arc Cutting. Here the work thesis work I will try to find out optimal value of MRR and Surface Roughness (Ra). For this consult to Fabrication Division of they suggested that Stainless Steel (304) materials are cheaply available and widely used in Plasma Cutting Machine .Taguchi method using design of experiments approach can be used to optimize a process

Here we apply D.O.E approach for modeling of MRR in PAC process and the various input parameters will be taken under experimental investigation and then model will be prepared then again experimentation work will be performed. The results obtain will be analyzed and the models will be produced by using MINITAB software. This will help in improving the effective and efficient working of the PAC process.

## 6.3 Various Input parameters:

1- Current.

2- Arc Gap.

3- Cutting Speed.

4- Gas Pressure

After extensive brain storming with the experts of Fabrication Division of it has been found that above are important input parameters for studying material remove rate .

perform the work on Silvering make Plasma Arc Cutting Machine No. B/0/2163 and after literature review four main input parameters selected are **Gas Pressure, Current Cutting Speed, and Arc Gap.** The material used is **Stainless Steel 304** in the overall experiment.

### 6.3.1 Selection of control factors:

The objective of this research work is to study MRR and Surface roughness, the design variables can be summarized as follows:

a) Three levels of the Gas Pressure (6Bar 6.5Bar and 7Bar).

b) Three levels of Current (150A 175A and 200A).

c) Three levels of Cutting Speed (400mm/min 500mm\min and 600mm/min).

d) Three levels of Arc Gap (2mm 3mm and 4mm).

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely Gas Pressure, Current, Cutting Speed and Arc gap) which would constitute the (304) orthogonal array. The two most important outputs are Material Removal Rate and Surface Roughness the same have been selected as response parameters for this research work also. The effect of the variation in input process parameter will be studied on these two response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor. The following machining parameters were kept fixed [15].

**Table 6.1 Fixed Machining Parameters**

| S.NO | Machining | Fixed value |
|---|---|---|
| 1- | Material type | Stainless steel (304) |
| 2- | Material Thickness | 1.2mm |
| 3- | Operation voltage | 200 V |

**Table 6.2 SELECTION OF ORTHOGONAL ARRAY AND PARAMETER ASSIGNMENT**

| Parameter | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| **Gas pressure** | Bar | 5 | 5.5 | 6 |
| **Current** | Ampere | 150 | 175 | 200 |
| **Cutting Speed** | mm\|min | 400 | 500 | 600 |
| **Arc gap** | Mm | 2 | 3 | 4 |

## 6.3.2 Selection of Orthogonal Array:

One of the steps included in the Taguchi parameter design is selecting the proper orthogonal array (OA) according to the number of controllable factors parameter [27.28]since three factors were studied in the research , for each three levels of each factor were considered . There for L9 Orthogonal Array was selected for each experiment of stainless steel

#### 6.3.2.1 Standard L9 Array with (3*4):

**Table 6.3 Experimental Layout in Coded Factor Levels**

| Exp No | Air | Current | Speed | Gap |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

The above table displays the L9 (3*4) Taguchi design (orthogonal array). L9 means 9 runs. 3*4 means 4 factors with 3levels each. This array is orthogonal; factor levels are weighted equally across the entire design. The table columns represent the control factors, the table rows represent the runs (combination of factor levels), and each table cell represents the factor level for that run.

After deciding parameters and levels as shown above orthogonal array L9 decided as per degree of freedom of each factor and doff of interaction

among the parameters. Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review. Now perform experiment as per orthogonal array (L9) on **Plasma Arc Cutting Machine Number PP260A**, output like MRR and surface roughness is being given in tabulated form. After the 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.. Then we calculated S/N ratio for MRR and surface roughness of specimens. Then we obtain optimal conditions has been calculated for MRR and surface roughness of specimen. The following table shows readings of MRR and surface roughness at each experiment, it also shows S/N ratio for MRR and surface roughness at each experiments.

## Table 6.4 MATERIAL REMOVAL RATE RESULT

| Exp No | Air | Current | speed | Gap | 1 | 2 | 3 | Avg |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 28.5 | 28.3 | 28.1 | 28.3 |
| 2 | 1 | 2 | 2 | 2 | 28.0 | 28.2 | 28.4 | 28.2 |
| 3 | 1 | 3 | 3 | 3 | 27.4 | 27.9 | 27.1 | 27.4 |
| 4 | 2 | 1 | 2 | 3 | 29.7 | 29.4 | 29.3 | 29.4 |
| 5 | 2 | 2 | 1 | 3 | 28.0 | 28.4 | 28.2 | 28.2 |
| 6 | 2 | 3 | 1 | 2 | 28.9 | 29.2 | 28.6 | 28.9 |
| 7 | 3 | 1 | 3 | 2 | 29 | 29.7 | 29.1 | 29.2 |
| 8 | 3 | 2 | 1 | 3 | 28.7 | 28.5 | 28.1 | 28.4 |
| 9 | 3 | 3 | 2 | 1 | 29.1 | 29.6 | 29.4 | 29.4 |

**Table 6.5 Surface Roughness Results**

| Exp | Air | Current | Speed | Gap | 1 | 2 | 3 | Avg |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 3.801 | 3.785 | 3.860 | 3.846 |
| 2 | 1 | 2 | 2 | 2 | 3.853 | 3.969 | 3.995 | 3.969 |
| 3 | 1 | 3 | 3 | 3 | 3.480 | 3.458 | 3.438 | 3.458 |
| 4 | 2 | 1 | 2 | 3 | 3.926 | 3.951 | 3.976 | 3.951 |
| 5 | 2 | 2 | 3 | 1 | 2.598 | 2.674 | 2.636 | 2.636 |
| 6 | 2 | 3 | 1 | 2 | 3.608 | 3.703 | 3.680 | 3.663 |
| 7 | 3 | 1 | 3 | 2 | 4.393 | 4.352 | 4.175 | 4.306 |
| 8 | 3 | 2 | 1 | 3 | 4.001 | 4.123 | 3.959 | 4.025 |
| 9 | 3 | 3 | 2 | 1 | 4.573 | 4.351 | 4.679 | 4.534 |

**Table 6.6 Material Removal Rate Result**

| A | B | C | D | MRR1 | MRR2 | MRR3 | MRRA | SNRA1 |
|---|---|---|---|---|---|---|---|---|
| 5.0 | 150 | 400 | 2 | 28.5 | 28.3 | 28.1 | 28.3000 | 29.0353 |
| 5.0 | 175 | 500 | 3 | 28.0 | 28.2 | 28.4 | 28.2000 | 29.0045 |
| 5.0 | 200 | 600 | 4 | 27.4 | 27.9 | 27.1 | 27.4667 | 28.7742 |
| 5.5 | 150 | 500 | 4 | 29.7 | 29.4 | 29.3 | 29.4667 | 29.3862 |
| …..5.5 | 175 | 600 | 2 | 28.0 | 28.4 | 28.2 | 28.2000 | 29.0045 |
| 5.5 | 200 | 400 | 3 | 28.9 | 29.2 | 28.6 | 28.9000 | 29.2170 |
| 6.0 | 150 | 600 | 3 | 29.0 | 29.7 | 29.1 | 29.2667 | 29.3260 |
| 6.0 | 175 | 400 | 4 | 28.7 | 28.5 | 28.1 | 28.4333 | 29.0755 |
| 6.0 | 200 | 500 | 2 | 29.1 | 29.6 | 29.4 | 29.3667 | 29.3565 |

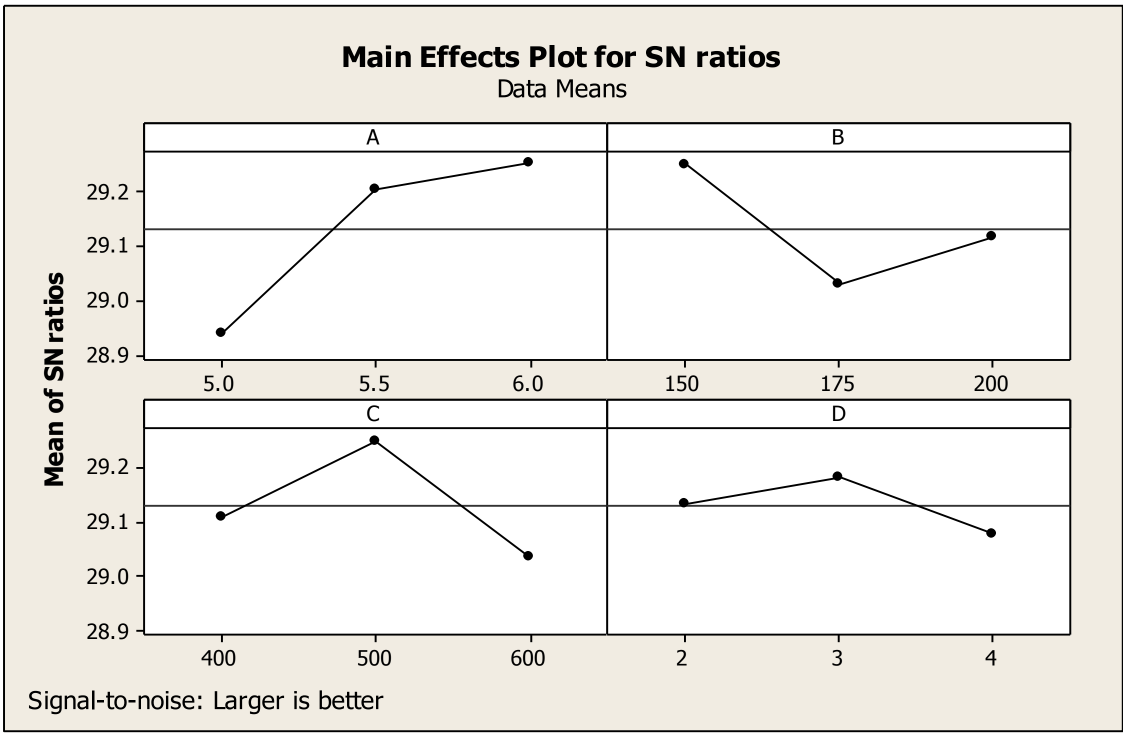



**Figure 6.2 Main Effects plot for s/n ratios for MRR**

By using MINITAB software we obtain some interactions if we look at the graph we will observe that with increase in Gas Pressure MRR S/N ratio is increasing. Material removal rate decreases with increase in Current, Cutting Speed and Arc gap.

Table (6.6) shows that the best material remover rate value was under the gas pressure (6 psi), current (150 A), cutting speed (500mm/s), Arc gap (3mm).

**Table 6.7 Surface Roughness Results**

| A | B | C | D | RA1 | RA2 | RA3 | RAV | SNRA1 |
|---|---|---|---|---|---|---|---|---|
| 5.0 | 150 | 400 | 2 | 3.801 | 3.785 | 3.860 | 3.81533 | -11.6310 |
| 5.0 | 175 | 500 | 3 | 3.853 | 3.969 | 3.995 | 3.93900 | -11.9088 |
| 5.0 | 200 | 600 | 4 | 3.480 | 3.458 | 3.438 | 3.45867 | -10.7783 |
| 5.5 | 150 | 500 | 4 | 3.926 | 3.951 | 3.976 | 3.95100 | -11.9343 |
| 5.5 | 175 | 600 | 2 | 2.598 | 2.674 | 2.636 | 2.63600 | -8.4195 |
| 5.5 | 200 | 400 | 3 | 3.608 | 3.703 | 3.680 | 3.66367 | -11.2788 |
| 6.0 | 150 | 600 | 3 | 4.393 | 4.352 | 4.175 | 4.30667 | -12.6849 |
| 6.0 | 175 | 400 | 4 | 4.001 | 4.123 | 3.959 | 4.02767 | -12.1024 |
| 6.0 | 200 | 500 | 2 | 4.573 | 4.351 | 4.679 | 4.53433 | -13.1342 |

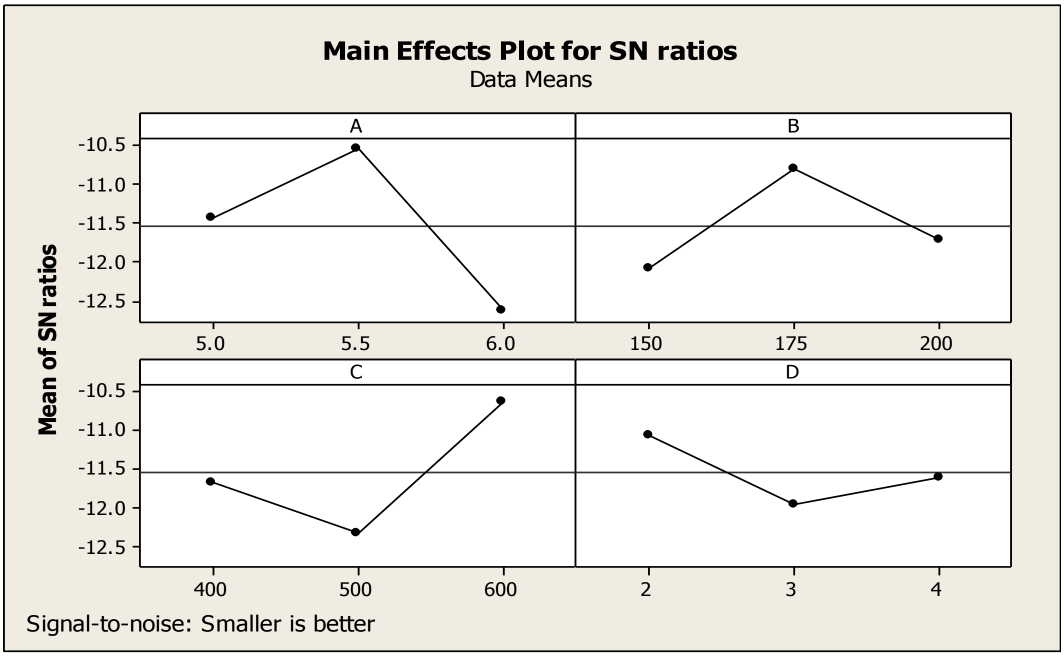



**Figure 6.3 Main Effects plot for s/n ratios for Surface Roughness**

Figure(6.3) represent the effect of parameters on Surface Roughness. It can be seen that as value of Gas Pressure and Current increases, S/N ratio of Surface roughness also decreases. However S/N ratio of Surface roughness increases with increase in the Cutting Speed and Arc Gap.

## 6.4 Analysis Of Variance (ANOVA)

Since as already stated ANOVA help us to identify which parameter is important for us after literature review following ANOVA table is obtained for MRR and Surface roughness .Minitab 15 software is used for statistical calculation purpose.

**Table 6.8 ANOVA for MRR**

| Parameter | DOF | SS | MS | S | P | Contribution |
|---|---|---|---|---|---|---|
| Gas pressure | 1 | 0.2456 | 0.2456 | 0.27 | 0.678 | 1.4392 |
| Current | 1 | 0.0343 | 0.0343 | 0.2 | 0.733 | 1.0016 |
| Cutting speed | 1 | 9.1254 | 11.1254 | 18.75 | 0.005 | 63.34 |
| Arc Gap | 1 | 0.8056 | 0.8056 | 1.98 | 0.193 | 5.42 |
| Residual Error | 11 | 4.7162 | 0.51879 | | | 32.09 |
| | 15 | 14.9271 | | | | 100 |

Table 6.8. shows the Analysis of Variance (ANOVA) for MRR response. The important information can be obtained here is the percentage influence2 of all factors over responses. P value less than 0.0500 indicate model terms are significant. In this case Cutting Speed is significant model term. Values greater than 0.1000 indicate the model terms are not significant. The percentage contribution by each of the

process parameter in the total sum of squared deviation SSt can be used to evaluate the importance of the process parameter change on the quality characteristic.

**Table 6.9** ANOVA for Surface Roughness (Ra)

| Parameters | DOF | SS | MS | F | P | Contribution |
|---|---|---|---|---|---|---|
| Gas pressure | 1 | 4.7795 | 4.7795 | 5.45 | 0.040 | 12.22 |
| Current | 1 | 5.6862 | 5.6862 | 6.48 | 0.027 | 14.53 |
| Cutting speed | 1 | 18.9228 | 18.9228 | 21.58 | 0.001 | 48.36 |
| Arc Gap | 1 | 0.0912 | 0.0912 | 0.10 | 0.753 | 0.23 |
| Residual Error | 11 | 9.6452 | 0.8768 | | | 24.65 |
| Total | 15 | 39.1250 | | | | 100 |

From table 6.9 we can conclude that Gas Pressure, Current and Cutting Speed are significant terms because their P values are less than 0.05. P values greater than 0.01 indicates that model terms are not significant. The P value for the factor Arc Gap is 0.753 which is not significant. There is 75.3% chance that a this large could occur due to noise. The percentage contribution by each of the process parameter in the total sum of squared deviation SSt can be used to evaluate the importance of the process parameter change on the quality characteristic.

## 6.5 Confirmation Test:

From 2S/N ratio and mean of each level of every factor we will construct response table for MRR and Surface Roughness which are given below:

**Table 6.10 Response for S/N ratio of MRR**

| Leve | Gas pressure | Current | Cutting speed | Arc GAP |
|---|---|---|---|---|
| 1 | 28.94 | 29.25 | 29.11 | 29.13 |
| 2 | 29.20 | 29.03 | 29.25 | 29.18 |
| 3 | 29.25 | 29.12 | 29.03 | 29.08 |
| Effect | 0.31 | 0.22 | 0.21 | 0.10 |
| Rank | 1 | 2 | 3 | 4 |

From above response table and main effect plot of MRR we can conclude that the o ptimum condition for MRR is, A3 B1 C2 D2 i. e:

Gas Pressure:6 Bar Current: 150 A

Cutting Speed: 500 mm/min

Arc Gap: 3mm

Similarly we can create the response table for S/N ratio of Surface Roughness.

**Table 6.11Response for S/N ratio of Surface Roughness**

| Level | Gas Pressure | Current | Cutting speed | Arc Gap |
|---|---|---|---|---|
| 1 | -11.44 | -12.08 | -11.67 | -11.06 |
| 2 | -1054 | -10.81 | -12.33 | -11.96 |
| 3 | -12.64 | -11.73 | -10.63 | -11.60 |
| Effect | 2.10 | 1.27 | 1.70 | 0.90 |
| Rank | 1 | 3 | 2 | 1 |

From the above table and main effect graph of Surface Roughness we can say that optimal levels of parameters for SR are A2 B2 C3 D1 i. e.

Gas Pressure:5 Bar

Current: 175A

Cutting Speed: 600 mm/min

Arc Gap: 2 mm

After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated Optimum S/N ratio using the optimal level of the design parameters can be calculated:

$$\eta = \eta m + \sum_{i=1}^{q} (\eta - \eta m) \ldots\ldots\ldots\ldots (1)$$

where,

$\eta_m$ is the total mean of the multi response signal-to-noise ratio,

$\eta_i$ is the mean of the multi-response signal-to noise ratio at the optimal level, and q is the number of the process parameters that significantly affect the multiple quality characteristics.

Based on the above equation the estimated multi response signal to noise ratio can be obtained.

### 6.5.1 Prediction of Optimum Value of MRR:

$$\eta = \eta m + \sum_{i=1}^{q} (\eta - \eta m) \ldots\ldots\ldots\ldots\ldots (2)$$

Here $\eta = 29.131$

Optimum S/N Ratio for MRR = 29.131 + (28.94-29.131) + (29.03-29.131) + (29.25 - 29.131) + (29.18 - 29.131)

Y = 29.007

And the corresponding value of MRR = $Y_{OPT}$ = 10 ∗ 1/$\eta^{\hat{}opt}$/10 = 0.03447

| Predicted Optimum Value of MRR, | Yopt = 0.18567 g/sec |
|---|---|

### 6.5.2 Prediction of Optimum Value of SR:

$$\eta=\eta m+\sum_{i=1}^{q}(\eta - \eta m)\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Here $\eta$=-11.5413

Optimum S/N Ratio for SR = -11.5413 + (-10.54+11.5413) + (-10.81+ 11.5413) + (-10.63 + 11.5413) + (-11.06 + 11.5413)

Y= -8.4161

And the corresponding value of SR = Yopt =10 1/-n/10 =0.11882

| Predicted Optimum Value of SR | Yopt = 0.3447m |
|---|---|

Once the optimal value of MRR and SR is predicted, the final step is to verify the improvement of the quality characteristic using the optimal level of the process parameters.

**Table 6.12 Confirmation Test Result for MRR**

| Number | Pressure (bar) | Current (A) | Cutting speed (mm/min ) | Arc Gap (mm) | MRR(g/sec) |
|---|---|---|---|---|---|
| 1 | 6 | 150 | 500 | 3 | 0.1823 |
| 2 | 6 | 150 | 500 | 3 | 0.1874 |
| 3 | 6 | 150 | 500 | 3 | 0.1811 |

**Average: 0.1836**

**Table 6.13 Confirmation Test Result for SR (Ra)**

| Number | Pressure (bar) | Current (A) | Cutting speed (mm/min ) | Arc Gap (mm) | SR (□m) |
|---|---|---|---|---|---|
| 1 | 5 | 175 | 600 | 2 | 0.3447 |
| 2 | 5 | 175 | 600 | 2 | 0.3524 |
| 3 | 5 | 175 | 600 | 2 | 0.3276 |

**Average 0.341566**

After performing experiment as per given optimum levels for MRR and SR following results obtained:

**Table 6.14 Summary Table for Results**

| | | | |
|---|---|---|---|
| MRR (g/sec) | Optimum value of A3B1C2D2 = 0.1856 | Experimental result of A3B1C2D2= 0.1836 | Percentage = 0.00*18%* |
| Surface Roughness (μm) | Optimum value of A2B2C3D1 = 0.3447 | Experimental result of A2B2C3D1= 0.34156 | Percentage = 0.0034% |

So we can say that there is 0.34 % improvement in Surface Roughness and also MRR reduce with0.18 %. This finding indicated that the experiments in this study possess excellent repetitiveness and great potential for future reference.

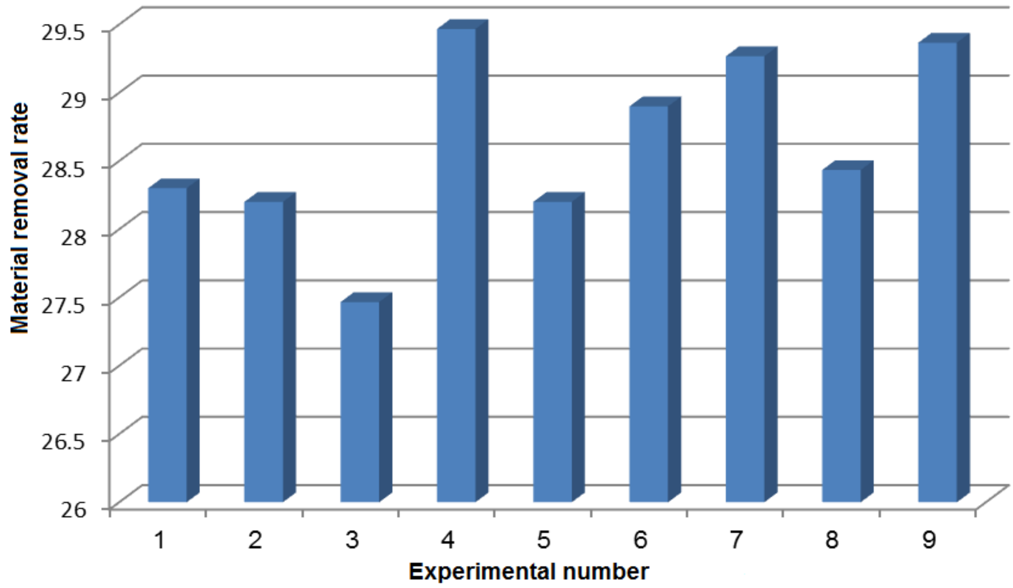



**Fig6.4 . illustrate the chart of material removal rate vs experimental number**

Figure(6.4) show the material removal rate (MRR) graph after plasma cutting process of stainless steel. Work piece using different plasma cutting parameters. The graph shows that the best material removal rate is the experiment number 4 becouse it has the largest value ( the largest is the best)

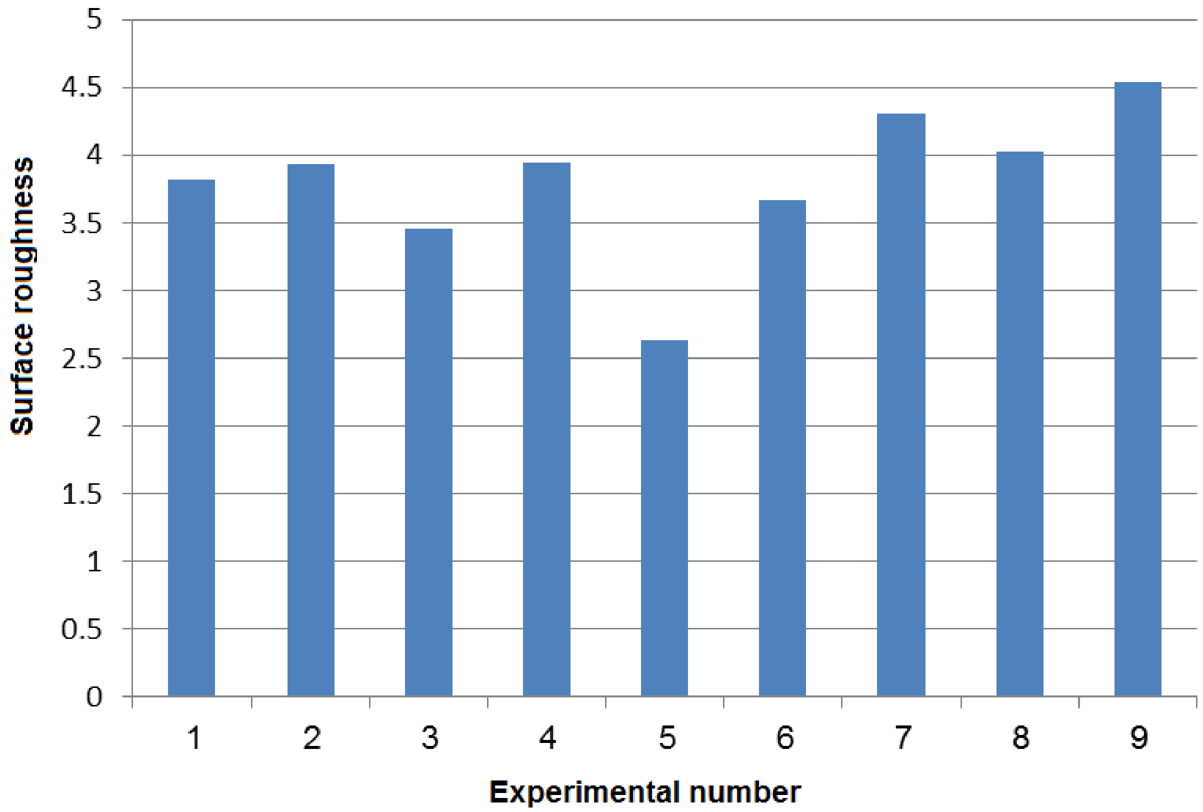



**Figure 6.5 illustrate the chart of surface roughness vs experimental number**

Figure(6.5) show the surface roughness (Ra) graph after plasma cutting process of stainless steel. Work piece using different plasma cutting parameters. The graph shows that the best surface roughness is the experiment number 5 becouse it has the smalest value ( the smalest is the best)

### 6.5.3 Kerf surface characterization .

The micro structural characterization of the kerf surface has been performed by means of multi-focal optical microscopy, scanning electron microscopy (SEM) with energy dispersive microprobe (EDS) for localized elemental analysis. Cross sections of two specimens (A, B) were cut and mounted in epoxy resin for metallographic analysis..

**Samples (A)**

**Samples (B)**

**Fig. 6.6 Macrographs (by multifocal optical microscopy) showing portions of the surface of AISI 304 samples cut at different operating parameters.**

Metallographic samples were polished by means of grit papers and diamond paste up to 1 μm, then chemically etched with Beraha II reactant (50% HCl, 0.8-1.0 $K_2S_2O_5$, 1% $NH_4F \cdot HF$) [7] for the observation of the cross sections with optical microscopy (OM)and SEM.

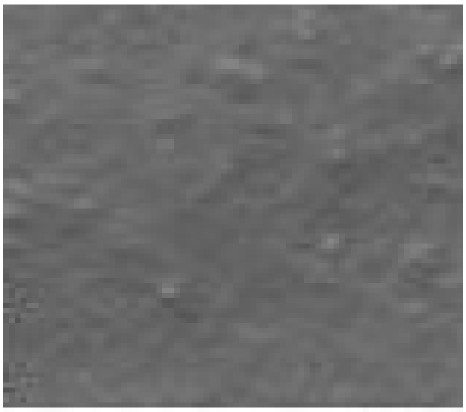
### 6.5.4 Microstructure.

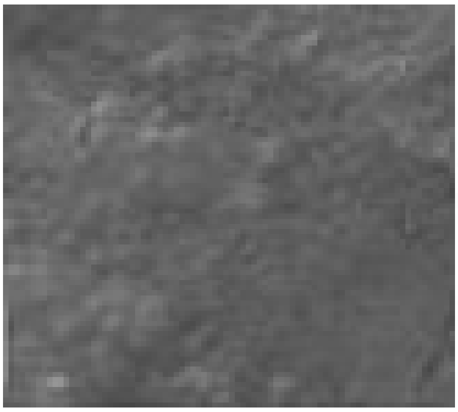
**Introduction .**

Tow samples of stainless steel (304) were prepared for microstructure .These were done to measure the melted surface lager and the evaluation of the effect of heating on material microstructure and atomic element concentration .

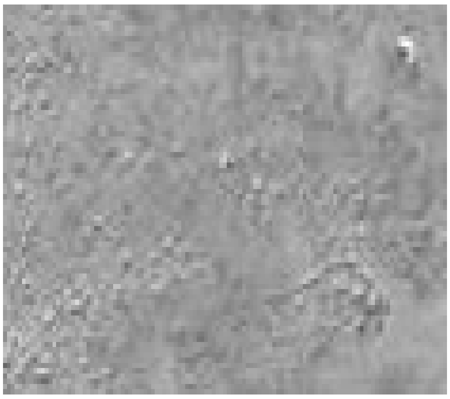
#### 6.5.4.1 Micro structural characterization

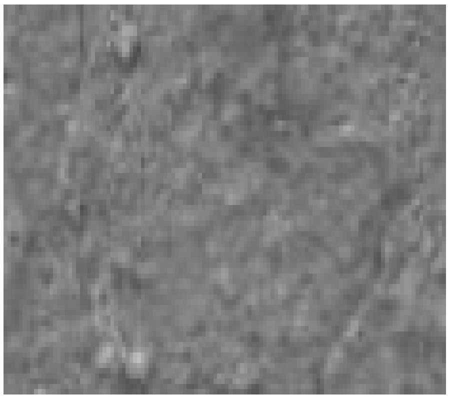
Depending on the different cutting conditions, the kerf surface exhibited a variety of distinguishable colours (Fig. 6.6), related to the physical properties of surface oxide layers [8]. It is known that the thin film interference effect can influence the appearance of a semi-transparent oxide coating when the coating thickness is on the order of the wavelength of the light incident on a specimen (400-700 μm for visible light).





**Samples (A) 50µm** **Samples (A) 10µm**





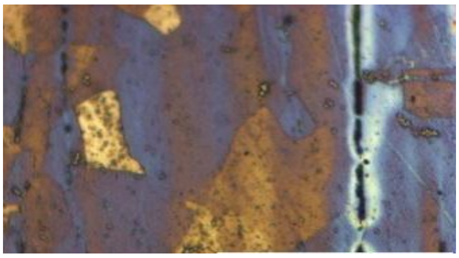
**Samples (B) 50µm** **Samples (B) 10µm**

**Fig. 6.7 SEM micrographs showing the surface of different AISI 304 samples cut at different operating parameters.**

In particular, constructive interference is likely to occur when the oxide thickness is equal to $\lambda/4n$ where n is the index of refraction for the oxide [9]. Apparently, the use of plasma cutting gas rich in nitrogen gave rise to darker surfaces (Fig. (6.6) A and B)

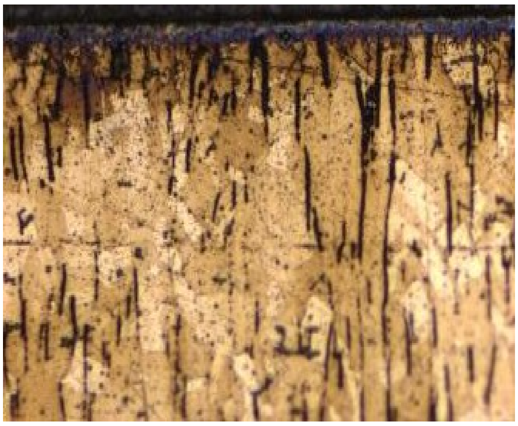
### 6.5.4.2. Cross sections

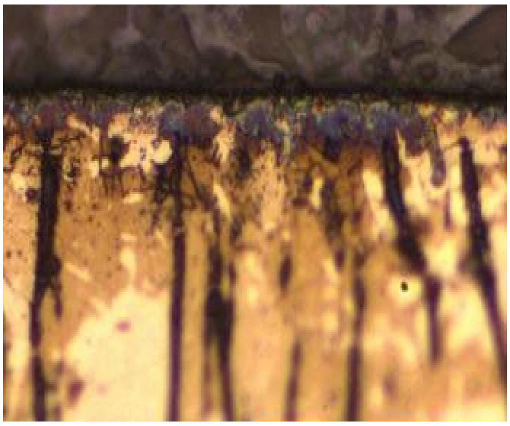
The base material shows a typical austenitic microstructure with a relevant presence of supplied inclusions (Fig. 6.8), preferentially elongated along the rolling direction. After being exposed to plasma the kerf surface exhibits the presence of a remolded surface layer. Sample A (H35) shows a layer with thickness ranging between 5 - 35 μ m along the kerf height (Fig. 4) while sample B (30% H35 – 70% N2) shows a layer between 160-180 μ m (Fig. 6.10). ). A dendritic microstructure characterized the melted zones (Fig.6.10). Both samples are 15 mm thick and have been cut at the speed of 2000 mm/s. For the same cutting speed a higher content of N2 as plasma gas causes a thicker remolded steel layer. This is probably caused by the higher thermal conductivity and heat capacity of the sample B cutting mixture that has a reduced amount of monatomic species (Ar) in favor of diatomic species (N2 and H2) with respect so sample A.



**Samples (A) 100μ** **Samples (B) 50μm**

**Fig. 6.8 AISI 304 base material microstructure (optical micro-scope).**

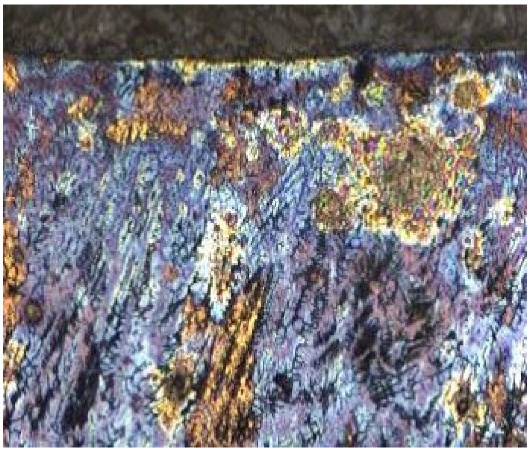


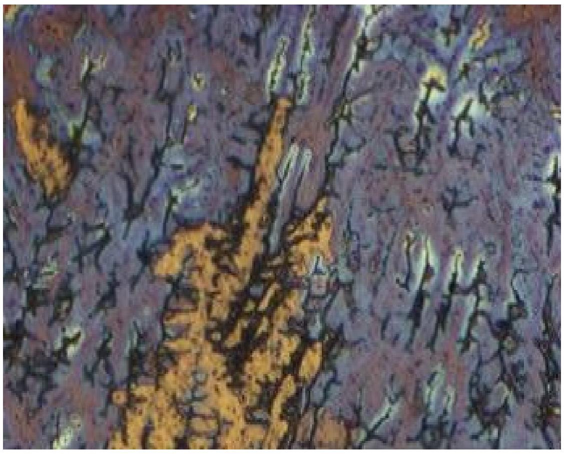


Samples (A) 100µm

Samples (A) 50µm

**Fig. 6.9 Cross section of sample A (top: optical microscope, bottom: SEM)**

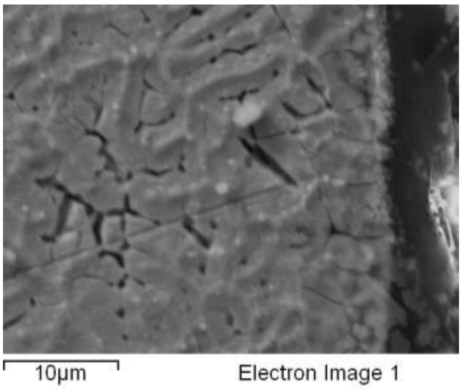




Samples (B) 100µm

Samples (B) 50µm

**Fig. 6.10 Cross section of sample B (top: optical microscope, bottom: SEM).**



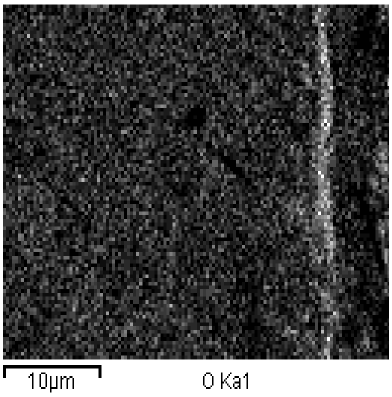



**Fig. 6.11 EDS oxygen concentration mapping of the sample B melted layer.**

## 6.5.4.3 Mechanical Testing

6.5.4.3.1 Hardness testing.( HV)

| **HAZ** | 10mm from HAZ | 20mm from HAZ | 30mm from HAZ |
|---|---|---|---|
| 46.4 | 44.3 | 41.5 | 40.1 |

The harding test ulistrate that the maximum hardenss was at heat effecting  zone, also the result in the above table indicate that the hardness decreass as we travel away from the heat effecting zone.

### 6.5.5 Results:

The Optimum levels of parameters for **maximizing MRR** are A3 B1 C2 D2 .

Gas Pressure: 6 Bar. Current: 150 A. Cutting Speed 500 mm/min.

Arc Gap: 3 mm.

The optimum levels of parameters for **minimizing Surface Roughness (Ra)** are A2 B2 C3 D1 .

Gas Pressure: 5 Bar. Current: 175 A. Cutting Speed: 600 mm/min.

Arc Gap: 2 mm.

After performing experiment as per given optimum levels for MRR and SR following results obtained:

Results Before and After Optimization.
MRR (g/sec) Predicted value of A3 B1 C2 D2 = 0.1856.
Experimental result of A3 B1 C2 D2=0.1836.
Percentage = 0.0018%.
Surface Roughness (μm). Predicted value of A2 B2 C3 D1 = 0.3447.
Experimental result of A2 B2 C3 D1=0.3415. Percentage = 0.0034%.

So we can say that there is 0.34 % improvement in Surface Roughness and also MRR reduce with0.18 %. This finding indicated that the experiments in this study possess excellent repetitiveness and great potential for future reference

### 6.5.6 DISCUSSION

- As per analysis, the significant parameter for optimum MRR calculation is Cutting Speed and the significant parameters for Surface Roughness calculation are Gas Pressure, Current and Cutting Speed.
- Although some parameters are not significant but we able to improve MRR and Surface Roughness.
- Table 6.8 shows the analysis result for MRR. In this case speed is significant model term. In the model term graph for speed is increase for MRR. It can determined that when the level of the factor increased, the MRR response also increase significantly. Values greater than 0.1000 indicate the model terms are not significant. Speed factor are most important to measured maximize Metal Removal Rate (MRR) for Stainless Steel (304) Material. Another factors influence for MRR is equipment system and environments. The equipment systems, torch vibration, nozzle gag (blocking air), and working table area are each factors influence MRR.
- Table 6.9 shows the ANOVA result for Ra. P values less than 0.0500 indicate model terms are significant. In this case there are Gas Pressure, Current and Cutting Speed are significant terms. In the main effect term graph for pressure and current are increased for minimizing Ra, and the speed is decreased for minimizing Ra

# CHAPTER SEVEN

# CONCLUSION AND RECOMMNDATION

## 7.1 Conclusion:

**1-** This thesis has presented an application of the Taguchi method to the optimization of the machining parameters of Plasma Arc Cutting Machine. As shown in this study, the Taguchi method provides a systematic and efficient methodology for determining optimal parameters with far less work than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal parameters. It has been shown that Material Removal Rate (MRR) and Surface Roughness (Ra) can be significantly improved in the Plasma Arc Cutting process using the optimum level of parameters. Plasma Arc Cutting Machine is widely utilized in AJAN company to cut materials such as Stainless Steel and steel Alloys. This is the basis work where Plasma Arc Cutting was utilized to perform the material removal process at finishing stage. The Plasma Arc Cutting (PAC) machining of Stainless Steel (304) has been performed with the application of combination with design of experiment (DOE).The PAC parameters studied were how to have setting for the parameter such as Gas Pressure, Current flow, Cutting Speed and Arc gap of machine. From ANOVA of **MRR** we can say that some parameters are not making any significant effect. This is because we must take large number of observations either by considering L18 0r L27 orthogonal array with 3 level designs .

**2-** In the present work, the effects of different Ar/H2/N2 plasma gas mixtures on the micro structural modifications of the AISI 304 stainless steel in high current (200A) plasma cutting has been experimentally investigated. The kerf surface always shows a presence of a remelted layer whose thickness is proportional to the heating capacity of the plasma cutting gas mixture. A higher percentage of diatomic species (N2 and H2) increases the deepness of the layer for samples A and B, from 5 to 180 **µ m**. A thin oxygen rich layer of about 1m is always formed on the kerf surface and it is responsible of the characteristic colour of the surface. For 15 mm plate thickness and fixed cutting speed, micro structural analysis of samples A (H35), B (H35 30% - N2 70%) showed that the amount of atomic oxygen on the kerf surface can be significantly reduced if a plasma cutting gas very rich in N2 is used, with the drawbacks of a thicker remelted layer and the presence of atomic nitrogen on the surface. However, comparisons between samples A and B shows that sample B, with lower oxygen amount but higher nitrogen content, has a darker colour with respect to sample A. For this reason, it can be concluded that the surface colour cannot be directly related only to the oxidation level, but more generally to the chemical composition and thickness of the external layer. A qualitative analysis of the colour surface can be used to evaluate general overheating but cannot be used as a standalone evaluation to distinguish between different oxidation levels and remelted layer thicknesses.

The harding test ulistrate that the maximum hardenss was at heat effecting zone, also the result in the above table indicate that the hardness decreass as we travel away from the heat effecting zone.

## 7.2 Recommendation And Future Work :

Based on result and discussion summary, this project had archive it main objective but an improvement still can be done to improve more on the Metal Removal Rate (MRR) and Surface Roughness (Ra) of parts by features. Some of the suggestions to improve the result include the replication of the model which can reduce the variations of the data and increase the reliability of the data. Based on this work many improvements can be made and the scope can also be widened. Following are suggestion for future work:

A. Using Plasma Arc Cutting system, add the parameter such as Kerf, Voltage, angle, material dimension, and change advance material such as brass and bronze then compare the result obtained.

B. Using other methodology in the same material of study to compare the results obtained such as Response Surface Methodology, Grey Relational Analysis, and Genetic Algorithm etc.

C. Study for manual calculation for other method in DOE to improve knowledge and skills.

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