(IJITR) INTERNATIONAL JOURNAL OF INNOVATIVE TECHNOLOGY AND RESEARCH
Volume No.5, Issue No.2, February – March 2017, 5777-5783.

# Analysis Of Oxy-Fuel Cutting Process Parameters Using Grey-Taguchi Technique For Mild Steel HRE350

**MOOLI HARISH**
Assistant Professor, Dept. of Mechanical Engineering
VEMU Institute of Technology, P.Kotha Kota, AP.

**P.KUMAR BABU**
Professor, Dept. of Mechanical Engineering
VEMU Institute of Technology, P.Kotha Kota, AP.

*Abstract:* **The aim of present study is to investigate the effect of process parameters such as Gas pressure, Cutting speed and Torch distance on the output responses in oxy fuel cutting. The work is also extended to optimize the process parameters to achieve the optimized responses during oxy fuel cutting of Mild steel HR E350 using grey taguchi technique.. In this research $L_{27}$ orthogonal array (OA) was selected for conducting experiments. The process responses such as Surface roughness (Ra) and kerf width ($k_w$) are measured for every experimental run. The purpose of optimization is obtaining minimum surface roughness and minimum kerf width simultaneously. For optimization Grey relational analysis which is coupled with Taguchi Technique is selected. Analysis of variance (ANOVA) is done for finding significant process parameters and also for finding percentage of contribution of each process parameters in oxyfuel cutting. Finally a statistical technique called response surface methodology has been used for study the effects of the process parameters on surface roughness and kerf width by using design expert 9.0.3.1.**

*Key words:* **HRE 350; $L_{27}$ Orthogonal Array; RSM; $R_a$ And Kerf Width;**

## I. INTRODUCTION

### *1.1 Oxy-Fuel cutting (OFC)*

The oxy fuel cutting process is generally used in many metal manufacturing industries. The process begins by heating a small area of metal surface to an ignition temperature by using oxy fuel gas flame. On obtaining ignition temperature of metal the oxygen stream is directed at pre heated spot, causing rapid oxidation of the heated metal and generating large amounts removal of material. Oxy fuel cutting does not required supporting devices that are fixtures and jigs for holding and guiding the work piece because it is a non-contact operation. Moreover, it does not need costly or disposable tools and does not produce mechanical force that can damage thin work pieces.

For cutting of metallic plates, general purpose shears are used. These are suitable only straight line cuts and cuts up to limited thickness. When the thicker plates and cuts to be made a specified contour shearing cannot be used. Controls of these problems we are consider the oxy fuel gas cutting up to 200mm thickness.

In this process oxidize iron and steel when it is heated to a temperature between 800°c to 1000°c. When a high pressure oxygen jet with a pressure of 300kpa is directed against a heated steel plate. The oxygen jet burns the metal and blows it away causing the cut (Kerf).The oxy acetylene gas cutting outfit is similar to that of oxy acetylene welding except for the torch tip. Here the torch tip has a provision for preheating the plate as well as providing oxygen jet. Thus the tip has central holes for preheating flame s shown in figure. That means heating the metal to kindling temperature then passing the stream of oxygen removal of metal takes place as an oxide slag to create the kerf.

This process is invented in 1887 by Thomas Fletcher is extensively used for cutting steel plates of various thickness, mainly because the equipment required is simple and can be carried anywhere without handling heavy steel plates. Another important application of gas cutting is in the making of bevels for edges to be used in subsequent welding purpose. Oxy fuel cutting would be useful only for those materials which readily get oxidized and the oxides have lower melting points than metals. Thus it is most widely used for ferrous materials. But it cannot be used for material such as Aluminium, bronze, stainless steel and like metals since they resist oxidation.

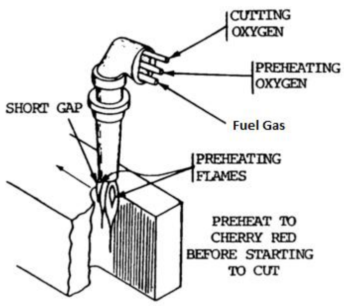


***Fig1. Schematic diagram of oxy fuel cutting process***

There are many researchers were studied oxy fuel cutting process. Some of literatures are given below:

  

**[Patricia Muñoz-Escalona et.al]**AISI 1045 carbon steel was cut using oxyacetylene and an oxypropane cutting process. Different tests, such as surface roughness, cut drag displacement; groove width, micro hardness, and microstructure were used to analyze the influence of the Vc and the combustion flame (oxyacetylene and oxypropane). His done the good surface finish is obtained at low cutting speeds due to characteristics and nature of a flame. The surface roughness increase while increasing acetylene and propane. By the using of oxypropane less slag adherence to the cut surface, the cutting drag displacement decreases and groove width willbe smaller. Hardness values of cutting surface are higher when using oxyacetylene.

**[N. Osawa, et.al]** A genetic algorithm based technique is used for finding the local heat transfer coefficient,α andthe gas temperature adjacent to the plate, TG and HYDROGEN-LP mixed gas and LPG are used as preheating gases. In these research to find time taken to the heating face temperature to the kindling temp. In these study to find the piercing time by numerical solutions.

The aim of this research is optimization of control variables namely gas pressure, Cutting Speed, torch distance for process responses. The process responses are surface roughness ($R_a$) and kerf width ($k_w$). For obtaining minimum $R_a$ and minimum kerf width, Grey relational analysis are coupled with taguchi technique is used in this research and additionally, ANOVA is performed on grey Relational grade to determine the percentage contribution of each control variables on grade and finally, RSM technique is employed for studying process parameters effects on Ra and $K_w$.

## II. EXPERIMENTAL PROCEDURE

### *2.1 Experimental setup*

Experiment was conducted on the CNC oxy-fuel cutting is shown in fig 2. (115/230V and 50-60 Hz), CNC oxy fuel cutting is comprised of machine tool, power supply unit, CNC control unit and machine tool unit. Machine tool unit comprises of work table, movable parts such as nozzle unit. Work piece is mounted and clamped on the work table. The gases used during cutting process are fuel gas as LPG gas and oxygen gas. For this research, the experiment was conducted with three control factors namely gas pressure, cutting speed and torch height and the process response variables are surface roughness (Ra) and kerf width (Kw). For measuring surface roughness Mitutoyo Talysurf equipment was used is shown in fig. 3 expressed in microns. Kerf width was measured by using tool makers' microscope.

*Fig 2: Oxy-fuel cutting equipment*

*Fig3: Talysurf equipment*

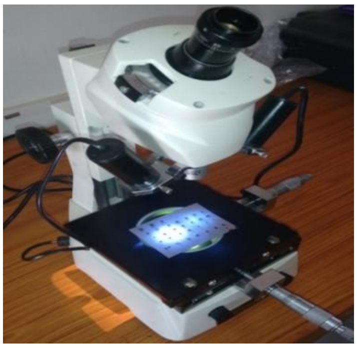

*Fig 4: tool makers' microscope*

### *2.2 Selection of work piece material*

The Mild steel HRE 350 plate was used as the work piece material in the experiment. Mild steel HRE350 material is a special engineering material. It is highly used in many industries and less expensive. The key applications of Mildsteel HR E350 include making of pipes, nuts and bolts, chains and ship buildings. The chemical composition and mechanical properties of MS HRE 350 is shown in table 1 and table2.

***Table 1: chemical composition (wt. %) of MS HRE 350***

| C | Mn | S | P | Si | Fe |
|---|---|---|---|---|---|
| 0.20 % | 1.55 % | 0.04 % | 0.04 % | 0.45 % | Balance |

***Table 2: Mechanical properties of MS HRE 350***

| **Property** | **Value** |
|---|---|
| Tensile strength(MPa) | 490 |
| Yield stress (MPa) | 320-350 |
| Percentage of Elongation | 22% |

  

### *2.3. Design of Experiment(DOE)*

Design of experiments (DOE) is one of tool for design and conducts the experiments. It is used to determine the relation between factors effecting the process and process responses. Taguchi Technique is used to finding the optimized machining process parameters in design of experiments. In taguchi technique the experiments are carried out as per the standard orthogonal arrays (OA). The selection of orthogonal array depends on the total degree of freedom (DOF).For the current research, process parameters have been selected 3 levels as shown in table.3.

***Table 3:Proces parameters and their levels***

| Process Parameters | Units | Symbo l | **Levels** | | |
|---|---|---|---|---|---|
| | | | **-1** | **0** | **1** |
| Gas pressure | Bar | A | 3 | 5 | 7 |
| Cutting Speed | mm/ min | B | 300 | 350 | 400 |
| Torch Distance | Mm | C | 7 | 10 | 13 |

In the present investigation to check the DOFs in the experimental design for the three level test, the three main factors take 6 is (3× (3-1)) DOFs. For three second order interactions (A×B, A×C, B×C) is 12.(3× (3-1) × (3-1)) and the total DOFs required is 18(6+12). SO $L_{27}$ OA is selected.

## III. EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental results for process responses such as Ra and kerf width is given in table 4.

***Table4: design of experiment with experimental results of Ra and Kerf width***

| **Exp. No.** | **Gas Pressure** | **Cutting speed** | **Torch Distance** | **$R_a$** | **$K_w$** |
|---|---|---|---|---|---|
| 1 | 3 | 300 | 7 | 1.32 | 1.51 |
| 2 | 3 | 300 | 10 | 1.49 | 1.31 |
| 3 | 3 | 300 | 13 | 1.57 | 0.25 |
| 4 | 3 | 350 | 7 | 1.45 | 1.17 |
| 5 | 3 | 350 | 10 | 1.57 | 0.67 |
| 6 | 3 | 350 | 13 | 2.05 | 0.65 |
| 7 | 3 | 400 | 7 | 1.57 | 0.75 |
| 8 | 3 | 400 | 10 | 1.69 | 0.75 |
| 9 | 3 | 400 | 13 | 1.77 | 0.99 |
| 10 | 5 | 300 | 7 | 1.86 | 2.22 |
| 11 | 5 | 300 | 10 | 2.36 | 1.29 |
| 12 | 5 | 300 | 13 | 2.38 | 1.2 |
| 13 | 5 | 350 | 7 | 2.16 | 1.97 |
| 14 | 5 | 350 | 10 | 2.10 | 1.46 |
| 15 | 5 | 350 | 13 | 2.41 | 1.05 |
| 16 | 5 | 400 | 7 | 2.27 | 1.75 |
| 17 | 5 | 400 | 10 | 2.20 | 1.21 |
| 18 | 5 | 400 | 13 | 2.4 | 1.21 |
| 19 | 7 | 300 | 7 | 2.11 | 2.27 |
| 20 | 7 | 300 | 10 | 2.12 | 1.77 |
| 21 | 7 | 300 | 13 | 2.42 | 1.96 |
| 22 | 7 | 350 | 7 | 3.03 | 1.91 |
| 23 | 7 | 350 | 10 | 2.73 | 1.89 |
| 24 | 7 | 350 | 13 | 3.09 | 1.43 |
| 25 | 7 | 400 | 7 | 2.84 | 1.95 |
| 26 | 7 | 400 | 10 | 2.54 | 1.77 |
| 27 | 7 | 400 | 13 | 2.71 | 1.5 |

### *3.1. Grey Taguchi technique*

Grey-Taguchi method is the development from the Taguchi method. For the optimization of multiple responses Grey Taguchi optimization technique is employed. By using Taguchi technique we can optimize process parameters for individual responses only. For overcome the disadvantage in the Taguchi technique, grey-relational analysis is coupled with taguchi technique for optimizing multiple responses.

#### *3.1.1. Grey-relation generation:*

Grey relation generation is the first step in the grey-taguchi technique. In this step, the process response values are normalized in the range of 0-1. In this research, Ra and kerf width are the process responses. In general, Ra and kerf width should be minimum for better cu quality, so minimization of surface roughness and minimization of kerf width is needed. For minimization of process responses lower the better criterion is used which is shown in eqn. 1. After substituting experimental results we can get normalized results of Ra and kerf width which is given in table 5.

  

***Table 5:.normalization of experimental result***

| Exp. No. | Normalized Result | |
|---|---|---|
| | **Ra** | **$K_w$** |
| 1 | 1 | 0.376 |
| 2 | 0.904 | 0.235 |
| 3 | 0.859 | 1 |
| 4 | 0.927 | 0.27 |
| 5 | 0.859 | 0.792 |
| 6 | 0.588 | 0.802 |
| 7 | 0.859 | 0.752 |
| 8 | 0.791 | 0.751 |
| 9 | 0.746 | 0.633 |
| 10 | 0.695 | 0.024 |
| 11 | 0.414 | 0.48 |
| 12 | 0.4 | 0.52 |
| 13 | 0.523 | 0.148 |
| 14 | 0.558 | 0.4 |
| 15 | 0.385 | 0.6 |
| 16 | 0.463 | 0.257 |
| 17 | 0.502 | 0.524 |
| 18 | 0.391 | 0.524 |
| 19 | 0.551 | 0 |
| 20 | 0.306 | 0.247 |
| 21 | 0.38 | 0.153 |
| 22 | 0.018 | 0.175 |
| 23 | 0.112 | 0.188 |
| 24 | 0 | 0.416 |
| 25 | 0.078 | 0.158 |
| 26 | 0.31 | 0.247 |
| 27 | 0.216 | 0.381 |

$Z_i\,(T) = \frac{\max Ki(T) - Ki(T)}{\max Ki(T) - \min Ki(T)}$ → (1)

Where $Z_i\,(T)$ = value after grey relation generation,

Min.$Ki(T)$= smallest value of $Ki(T)$ *for* the T$^{th}$ response

$maxki(T)$= Largest value of $Ki(T)$ for the T$^{th}$ response.

### *3.1.2. Grey relational coefficient:*

The second step in grey relational analysis is the calculation of grey relation coefficient. Grey relation coefficient are used to express the relation between actual and ideal=1 experimental results. The grey relation coefficient can be calculated as:

$$\varepsilon_i\,(k) = \frac{\Delta_{min} + \varphi\,\Delta_{max}}{\Delta_{oi}(k) + \varphi\,\Delta_{max}}$$

Where $\Delta_{0i}$=quality loss function=$|U_0\,(M) - U_i\,(M)|$, $\Delta_{min}$= minimum value of the differences of $\Delta_{0i}$.

$\Delta_{max}$ = Maximum value of the differences of $\Delta_{0i}$.

'Ψ' = distinguish coefficient which is used for, when $\Delta_{max}$ is too large, it helps to weaken its impact.

Generally, 'Ψ' value in the range of o to 1, for this research, we consider it as 0.5.

The grey relational coefficient values for Ra and kerf width are given in table 6.

***Table 6:.Grey relational coefficient data for normalized values of Ra and Kerf width***

| Exp. No. | Grey relational coefficient | |
|---|---|---|
| | **Ra** | **$K_w$** |
| 1 | 1 | 0.445 |
| 2 | 0.839 | 0.395 |
| 3 | 0.780 | 1 |
| 4 | 0.873 | 0.407 |
| 5 | 0.78 | 0.706 |
| 6 | 0.548 | 0.716 |
| 7 | 0.78 | 0.668 |
| 8 | 0.705 | 0.668 |
| 9 | 0.663 | 0.577 |
| 10 | 0.621 | 0.339 |
| 11 | 0.460 | 0.49 |
| 12 | 0.455 | 0.51 |
| 13 | 0.512 | 0.37 |
| 14 | 0.531 | 0.455 |
| 15 | 0.448 | 0.556 |
| 16 | 0.482 | 0.402 |
| 17 | 0.501 | 0.512 |
| 18 | 0.451 | 0.512 |
| 19 | 0.527 | 0.333 |
| 20 | 0.419 | 0.399 |
| 21 | 0.446 | 0.371 |
| 22 | 0.337 | 0.377 |
| 23 | 0.36 | 0.381 |
| 24 | 0.333 | 0.461 |
| 25 | 0.352 | 0.373 |
| 26 | 0.42 | 0.399 |
| 27 | 0.389 | 0.447 |

### *3.1.3. Grey relational grade and grade order:*

Grey relational grade is the third step in grey relational analysis. Byaveraging the grey relational coefficients corresponding to the process response values, the grey relational grade is calculated. The purpose of grey relational grade converting multiple responses into single response values. The grey relational grade is calculated as:

$\gamma_i = \frac{1}{n} \sum_{M=1}^{n} \xi i(M)$ → (4)

Where n=number of output responses.

  

The Grey relation grades and their grade orders are given in table7.

***Table 7:Grey relational grade and their order.***

| Exp. No. | Grey relational grade | Order |
|---|---|---|
| 1 | 0.7225 | 4 |
| 2 | 0.617 | 9 |
| 3 | 0.89 | 1 |
| 4 | 0.64 | 6 |
| 5 | 0.743 | 2 |
| 6 | 0.632 | 7 |
| 7 | 0.724 | 3 |
| 8 | 0.6865 | 5 |
| 9 | 0.62 | 8 |
| 10 | 0.48 | 15 |
| 11 | 0.475 | 16 |
| 12 | 0.4825 | 13 |
| 13 | 0.441 | 18 |
| 14 | 0.493 | 12 |
| 15 | 0.502 | 11 |
| 16 | 0.442 | 17 |
| 17 | 0.5065 | 10 |
| 18 | 0.4815 | 14 |
| 19 | 0.43 | 19 |
| 20 | 0.409 | 22 |
| 21 | 0.4085 | 23 |
| 22 | 0.357 | 27 |
| 23 | 0.3705 | 25 |
| 24 | 0.397 | 24 |
| 25 | 0.3625 | 26 |
| 26 | 0.4095 | 21 |
| 27 | 0.418 | 20 |

### 3.2. Effects of process parameters on Grade:

The main effect plot for grey-relational grade is given in fig 5. Which is created by using Minitab 17 software? The main effect plots are used to find the individual effects of process parameters on Ra and kerf width and also it gives optimized condition for obtaining minimum Ra and minimum kerf width simultaneously. In the main effect plot most significant parameter is one which having highest inclination to the center line. So, it has more effect on Ra, kerf width. The less significant parameter is one which is being near to the center line. So, it has less effect on Ra and kerf width. From the main effect plot for means of Grade, gas pressure (A) has highest inclination to center line, so it is the most significant parameter, and Torch height(C) has less significant effect which is nearer to the center line. From the main effect plot, the optimized setting for minimum Ra and minimum kerf width during oxy fuel cutting of HRE 350 is found to be at A1 B1 C3 i.e. Gas pressure at 3 bar, cutting speed at 300 mm/min, torch height at 13 mm.

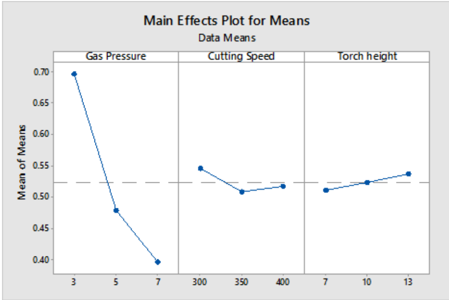


***Fig 5:main effect plot for grade***

### 3.3. Analysis of variance (ANOVA):

***Table 8: Analysis of variance***

| Source | D.F | Seq.S.S. | Seq.M.S. | F | P | %contribution |
|---|---|---|---|---|---|---|
| A | 2 | 0.436926 | 0.218463 | 47.08 | 0.00 | 86.1 |
| B | 2 | 0.007046 | 0.003523 | 0.76 | 0.499 | 1.4 |
| C | 2 | 0.003005 | 0.001257 | 0.32 | 0.732 | 0.6 |
| A*B | 4 | 0.005029 | 0.001257 | 0.27 | 0.889 | 0.9 |
| B*C | 4 | 0.002010 | 0.00503 | 0.11 | 0.976 | 0.4 |
| A*C | 4 | 0.016209 | 0.004052 | 0.87 | 0.520 | 3.2 |
| Error | 8 | 0.037122 | 0.004640 | | | 7.3 |

The ANOVA was used to find out the percentage contribution of each process parameter on the Ra and kerf width is as shown in table 8. ANOVA table was created by carrying out the analysis of variance (ANOVA) in Minitab17 software. The higher F-ratio shows more effect and more amount of contribution of process parameters on the Ra and kerf width. From the ANOVA table, it is find that pulse on time has the higher percentage of contribution. % contribution for the factor is the ratio between the control factor adjusted sums of squares to the total sum of square which is given in equ5.

$$P = \frac{SS_d}{SS_T} (5)$$

## IV. EFFECT OF CONTROL FACTORS ON PROCESS RESPONSES WITH SURFACE PLOTS

In this experiment there are three independent parameters, which are gas pressure, cutting speed and torch distance. As a function of the independent parameters three dimensional surface plots are drawn for SR and kerf width.

  

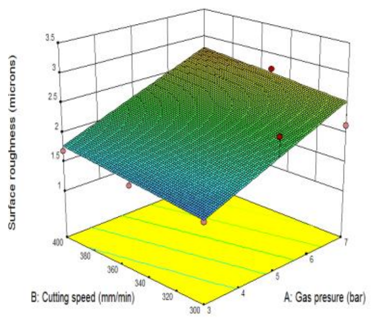


***FIG 6.1: surface roughness with cutting speed and gas pressure .***

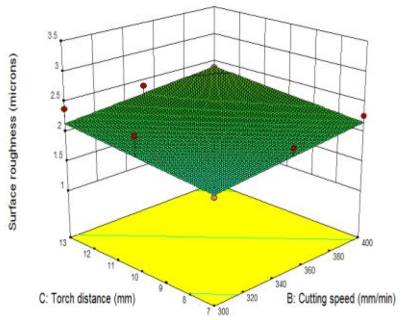


***FIG 6.2: surface roughness with cutting speed and torch distance***

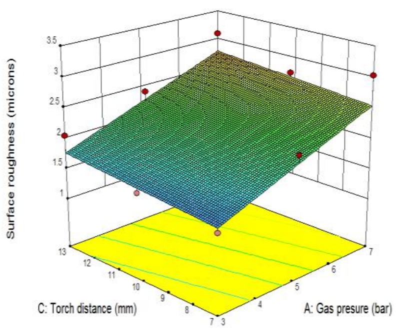


***FIG 6.3: surface roughness with torch distance and gas pressure.***

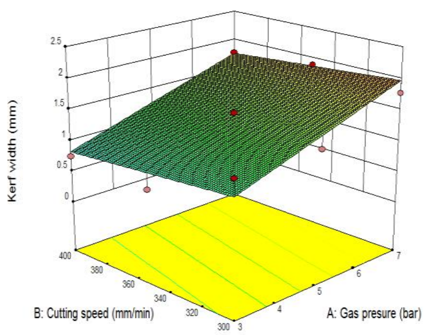


***FIG 6.4: kerf width with cutting speed and gas pressure***

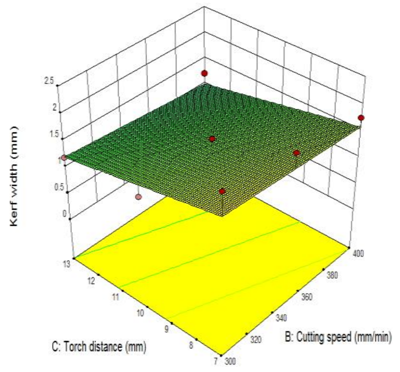


***FIG 6.5: kerf width with cutting speed and torch distance.***

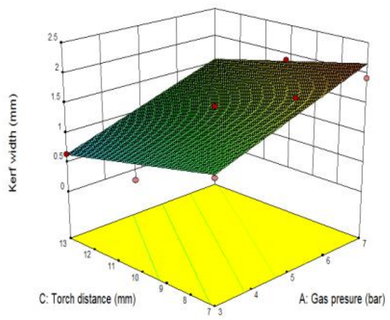


***FIG 6.6:kerf width with torch distance and gas pressure.***

By keeping the one of the three independent variables as constant, the three dimensional plots are drawn.fig 5.1 and 5.3 shows that SR increase rapidly with increase of gas pressure and torch distance. The reason for this is that large amount of heat to the work material, so that it will effect the large amount of heat on work piece. Fig 5.1 and 5.2 shows that SR increases with the increase of cutting speed. The Reason here for increasing of SR is that, when speed of nozzle increases the flow of heating gas on the work material same due to these high effect on work piece material and increases the surface roughness. From the Fig 5.4 shows that, kerf width (Ra) increases with the increase of gas pressure. Because of the large amount of gas creates the higher removal of material due to these there will be create the large distance between base material and cut material that's why kerf width will be increases. from the fig 5.4 and 5.5 the cutting speed increases the kerf width will be decreases because of the effect of gas on to the work piece will be decreases. in the case of torch distance the kerf width will be decreases because of the effect of flow of gas on to the work piece will be create less amount these are shown in fig.5.5 and fig.5.6.

  

## V. CONCLUSION

1) In this research gas pressure, cutting speed and torch distance are influencing of oxy fuel cutting on mild steel HRE 350 are studied.

2) By using grey taguchi method optimum setting for obtaining the minimum surface roughness and kerf width is A1 **(Gas pressure, 3 bar), B1 (cutting speed, 300 mm/min), C3 (Torch distance, 13mm).**

3) By conducting ANOVA it can be observed that gas pressure is the more effecting parameter compared to cutting speed and torch distance.

4) From the study of three dimensional surface plots gas pressure, cutting speed and torch distance are directly proportional to $R_a$. in the case of kerf width is directly proportional to gas pressure and is inversely proportional to cutting speed and torch distance.

## VI. REFERENCES

[1] Patricia Muñoz-Escalona, Maria Carolina Payares, Minerva Dorta, and Ronald Diaz, Analysis and Influence of Acetylene and Propane Gas during Oxyfuel Gas Cutting of 1045 Carbon Steel, ASM International, 1059-9495, submitted February 17, 2006; in revised form April 5, 2006.

[2] n.osawa, j.sawamura,y.lkegami and n.okamoto ,study of heat transfer during piercing process of oxyfuel gas cutting, Doc. IIW-2152, recommended for publication by Commission I "Thermal Cutting and Surfacing."2012.

[3] Welding, Brazing and Soldering, Vol 6, ASM Handbook (formerly Metals Handbook, 9th ed.), ASM International, 1993, p 896.

[4] P. Muñoz-Escalona, M.C. Payares, and T.Ascanio, "Influence of Gas Type on the Mechanical Properties of Heat Affected Zone During oxyfuel Cutting of Carbon Steel," presented at ASME Pressure Vessels and Piping Conference PVP, Atlanta, GA, Vol 427, 2001, p 129-132.

[5] "Standard Test Method for Microindentation Hardness of Materials," E-384, Annual Book of ASTM Standards, ASTM, p1-33.

  