ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 49 Jul. 2021, pp 49-59

Journal Homepage: http://erj.bu.edu.eg

Experimental Study of Cutting Steel Hardox400 Using Plasma Arc Cutting

Sarah A.Afifi[1], Mervat Tawfik[2], Omar M.Koura[1], Samah S.Mohammed[2]

[1]Faculty of Engineering, Modern University for Technology and Information

[2]Faculty of Engineering at Shobra, Benha University

ABSTRACT:HARDOX 400 IS AN ABRASION AND WEAR RESISTANT STEEL PLATE WITH A HARDNESS OF 400 HBW. IT IS INTENDED FOR APPLICATIONS WHERE DEMANDS IMPOSED ON ABRADING AND WEAR ARE HIGH. NON-CONVENTIONAL CUTTING METHODS ARE USED TO CUT HARDOX TO AVOID DEFECTS WHICH OCCUR IN CONVENTIONAL CUTTING METHODS. HARDOX 400 OPENS FOR SMARTER, LIGHTER STRUCTURES WITH EXTREME PERFORMANCE AND EXTENDED SERVICE LIFE.

The aim of this study is to evaluate the cutting parameters for cutting steel plates Hardox 400 using Plasma arc cutting technology. In plasma arc cutting, the parameters that were taken into consideration are arc gap, cutting speed, plasma gas pressure. The effect of these parameters on the quality of cut in terms of kerf width, surface roughness and heat affected zone studied.

The experiment carried out using CNC plasma arc cutting machine. The results indicated that the minimum Kerf width is 4.658mm, the minimum Ra is 3.152 µm and the minimum HAZ is 0.886mm all of them were obtained at the maximum cutting speed 700mm/min.

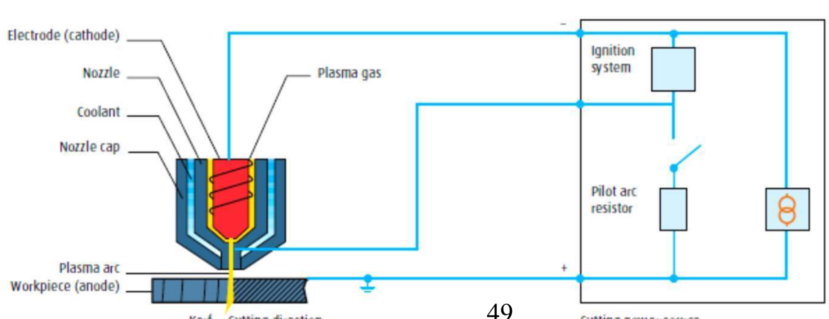
Key Words:

Hardox, Plasma arc cutting, Wear resistant material

1. INTRODUCTION:

Plasma cutting is a thermal cutting process in which a plasma arc is constricted through a nozzle. The transferred arc, which occurs when electricity flows from the non-melting electrode (cathode) to the workpiece (anode) as shown in (**Figure 1**), is used to cut electrically conductive materials. This is the most commonly used form of plasma cutting. The plasma gases are partially dissociated and ionized in the arc, thereby making them electrically conductive. The metal material melts and partially vaporizes due to the thermal energy of the arc and plasma gas. . Plasma cutting grew out of plasma welding in the 1960s, and emerged as a very productive way to cut sheet metal and plate in the 1980s. It was designed to be used on all metals that, due to their chemical composition, could not be subjected to oxy-fuel cutting. Plasma is an effective means of cutting thin and thick materials alike. 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

The plasma power source supplies the operating voltage and the cutting current for the main and



auxiliary arc. In order to avoid further processing after plasma cutting, the right plasma gas should be used for the given material. The physical and mechanical properties of the gases should be taken .

into account when selecting a gas. Inert and active gases and mixtures thereof are generally suitable as plasma gases

Plasma cutting is commonly used for the cutting of metal plates in processing or manufacturing units. In order to find the optimal cutting conditions for improving the quality characteristics of the plasma arc cutting process, Taguchi based desirability analysis (TDA) was observed by **D.K .Naik and K.P .Maity**. The purpose of the experiment was to maximize the MRR and minimize other production

reactions. The confirmation test was obtained with the optimum setting of the process parameter in order to increase the performance of the plasma arc cutting system. The outcome of this study would provide the industry with a better database. The results of the research clearly demonstrate that the enhanced machinability was achieved by the specific set of input process parameters. [2]

Chirag.K.Kolambe and Sambhaji.V.Sagare their object of studying the plasma arc cutting machine is to use the Taguchi method to determine the surface roughness due tc

analyze the air gap. [1]

K. Salonitis et al [6] were investigating experimentally the Plasma Arc Cutting Process. All experiments were performed on a CNC plasma cutting system (Kaltenbach KF 2512 – HPR 260) with a dual flow torch. The cuts were performed on 15 mm thickness S235 mild steel sheets, with the use of oxygen as plasma (primary) gas and air as shielding (secondary) gas. The specimens were made up of a linear cut 150 mm in length and a rectangular cut of 50 mm side, in order to measure cutting edge roughness, the iconicity, and the heat affected zone (HAZ). All cuts were made parallel to the rolling direction. The materials were allowed to cool to room temperature between cuts. Every experiment was conducted five times, while for the cutting edge roughness five measurements were taken along the cut. Design of experiments (DOE) is a family of structured, organized techniques used to empirically understand the impact of process parameters. The key process parameters are the cutting speed (CS), the cutting current (CC), the cutting height (CH) and the pressure of the plasma gas (PPG). For setting up the DOE a number of screening experiments were performed. The cut quality was assessed in terms of cutting edge surface roughness, conicity (edge inclination) and HAZ. In this research, they found some general results from their experiments. Firstly, the cutting height has the strongest effect on the quality characteristics and especially on conicity and on the surface roughness of the cut. The cutting height effect on conicity is due to the fact that the plasma gas beam is not of cylindrical shape but resembles the shape of a reversed candle flame. Therefore, depending on relative position of the plasma to the workpiece surface, the conicity is changed respectively. Secondly, the cutting current has the strongest effect on the HAZ. In general, increasing

ed

results in the increase of the HAZ. The lower cutting current and the higher cutting speed will result in reducing the dimensions of HAZ. Since the plasma is supplied with excess oxygen. Regarding the roughness of the cutting edge, they found that cutting height has the strongest impact, whereas cutting speed and cutting current are minor influencing parameters.

V. Singh (2011) analyzes the process parameters of Plasma Arc cutting. During his work, 16 test specimens having dimension 30mm x 30mm x 12 mm were prepared for the experimental work. The material for test specimen was Stainless Steel ASTM A 240 TP 316 L. Here L stands for Low Carbon Content. The design factors are gas pressure, current flow rate, cutting speed, arc gap. The plasma arc cutting responses are Material removal rate and surface roughness.

The design variables can be summarized as follows:

a) Two levels of the Gas Pressure (5Bar and 6Bar).

b) Two levels of Current Flow Rate (150A and 200A).

c) Two levels of Cutting Speed (400mm/min and 600mm/min).

d) Two levels of Arc Gap (2mm and 4mm)

Fixed machining parameters are material type (stainless steel 316L), material thickness (12mm), Kerf (5mm), and operating voltage (200V). The results of this research shows that better surface roughness obtained at high gas pressure, high current, low cutting speed, and low arc gap. In addition, the material removal rate increases at the same previous conditions and but the machining time is increased.

Milan Kumar das et al [6] investigated the parametric optimization of plasma arc cutting process of EN 31 steel. Three process parameters viz. cutting current, gas pressure and standoff distance are taken in to consideration and experiments have been conducted based on L27 orthogonal array. Response parameters such as material removal rate and surface roughness of machined surface are measured. The analysis of variance is performed to find the contribution of each process parameter on the performance characteristics and concluded that the gas pressure is the parameter has a significant effect whereas the other parameters viz. cutting current and standoff distance are less effective.

Subbarao chamarthi et al [7] investigated effect of parameter on cutting of 12 mm thick plate of Hardox 400 through PAC. High tolerance voltage, cutting speed and plasma flow rate are considered as the main parameters. The effect of these parameters on the unevenness of the surface to be cut is evaluated. The design of experiment (DOE) is used to identify the significant parameter in order to define geometry of cut profile. The analysis of variance (ANOVA) is performed. From the analysis of results it is concluded that the unevenness of the surface can be reduced by reducing the cutting speed also shown that the cutting quality can be improved by changing cutting voltage and plasma flow rate.

Bogdan Nedik et al [8] analyzed the quality of cut in plasma arc cutting. In this paper, the samples of 15 mm thick plates of S235 were used to create 17 cuts. The significant parameters taken in to consideration are cutting speed and cutting current. The experimental results are found consistent with theoretical consideration and previous experimental results. It is concluded that the best quality of cut can be obtained by increasing the cutting speed by 20% than the tablet speed value.

Yaha hisman selic et al [9] studied material S235JR using the CNC plasma cutting machine at different cutting speeds, cutting current, and arc voltage and measured the effect of variation on temperature distribution, hardness, thickness of heat affected zone and surface roughness of the material after cut. From the results of the experiments he had concluded that the quality of plasma CNC machine depend on the cutting current, cutting speed, arc voltage and material thickness. To get the best surface roughness the cutting current and the cutting voltage kept low and cutting speed must be high for the thin sheet.

Tetyana Kevka et al [10] investigated the effect of nature of gas on the plasma arc cutting of mild steel. In this paper the study is been carried out on the influence of the nature of gas on the arc behavior and the cutting performance of mild steel. Usually the plasma arc cutting system is operated on steam has been modified to usage of different plasma gases. Experimental results are obtained from the cutting of 16 mm thick mild steel plate at 60 A with steam, nitrogen, air, and oxygen as the plasma gases. From the experimental results it is concluded that the steam as the plasma gas will generate more energy than other gases for the same current value and the plasma jet generated is much narrowed when nitrogen and air is used as plasma gases.

2 EXPERIMENTAL PROCEDURES:

The experimental procedures Plan was conducted as the following:

2.1 Raw Material:

1. Preparing the material which is Hardox 400 wear resistant steel with a hardness of 400 HBW. And its chemical composition is shown in (**Table1**)

Table 1 Chemical Composition of Hardox 400

Element	S	Si	Mo	Mn	C	Ni	B	P	Cr	Fe
Wt.%	0.010	0.70	0.60	1.46	0.32	1.50	0.04	0.025	2.50	Balance

2. Start by cutting a Hardox sample of dimensions (10cm*25cm) a cut of 5cm is done on every spacemen from its middle.
3. Impact Properties
   Charpy V-notch test according to EN 10 045-1 typical value for 20 mm plate thickness:
   Test temperature: -40 (-40° F).
   Impact energy Charpy-V (J): 45.

4. 15 samples will be cut.
5. The cuts will be through cut so a surface roughness and kerf width measurements could be conducted on the samples.
6. In order to achieve the optimum cutting parameters for best cut quality, the most dominant parameters that are going to be altered to get the optimum cutting conditions in plasma arc cutting process which are:
    A. Cutting Speed: (300-700)mm/min
    B. Standoff Distance (arc gap) : (1-5)mm
    C. Plasma Gas pressure: (4-6)bar
7. The cutting height was achieved by means of block gauges of 1, 2,3,4,5 mm.

It is shown in (**Table 2**) the 15 runs with different cutting parameters:

Table 2

Runs	Cutting speed(mm/min)	Standoff Distance(mm) ()_(mm)	Plasma gas pressure(kPa) (bar)	Kerf width(mm)	Ra (µm)	HAZ (mm)
1	300	3	500	5.833	8.247	1.943
2	400	3	500	5.63	7.326	1.522
3	500	3	500	5.58	6.583	1.321
4	600	3	500	4.938	4.877	1.248
5	700	3	500	4.658	3.152	0.886
6	400	1	500	5.281	4.151	1.2
7	400	2	500	5.486	4.364	1.48
8	400	3	500	5.692	4.475	1.599
9	400	4	500	6.388	4.734	2.089
10	400	5	500	6.506	5.077	2.148
11	400	3	400	5.357	6.894	1.061
12	400	3	450	6.195	6.633	1.657
13	400	3	500	5.69	6.482	1.775
14	400	3	550	5.236	6.144	1.829
15	400	3	600	5.5	4.794	1.932

2.2 Plasma Cutting Machine:

1) The machine provides cutting speeds varying form 100 mm/min to 800 mm/min
2) The pressure of the plasma cutting machine has a range from 1 Bar to 8 Bars.
3) It has a current range of 30 A to 160 A.
4) A nozzle of 1.1 mm Diameter was used during the whole experimentation.

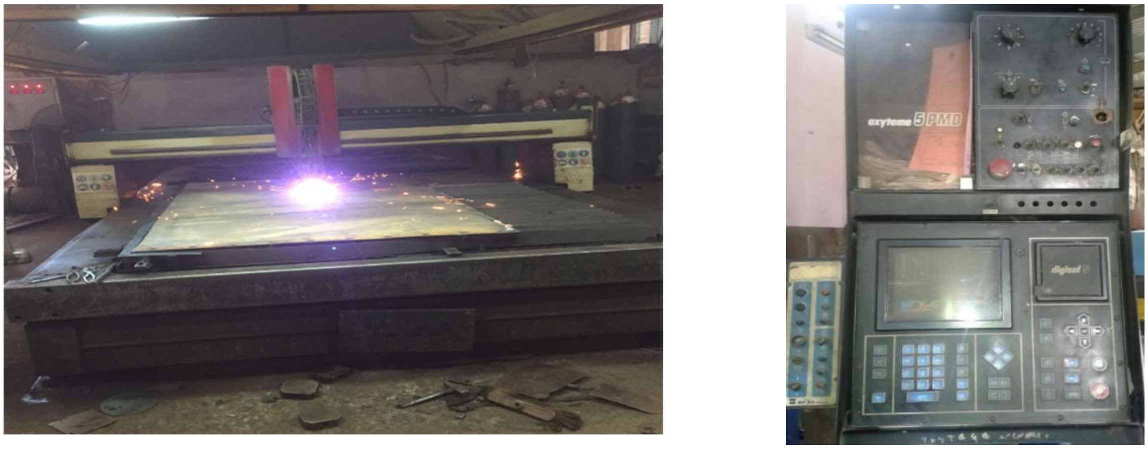


Figure 1 Plasma Cutting Machine

2.3 Measuring Devices:

2.3.1 Kerf Width Measurements:

The Kerf Width measurements have been evaluated using MarVision Workshop Measuring Microscope MM 320 as shown in **Figure 3.** An average of eight measurements was taken along the 5cm cut in the middle of the sample and a mean value was taken into the analysis. All the curves plotted where generated using Microsoft excel.

Figure 3 (MarVision Microscope)

2.3.2 Surface Roughness Measurements:

The measurements were conducted on each sample in the middle of the through cut , the probe of the apparatus moves 5.6mm divided on 7 divisions each of 0.8mm the first and the seventh division are neglected from the apparatus as there might be distortion or vibration at the beginning and the end of the measurement. The device used is Mahr Pocket Surf PS1 as shown in **Figure 4**.

Figure 4 (Mahr Pocket Surf PS1)

2.3.3 Heat affected zone Measurements:

The samples were first manually grinded to clear the surface from slag and impurities automatic grinding was not carried as it generates heat energy that's could cause disturbance in the heat affected zone generated from the plasma cutting process. After grinding the samples were etched using a Nital solution then they were dried. Nital is a solution of alcohol and nitric acid commonly used for routine etching of metals. It is especially suitable for revealing the microstructure of carbon steels. The alcohol can be methanol; ethanol or methylated spirits. The heat affected zone was measured by Mahr workshop microscope as shown in **Figure 5**.

Figure 5 (MarVision Microscope)

3 RESULTS AND ANALYSIS:

3.1 Kerf Width Measurements:

3.1.1. The effect of cutting speed on Kerf width:

When Cutting Speed increases it greatly influences the top kerf width measurement, As Cutting speed increases the kerf width is narrower comparing the readings from the 300mm/min and the 700mm/min it is obvious that it decreased the kerf width by nearly 1.2mm. At low speeds, the arc supports more energy than the energy needed to cut the material through and over melts the material thus giving bigger kerf width. At high speed, the concentration of the heat generated by the arc on the workpiece is less than heat concentration on the workpiece at low speeds, so in high speeds kerf width decreases as it supports the workpiece with the energy needed just to cut the material through as shown its effect on. (**Figure 6**) shows the relation and (**Figure 7** & **Figure 8**) the different results on different Kerf width.

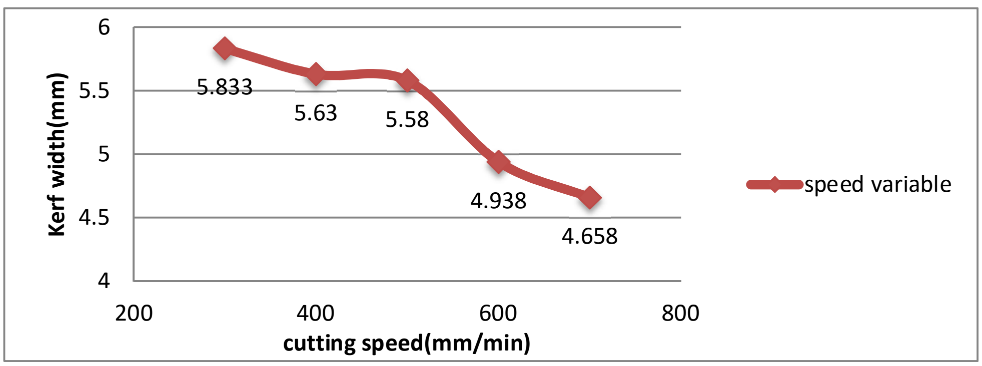


Figure 6: The effect of cutting speed on Kerf width

Figure 7: Showing widest kerf width at the lowest cutting speed (300mm/min))

Figure 8: Showing narrowest kerf width at highest cutting speed(700mm/min)

3.1.2. The effect of Plasma gas pressure on kerf width:

The zigzag variation in the curve may be caused due to contamination in the gas used as air was used and compressed during cutting. As the air pressure increases the rate of ionization of the gas increases therefore a higher current must be achieved to compensate, the high pressure to achieve the higher rate of ionization needed. If there is no current compensate the nozzle, the nozzle is just blowing high pressurized air which is not all ionized which have unsteady energy to perform the cut. So this effect may be caused due to the increase in the air pressure with no compensation in the current used. (**Figure 9**) represents the relation between the pressure and the kerf width.

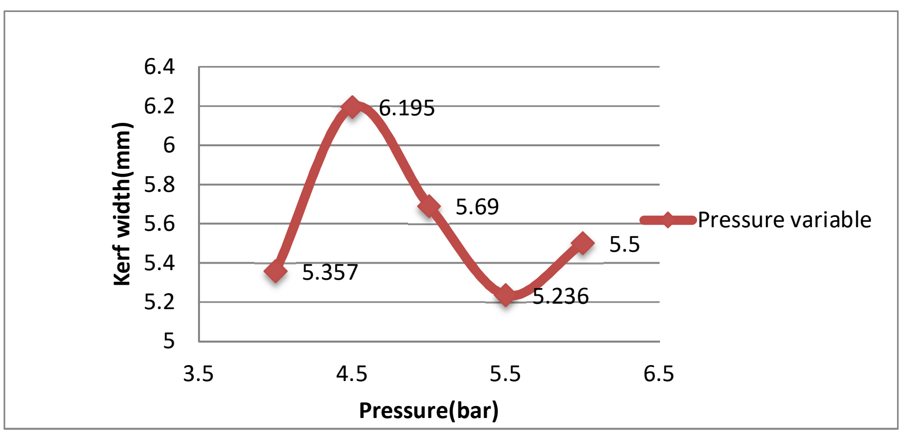


Figure 9: The effect of Plasma gas pressure on kerf width

3.1.3. The effect of Arc Gap on top kerf width:

As the arc gap changes it greatly affects the kerf width measurements, , As arc gap decreases the kerf width is narrower comparing the readings from the 1 mm gap and 5 mm gap it is obvious that the difference in the kerf width is nearly 1.2mm. As the plasma gas beam is not of cylindrical shape but resembles the shape of a reversed candle flame. Therefore, depending on the relative position of the plasma to the workpiece surface, the top kerf width changes significantly and, as the arc gap decreases the concentration of heat is on the bottom of the workpiece thus less heat on the top of the material which endures narrower kerf width due to the reversed candle flame shape of the arc. As the arc gap increases the arc concentrates the heat on the top of the workpiece thus over melting the material which endures wide kerf width. (**Figure 10**) shows the relation between both and (**Figure 11**) shows a schematic demonstration.

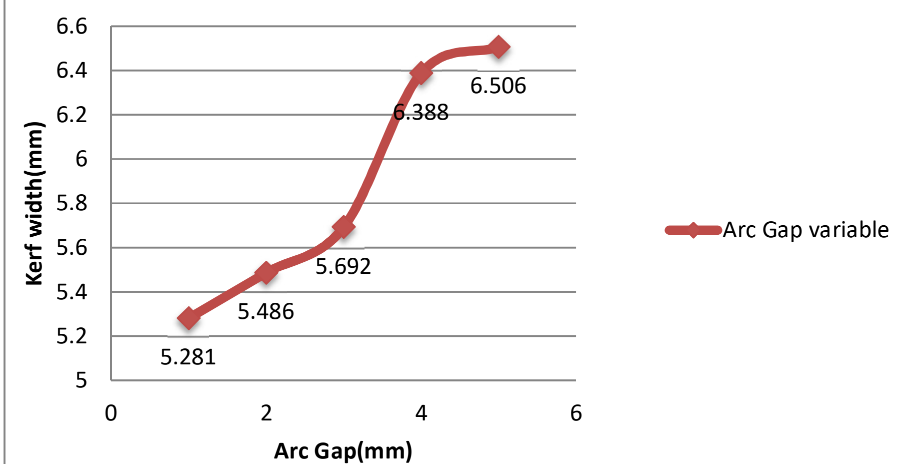


Figure 10: The effect of arc gap on kerf width

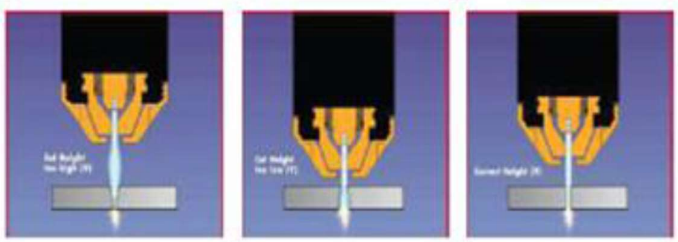


Figure 11 : schematic demonstrations showing the effect of different arc gap distances on the top kerf width [4]

3.2. Surface roughness measurements:

3.2.1. The Effect of Cutting Speed on surface roughness:

It is obvious that the cutting speed has the most significant influence on surface roughness, as the cutting speed increases the surface roughness decreases, comparing the readings of the 300mm/min and the 700mm/min readings the difference in surface roughness (Ra) is almost 5.3 µm. As the cutting speed increase the plasma gas gives a clean cut because of its kinetic energy induced from the high cutting speed which provides a smoother surface relatively with no irregularities in the surface. And at low cutting speed the plasma gas cuts the material and keep over melting the surface that the surface become rough as the some particles of the molten metal adheres itself on the surface after being cut. (**Figure 12**)

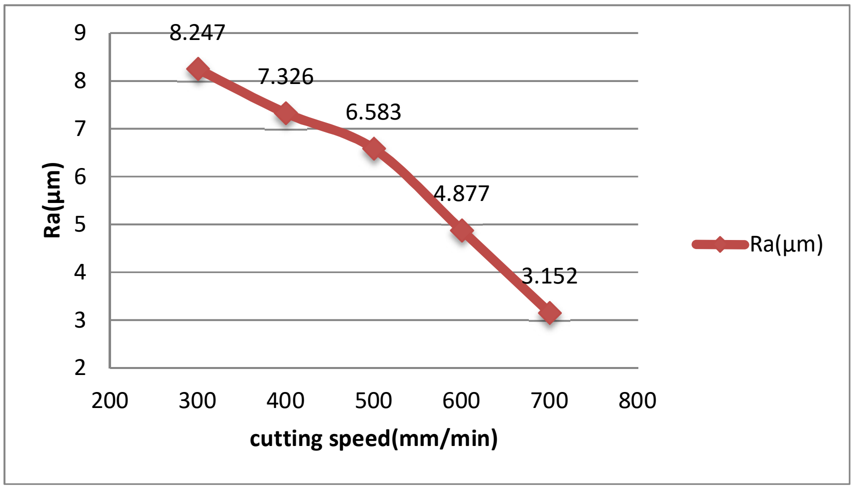


Figure 12: The effect of cutting speed on surface roughness

3.2.2. Effect of Pressure on surface roughness:

It is obvious that plasma gas also have an effect on surface roughness (Ra), As the plasma gas pressure increases the surface roughness decreases , comparing the readings of the 4 bar and 6 bar readings the difference in surface roughness (Ra) is almost 2.5 µm. At high plasma gas pressure the plasma gas blows away the molten metal form the cut with higher speed as the flow of gas is high thus giving good surface cut (low surface roughness (Ra)). At low plasma gas pressure the gas flow is just sufficient to cut but not to entirely blow the metal form the surface of the cut thus irregularities in the surface of the cut giving hig surface roughness (Ra)(**Figure 13)**

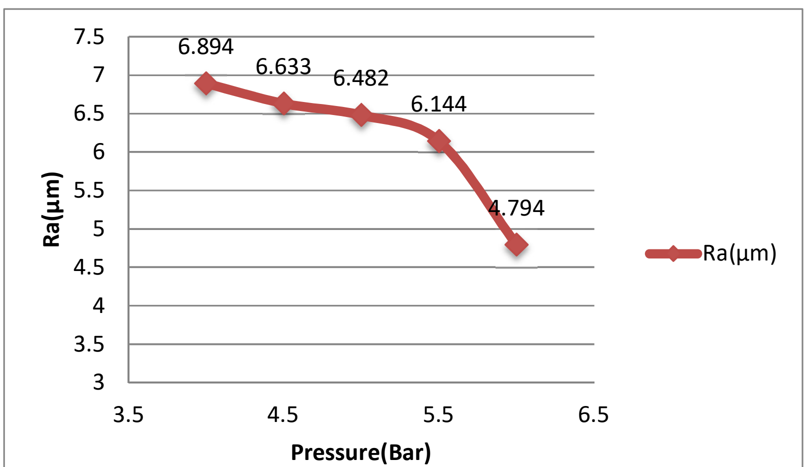


Figure 13: The Effect of plasma gas pressure on

3.3. Heat affected zone analysis:

3.3.1. Effect of Cutting Speed on Heat affected zone:

As the cutting speed changes the Heat affected zone significantly changes, as the cutting speed increases the Heat affected zone decreases, comparing the readings of the 300mm/min and the 700mm/min readings it is found that heat affected zone decreased to more than the half of its value. As the cutting speed increases the heat energy absorbed by the workpiece is just sufficient for cutting through the metal no excess heat is absorbed by the metal thus giving us small heat affected zone. On the other hand at low cutting speeds the amount of heat energy absorbed by the workpeice is high thus over heating the material which increases the heat affected zone.

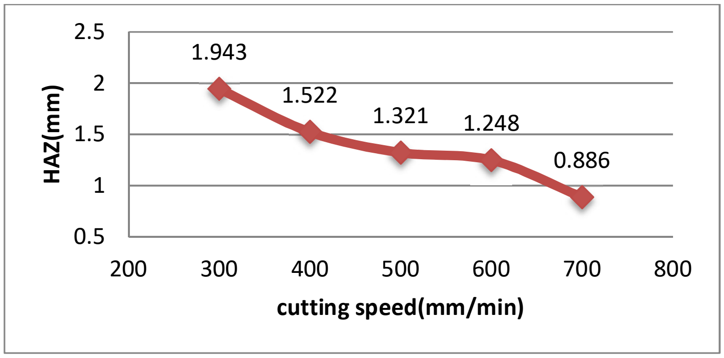


Figure 14: Effect of cutting speed on heat affected zone

3.3.2. Effect of Pressure on Heat affected zone:

As the plasma gas pressure changes the Heat affected zone significantly changes, as the plasma gas pressure increases the Heat affected zone increases, comparing the readings of the 4 bar and the 6 bar readings it is found that heat affected zone is nearly doubled of its value. low plasma gas pressure the flow of gas gives heat energy just sufficient for cutting the material meaning no excess heat in absorbed by the material thus inducing narrow heat affected zone. On the other hand at the high pressure's flow of plasma gas gives high kinetic energy of the plasma gas particles thus increases the heat energy absorbed by the workpiece thus inducing wide heat affected zone.

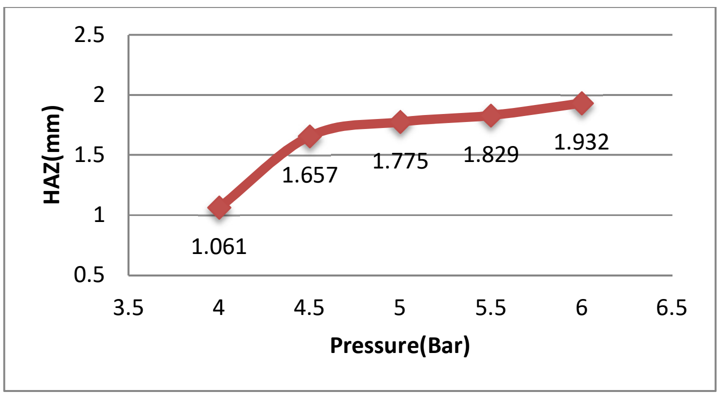


Figure 15: Effect of plasma gas pressure on heat affected zone

3.3.3. Effect of Arc Gap on Heat affected zone:

As the arc gap changes it greatly affects the heat affected zone, as arc gap decreases the heat affected zone is narrower comparing the readings from the 1 mm gap and 5 mm gap it is obvious that the heat affected zone is almost doubled. And as the arc gap decreases the concentration of heat is on the bottom of the workpiece thus less heat on the top of the material which means less heat energy absorbed by the material which endures narrower heat affected zone due to the reversed candle flame shape of the arc .

As the arc gap increases the arc concentrates the heat on the top of the workpiece thus over melting the material which means more heat energy is absorbed by the material which endures wide heat affected zone.

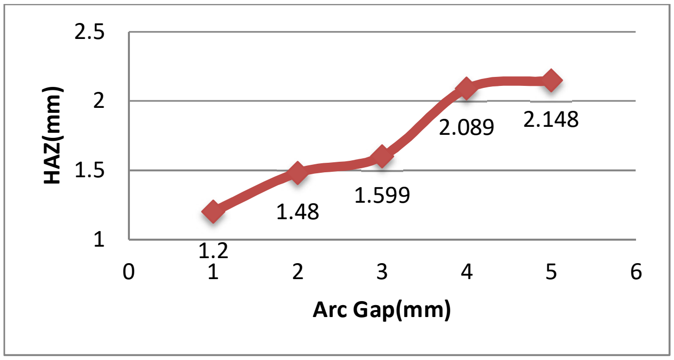


Figure 16: Effect of arc gap on heat affected zone

4 CONCLUSIONS:

The study came with the following conclusions:
For Plasma arc Cutting:

1. The smallest top kerf width is 4.658 mm was obtained at high cutting speed 700mm/min with moderate plasma gas pressure 300 kPa, arc gap 5mm and relatively high current 120A.
2. The lowest surface roughness value is 3.152µm was obtained at high cutting speeds 700mm/min with moderate plasma gas pressure 300 kPa, arc gap 5mm and relatively high current 120A.
3. The smallest heat affected is 0.886mm was obtained at high cutting speed 700mm/min with moderate plasma gas pressure 300 kPa, arc gap 5mm and relatively high current 120A.

5 REFERENCES:

[1] Chirag.K. Kolambe, Sambhaji.V.Sagare, "Plasma arc Cutting Parameters using Taguchi Method", " International Journal for Scientific Research & Development(IJSRD)", (2020)
[2] Deepak Kumar Naik , K.P. Maity, "An optimization and experimental analysis of plasma arc cutting of Hardox-400 using Taguchi based desirability analysis" , International Conference on Materials Manufacturing and Modeling (ICMMM), (2017)
[3]https://www.ssab.com/products/brands/hardox/products/hardox-500
[4] Singh, Vivek, "Analysis of Process Parameters of Plasma Arc Cutting using Design of Experiment". Department of Mechanical Engineering, National Institute of Technology Rourkela Thesis. (2011)
[5] K. Salonitis, S. Vatousianos, "Experimental Investigation of the Plasma Arc Cutting Process" Procedia CIRP, vol. 3 pp. 287 – 292, (2012)
[6] Milan Kumar Das, Kaushik Kumar, Tapan Kr Barman, Prasanta Sahu, "optimization of process parameters in plasma arc cutting of EN 31 steel based on MRR and multiple roughness characteristics using grey relational analysis" Procedia material science, vol. 5, pp. 1550-1559, 2014.
[7] Subbarao Chamarthi, N. Sinivasa Reddy, Manoj Kumar Elipey, D.V Ramana Reddy, "Investigation Analysis of Plasma arc cutting Parameters on the Unevenness surface of Hardox-400 material" Trans. Procedia Engineering, vol. 64 , pp. 854 – 861, 2013.
[8] Bogdan Nedik, Marko Janakovik, Miroslav Radovanovik, Gordana Globocki akic, "Quality of plasma cutting" kragujevak, Serbia, vol. 15, pp. 314 – 319, 2013.
[9] Yahya Hisman Selic, "investigating the effect of cutting parameters on material cut in CNC plasma" materials and manufacturing processes, vol. 28, pp. 1053 – 060, 2013.
[10] Tetyana Kavka, Alan Maslani, Milan Hrabivsky, Thomas Stechre, Heribert Pauser, "experimental study of effect of gas nature on plasma arc cutting of mild steel" Journal of physics D: appl. Phys, vol. 46, pp. 1 – 13, 2013.