Indepth Investigations into the Capability of Plazma Arc Cutting of Mild Steel Tubes

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ABSTRACT

Plasma Arc cutting (PAC) is a process of cutting steel and other metals (or sometimes other materials) using a plasma torch. In this method, an inert gas (in some units, compressed air) is blown at high speed out of a nozzle. 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. In Plasma Arc Cutting (PAC), the plasma gas flow is enhanced so that the intense and deeply penetrating plasma jet cuts through the material and molten material is removed as cutting dross. PAC differs from oxy-fuel cutting 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. Unlike oxy-fuel cutting, the PAC process can be applied to cutting metals which form refractory oxides such as stainless steel, cast iron, aluminum, and other non-ferrous alloys. In this paper the deviations in the thickness of the cut profile of the square tubes are critically analyzed for assessment of the deviations in the cut surface of the square tubes of structural steel due to the phenomena like top edge rounding, dross, cut surface bevel angle, top spatter and extended kerf width etc.

Key words: Top edge rounding, kerf width, dross, top spatter, cut surface bevel angle.

INTRODUCTION

Plasma Arc cutting is a thermal material removal process that is primarily used for cutting thick sections of electrically conductive materials. The cutting action is the result of an extremely high-temperature thermal source interacting with the melting workpiece. Plasma arc cutting is most often applied to materials that are difficult to cut by conventional oxy fuel methods because of their thermal conductivity, heat capacity, or oxidation resistance. Aluminium and stainless steel are examples of materials that fall into this classification. High temperature plasma is the source of thermal energy for the PAC process. Plasma is the name given to the glowing, ionized gas that results from heating a material to extremely high temperatures. Plasma is composed of free electrons that have become dissociated from the main gas atoms, positive ions and neutral atoms. The temperature of plasma can be as high as **33, 000° C (60, 000° F)** which means that literally all metals can be rapidly cut **[Benedict, 1987]**. A close up view of a high temperature plasma cutting is shown in the **[figure 1]**.

Plasma Arc 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 (in some units, compressed air) is blown at high speed out of a nozzle; 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. In Plasma Arc Cutting (PAC), the plasma gas flow is enhanced so that the intense and deeply penetrating plasma jet cuts through the material and molten material is removed as cutting dross. PAC differs from oxy-fuel cutting 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. Unlike oxy-fuel cutting, the PAC process can be applied to cutting metals which form refractory oxides such as stainless steel, cast iron, aluminum, and other non-ferrous alloys. Since PAC was introduced by Praxair Inc.

at the American Welding Society show in 1954, many process refinements, gas developments, and equipment improvements have taken place since then **[Benedict 1987].**

Plasma arc cutting can ensure the speed and efficiency of both sheet and plate metal cutting operations. Machine builders for transportation and agricultural sector, heavy machinery, aircraft components, air handling equipment and many other products have discovered the benefits Plazma Arc Cutting. Plasma cutters are used in place of conventional sawing, drilling, machining, punching, and cutting. The high-temperature plasma arc cuts through an extensive variety of metals at substantially higher speeds in comparison to the competing processes. Although plasma arc cutting can cut most metals with ease at thicknesses of up to 4" to 6", yet it provides the appreciable economic advantages, speed, and quality on carbon steels under 1" thickness and on aluminum and stainless steels under 3". It has been appreciated in both hand-held and automated form of cutting operations. Some of the striking results can be achieved in the domain of automated systems. The recent advances in computer numerical controls (CNC), robots, and other mechatronic techniques have been able to offer manufacturers higher cutting speeds through plasma arc cutting. Augmented torch designs and distinctively efficient power supplies have made plasma arc cutting increasingly popular. Newer areas of technology in plasma arc cutting systems include non-transferred arc plasma, which allows plastics and other nonconductive materials to be cut. Research on cutting plastics is conti-nuing and at least one commercial process is currently available.

LITERATURE SURVEY

High Temperature plasma was first considered for cutting applications in the 1950's when it was discovered that the arc from a tungsten inert gas (TIG) welder could be constricted to produce much hotter plasma that could then be used for cutting. By passing the arc through a 4.5 mm (3 /16 .in) diameter water cooled copper nozzle the plasma would attain higher temperature and disperse a slower rate. Plasma cutting was introduced to industry in 1955 for cutting aluminium and stainless steels. However it did not gain wide acceptance until approximately 1970 when new PAC techniques markedly improved the quality of the cut. Modern PAC equipment can deliver upto 1000 amp at approximately 200 VDC and generate plasma temperature upto 33,000° C (60,000° F). The flowing gas is delivered to the torch pressure upto 1.4 MPa (200 psi) resulting in a plasma velocity of

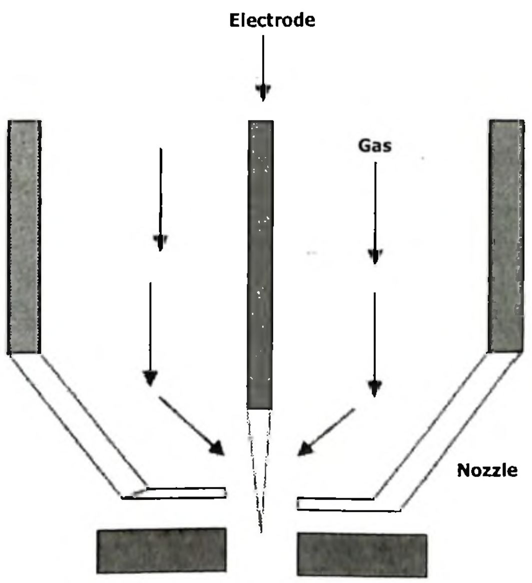

Figure 1 Scheme of Plasma Arc Cutting System [Mishra, 2007]

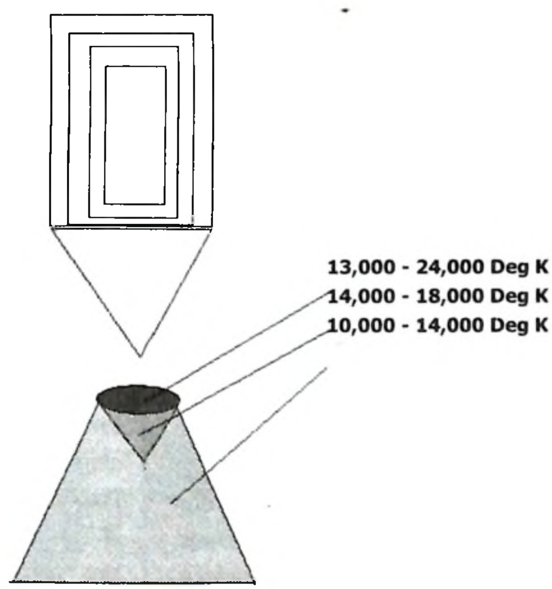

Figure 2 Temperature Distribution in Plasma without constriction [Benedict, 1987]

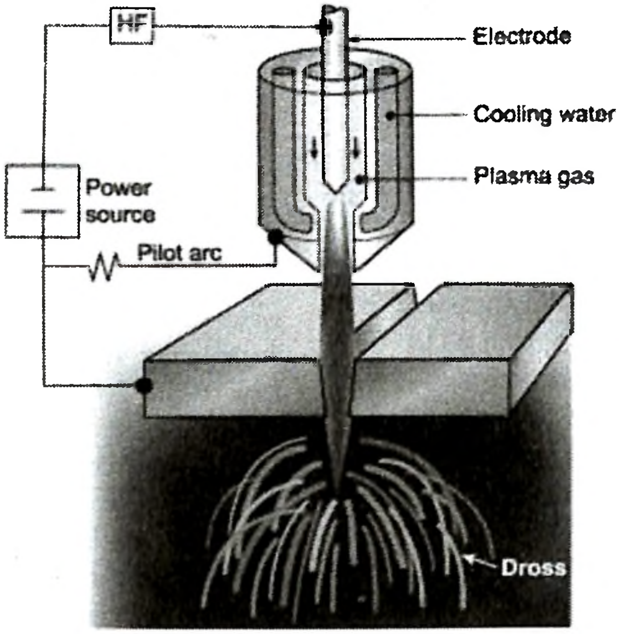

Figure 3 : Plasma Arc Cutting Process
[www.twi.co.uk/content/jk51.html, April,2009]

several hundred meters per second. The high gas flow rate increases the efficiency of the process by adding momentum to the plasma jet to facilitate the removal of molten metal from the cut zone. The high flow rate also constricts the plasma jet and acts to provide cool gas layer between the nozzle wall and the plasma jet. Further plasma constriction is sometimes achieved by swirling the gas through the nozzle. **[Benedict, 1987].**

APPLICATIONS

Plasma cutting is most commonly used to cut sheet metals from 24 gauge up to 1/8" thick at high speeds on carbon steels, aluminum, and stainless steels. Plasma cutting systems are also used in the heating, ventilating, and air conditioning industry to cut complex profiles in the duct work. Industries engaged in cutting plate thicknesses also find extensive applications for plasma cutting. Plasma systems cut plate thicknesses from 1/8 to 3", but the most common applications are for carbon steel plate ¼ to ¾ inch thick. Fabrication shops can cut large plates of steel down to size easily with plasma. Manu-facturers of heavy duty construction machinery, mining equipment, and material handling devices utilize plasma cutting to build cranes, bulldozers, and other large equipment. Plasma cutting also produces structural steel framework for railroad cars, trucks, and other heavy equipment. Other applications take into account of cutting metal for ship building and the pressure vessels. Plasma cutting is not limited to flat sheets of metal. Plasma torches held by the robotic manipulators are most extensively used for contour cutting of tubes, pipes and vessels, removal of sprues and risers from castings, and cutting of formed shapes, angles, and curves in various planes **[Wikipedia, 2009].**

Oxyfuel cuts by burning, or oxidizing, the metal. 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 oxyfuel 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 oxyfuel cutting. PAC finds widespread application in the metal fabrication and metal plate industries for shape cutting. Very high volume operations often utilize multiple torch systems for cutting many shapes simultaneously from one plate. The pipe industry uses PAC as a tool for preparing the ends of pipe sections before welding. In this application, the torch is mounted at a fixed angle and the pipe is rotated underneath. This results in a bevel cut on the end of the pipe. The slag build up that remains on the underside of the cut is easily removed with a chipping hammer. Since about 1980, PAC, equipment has successfully married to CNC punch presses for relatively light duty plate shape cutting in job shops and in companies where fast turnaround time and small quantities are the normal order of the day. The CNC plasma "punch" lowers down throughput time and reduce costs through the elimination of hard tooling [**Weymuiler, 1983].**

PROCESS

The HF Contact type typically found in budget machines uses a high-frequency, high-voltage spark to ionize the air through the torch head and initiate an arc. The arc can only be formed if the torch is in contact with the job material. HF Contact type machines are not suitable for applications involving CNC cutting. The Pilot 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 of plasma 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 itself until it is brought into proximity of the workpiece where it ignites the main plasma cutting arc. Plasma arcs are extremely hot and are in the range of 15,000° - 33000° Celsius.

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 workpiece. Since plasma cutters produce a very hot and very localized "cone" to cut with, they are extremely useful for cutting sheet metal in curved or angled shapes **Wikipedia, 2009].**

The inert or underactive 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. 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 **[www.twi.co.uk/content/ jk51.html, 2009].**

EQUIPMENT

The PAC equipment used in a typical production installation consists of a power supply, gas supply, cooling water system, and control console and plasma torch. Of the five major items making up a system, the plasma torch designs have been introduced to the market, with each design having its advantages and disadvantages. The most successful torch design that remains in common use today are the air plasma, dual gas, oxygen-injected and water injected plasma units **[Benedict 1987].**

SPECIFICATIONS

The specifications of the equipment used for cutting are as followed.

The equipmrnt is **Hypertherm Power Max 350** high Performance portable Plasma Cutting System, recommended Capacity ¼" (6 mm), Maximum capacity 3/8" (10 mm), Severance -½" (12 mm), Convenient operating voltage 115 V with switch for 230 V operation, Power torch without high frequency starting,

Figure 4
Plasma Arc responsible for cutting metals [Source: Indian School of Mines, University workshop]

Figure 5
Control unit of the Hypertherm Plasma Arc Cutting Machine [Source: Indian School of Mines, University workshop]

Figure 6
Plasma Arc Cutting is taking place [Source: Indian School of Mines, University workshop]

SPECIFICATION OF THE COMPRESSOR

ELGI equipment Ltd., Model No. TS03, Maximum working pressure 12 kgf/cm^2, RPM 925

Figure 7 : Compressor responsible for supplying compressed air for Palsma Arc Cutting
[Source: Indian School of Mines, University workshop]

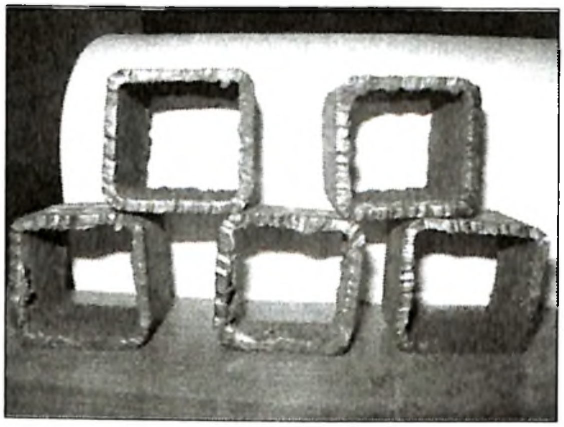

Figure 8 : Plasma Arc cut profiles are stack together which were cut for the fabrication of small structural supports for metallic cots for the hostel of the students
[Source: Indian School of Mines University workshop]

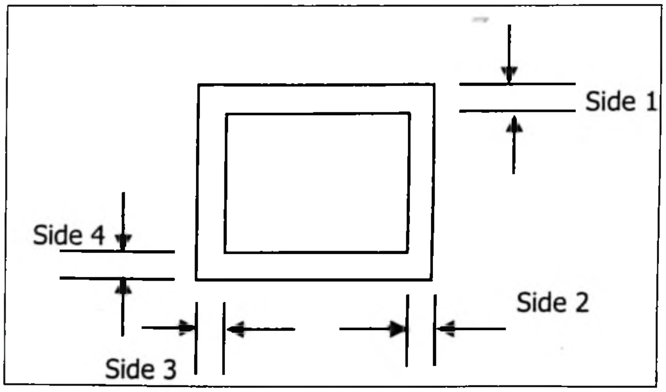

Figure 9 : Dimensions of the plasma cut profiles of the square tube of structural steel

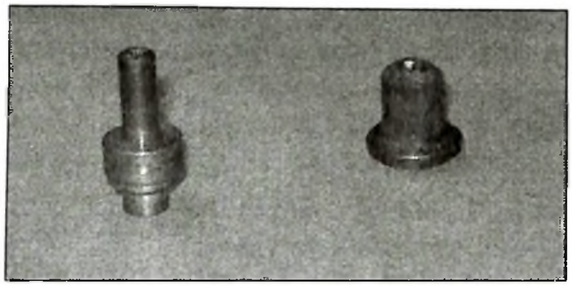

Figure 10 : Used Hypertherm Electrode code No. 020382 and Nozzle nozzle code No. 120504 for PA
[Source: Indian School of Mines, University workshop]

Table 1 : Thicknesses of the Plasma Arc cut samples Operating Voltage115v, current - 22 amp, air pressure 62 psi for 2.8mm thick hollow square tube of structural steel

Samples	**Sides**	**Measurement of thickness in mm**								
		Side 1	**Side 2**	**Side 3**	**Side 4**	**Avg.**	**Max.**	**Min.**	**Range**	**Std. Devn.**
Sample 1	Top Side	3.66	2.75	2.99	3.75	3.29	3.75	2.75	1.00	0.43
	Bottom Side	4.69	4.73	2.94	5.09	4.36	5.09	2.94	2.15	0.84
Sample 2	Top Side	3.87	2.92	4.89	2.91	3.65	4.89	2.91	1.98	0.82
		4.57	3.02	3.83	2.76	3.55	4.57	2.76	1.81	0.71
Sample 3	Top Side	4.72	4.42	4.73	4.56	4.61	4.73	4.42	0.31	0.13
	Bottom Side	4.26	2.51	2.87	2.61	3.06	4.26	2.51	1.75	0.70
Over all						**3.75**	**5.09**	**2.51**	**2.58**	**0.88**

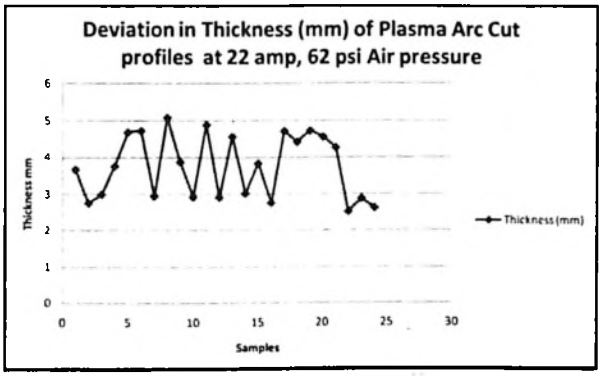

Figure 11 : Deviation in Thickness (mm) of Plasma Arc Cut profiles at 22 Amp

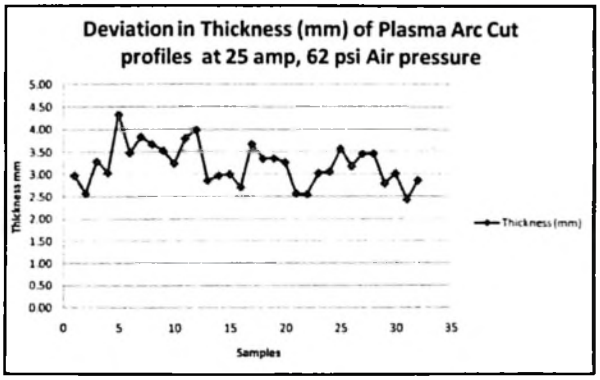

Figure 12 Deviation in Thickness (mm) of Plasma Arc Cut profiles at 25 A

Table 2 : Thicknesses of the Plasma Arc cut samples Operating Voltage115v, current - 25 amp, air pressure 62 psi for 2.8mm thick hollow square tube of structural steel

Sample No.	**Sides**	**Measurement of thickness in mm**								
		Side 1	**Side 2**	**Side 3**	**Side4**	**Avg.**	**Maxm.**	**Minm.**	**Range**	**Std. Dvn.**
1	Top	2.98	2.58	3.29	3.03	2.97	3.29	2.58	0.70	0.25
	Bottom	4.33	3.48	3.84	3.67	3.83	4.33	3.48	0.85	0.32
2	Top	3.53	3.24	3.81	3.99	3.64	3.99	3.24	0.75	0.28
	Bottom	2.86	2.97	3.00	2.72	2.89	3.00	2.72	0.28	0.11
3	Top	3.68	3.35	3.35	3.27	3.41	3.68	3.27	0.41	0.16
	Bottom	2.57	2.55	3.02	3.06	2.80	3.06	2.55	0.50	0.24
4	Top	3.57	3.18	3.45	3.46	3.41	3.57	3.18	0.40	0.15
	Bottom	2.80	3.01	2.44	2.86	2.78	3.01	2.44	0.58	0.21
	Over all					**3.22**	**4.33**	**2.44**	**1.90**	**0.45**

instant start, recommended air pressure 60 psi (4 bar), Max. Pressure 8 bar (120 psi), retaining cap code No. 020218, swirl ring Code No. 020239, electrode code No. 020382, nozzle code No. 120504, Operating frequency 50 -60 Hz, Cos φ = 0.8, power rating 2.9 KVA @ 115v 21 amp, 3.8 KVA @ 115v 27 amp.

ANALYSIS OF RESULTS

The quality of the plasma cut edge is similar in comparison 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. This is responsible of arriving at higher thickness of the cut profiles higher than the thickness of the materials before cutting. These limitations are inherently associated with the degree of constriction of the arc and for that several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut. The temperature of the plasma arc melts the metal and pierces through the workpiece while the high velocity gas flow removes the molten material from the bottom of the cut, or the kerf. In addition to high energy radiation (Ultraviolet and visible) generated by plasma arc cutting, the intense heat of the arc creates substantial quantities of fumes and smoke from vaporizing metal in the kerfs. Because of these localized melting and subsequent solidification, deviations in the dimensions of the cut profile can be observed **[Table 1] [figure 11 & 12].** The large deviations can be found out from the average value of **3.75 mm**. The range of the variations of the thickness is as large as **2.58 mm** with standard deviation at about **0.88 mm**. The deviations are reduced to an extent when current for plasma arc is around **25 amp [Table 2] [figure 12]**. The range of deviation is reduced to **1.90 mm** from **2.58 mm** and the average thickness is hovering about 3.22 mm. This leads to the conclusion that the higher the amperage for PAC reduced deviations can be observed. But there is no denial of the fact that the thicknesses of the PAC cut plates is on the higher side in comparison to the initial dimension of **2.88 mm** in this case. The cut surface finish from the plasma arc process is normally rougher than that achieved by oxy-fuel cutting on carbon steels and it is definitely rougher than most machining processes. In most metals, this roughness usually appears as ripple along the cut surface. This is partly due to the output waveform of the dc power supply (the smoother the output the smoother the cut), but it is also determined to an extent by the gases used and the torch design. Most metals experience top edge rounding when PAC process is applied. Top edge rounding is more pronounced on the thinner metals. This rounding off is due to a higher heat concentration at the top of the cut and can be minimized by using a gas-shielded PAC process. The kerf width obtained by plasma arc cutting will be greater than that achieved by oxy-fuel cutting on carbon steel but not as great as that obtained by other processes such as abrasive cutting. The rule of the thumb for estimating the kerfs in plasma arc cutting is that its width will be approximately 1.5 to 2 times of the tip orifice diameter.

CONCLUSIONS

- For plasma arc cutting for thinner plates of thickness 2.88 mm of a square tube of structural material, substantial deviations are observed.
- Theses deviations are due to the edge rounding, kerf width, dross, top spatter, cut surface bevel angle phenomenon inherently associated with PAC.
- The large deviations can be found out from the average value of **3.75 mm**. The range of the variations of the thickness is as large as **2.58 mm** with standard deviation at about **0.88 mm**. The deviations are reduced to an extent when current for plasma arc is around **25 amp [Table 2] [figure 12]**. The range of deviation is reduced to **1.90 mm** from **2.58 mm** and the average thickness is hovering about **3.22 mm**. This leads to the conclusion that the higher the amperage for PAC reduced deviations can be observed. But there is no denial of the fact that the thicknesses of the PAC cut plates is on the higher side in comparison to the initial dimension of **2.88 mm** in this case.
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