Advance Manufacturing Processes Review Part VI: Plasma ARC Machining (PAM)

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***Abstract**- Technology today in metal cutting process require good dimensional correctness and high-quality cut surfaces without further operation. Plasma arc machining process does high temperature and high velocity contracted arc through an amount of gas between the electrode and the work material to be inscribe. It is essential to have a good knowledge of the process to get better results. This paper focus on current research work and results obtained by using plasma arc machining process based on certain processing parameters, experiments and various optimization techniques that has been used for optimization of plasma machining process. The quality of the cut is generally monitored by measuring the kerf taper angle (conicity), the edge roughness and the size of the heat-affected zone (HAZ). This work aims and explains the evaluating processing parameters, such as the scanning speed, cutting power, cutting height and plasma gas pressure. The regression analysis has been used for the development of empirical models which are able to describe the effect of the process parameters on the quality of the cutting.*

***Keywords:** AM, Parameters, Machining, Quality Characteristic*

1. INTRODUCTION TO PLASMA ARC MACHINING

The three states of matter are solid, liquid and gases. The fourth state of matter is obtained when gases are heated to temperatures about 5500^{0}C. At this temperature, the gases are partially ionized and exits in the form of a mixture of free electrons, positively charged ions and neutral atoms. This mixture is termed as plasma. When a gas is heated, then the number of collisions between the atoms increases. Due to this the gas ionizes, (i.e. the atoms are stripped- off their outer electrons) which results in electrons and ions. The electrons thus produced, in turn, collide with atoms, increase their kinetic energy and ionize them so that more electrons and ions are produced. Thus, the plasma has an ability to conduct electricity due to the presence of electrons. When the gas is completely ionized, then the temperature of the central part of the plasma is between 11000^{0}C to 28000^{0}C. When such an ionized gas is directed on the workpiece through a high velocity jet, the metal is removed by melting.

2. LITERATURE SURVEY

K. Salonitis, S. Vatousianos studied Experimental Investigation of the Plasma Arc Cutting Process, plasma cutting process is investigated experimentally in the paper for assessing the quality of the cut. The quality of the cut has been monitored by measuring the kerf taper angle (conicity), the edge roughness and the size of the heat-affected zone (HAZ). This work aims at evaluating processing parameters, such as the cutting power, scanning speed, cutting height and plasma gas pressure. A statistical analysis of the results has been performed in order for the effect of each parameter on the cutting quality to be determined. The regression analysis has been used for the development of empirical models able to describe the effect of the process parameters on the quality of the cutting and concluded that the scope of the present paper was the experimental study of the plasma arc cutting in order to identify the process parameters that influence the most the quality characteristics of the cut. Four process parameters were examined, namely the cutting speed, the cutting current, the plasma gas pressure and the distance of the plasma torch from the workpiece surface (cutting height). The quality characteristics that were assessed included the surface roughness, the heat affected zone and the conicity of the cut geometry. Using design of experiments and analysis of variance, it was found that the surface roughness and the conicity are mainly affected by the cutting height, whereas the heat affected zone is mainly influenced by the cutting current [3].

Jainish A. Patel, Karan H. Patel, Chirag. Prajapati, Montu D. Patel, Rakesh B. Prajapati reviewed Experimental Investigation of Plasma Arc Cutting by Full Factorial Design and studied plasma cutting is a manufacturing process is leading in developing in arc cutting process which is higher productivity and Good in quality. Nitrogen is used as a shielding gas in the PAC. The shielding gas can influence the cut strength, ductility, and toughness and corrosion resistance. By Plasma arc cutting it is possible to cut is very easy. Optimization of the parameter will be carried out by Full factorial method. We will use Stainless Steel 304 material which is more use in filler material, Food processing equipments, chemical containers and Heat exchangers. S.S 304 plates with Dimensions 250mm x

125mm x 6mm with straight cut. The parameters are the most important factors affecting the quality, productivity and cost of cutting. Where the input parameters are Voltage, cutting speed, Standoff distance and Output parameters are Material Removal Rate, Kerf width, Surface Roughness value (RA value). In this study the effects of different parameters on Kerf width, Surface Roughness value and MRR will be predicted. A plan of experiments based on Full Factorial techniques has been used to acquire the data [4].

N.Senthilkumar, P.Aravinda samy, M.Arun, A.Bruno Abilash, D .Ganesh had given a brief review on plasma arc machining and includes Technology today in metal cutting process require high quality cut surfaces and good dimensional correctness without further operation. Plasma arc cutting process does high temperature and high velocity contracted arc via a amount of gas between the electrode and the work material to be engrave. There are a variety of process parameters such as arc voltage, arc current, gas pressure, cutting speed, standoff distance and gas flow rate that affect the quality distinctiveness of plasma cut like kerf generated, bevel angle, heat affected zone (HAZ) and surface finish. It is very vital to have a good knowledge of process to get better excellence in cut. This paper focus on current research work and results obtained by using plasma arc machining process based on experiments and various optimization techniques that has used for optimization of plasma machining process [5].

Mr. Ketul N. Prajapati, Assi.Prof. H.R.Sathavara, Assi.Prof. D.K.Soni had given a review on plasma arc cutting (PAC) and discuss a variety of fundamental research on plasma arc cutting (PAC) process parameters which the authors have recently performed. Plasma arc cutting process is the non-conventional thermal process which is applicable to perform various operations such as cutting, welding, coating etc. Plasma arc cutting is machining process where material is cut by plasma arc. In this review the research and progress in plasma arc cutting process parameters of different materials are critically reviewed from different perspectives. Some important plasma arc cutting processing parameters and their effects on MRR and surface roughness are discussed. This paper deals with the review of papers by authors [6].

Zeki Cinar, Mohammed. Asmael, Qasim. Zeeshan reviewed developments in plasma arc cutting (pac) of steel alloys and discuss the Plasma Arc Cutting (PAC) process was developed for difficult-to-machine materials in order to overcome the inefficiency and ineffectiveness of conventional machining methods when it comes to complex shapes and tool wear due to the contact between the tool and the workpiece. PAC consumes ionized gas, known as the heat source, and a high energy stream, known as the plasma. Many researchers have examined the PAC of steel alloys by considering the cutting power, scanning speed, cutting height and plasma gas pressure as the process parameters, and analysing the effects on the edge roughness, the kerf taper angle (conicity), burr formation, Heat Affected Zone (HAZ), Material Removal Rate (MRR), surface quality after cutting, and the metallurgical effects of the cut. A comprehensive review was carried out on developments in the analysis and optimization of PAC for steel alloys. It is observed that, the feed rate and edge roughness have a significant effect on the machining characteristics; however, less consideration was given by the researcher to these parameters. In addition, a critical comparison was made of the process parameters involved and the methods of analysis used, with the aim of providing the status of current research and guidance for future research [7].

Dakshesh M. Pandya, Viral M. Patel, Krunal B. Patel reviewed study and optimization of process parameter in plasma arc cutting and described the plasma arc cutting process was developed for difficult to machine materials in order to overcome the inefficiency and ineffectiveness of conventional machining method when it comes to complex shape and work piece. Plasma cutting is a process that cut through electrically conductive material by means of jet of hot plasma. In this research work the study has been carried out on the PAC of Carbon steel by considering gas pressure (bar), current flow rate (A), cutting speed (mm/min) and arc gap (mm) as the process parameters and analysing the effect on the surface roughness (Ra), material removal rate. A comprehensive review was carried out on development in analysis and optimization of PAC for Carbon steel (A36). The Experimental study has been carried out by using Taguchi design methods and ANOVA analysis for Material removal rate (MRR), Surface roughness by performing cuts of different run sets of L9 orthogonal Array [8].

R. K. Tyagi reviewed on Plasma welding/cutting with and without velocity shear instability in plasma described engineering applications of plasma welding technology hold a marked significance in manufacturing industry. The effect of variation of electric field, magnetic field and other parameters on plasma heat flux, Debye length, temperature of ions etc. has been demonstrated in selected lead range for plasma welding/cutting for metallurgical and non-metallurgical use. This review article analyses the experimental and theoretical effect of different plasma factors namely magnetic field, homogenous DC electric field, shear scale length, temperature anisotropy, heterogeneity in DC electric field and density gradient on the heat flux, Debye length, temperature and the number of ions. In this process, effectiveness of heat transfer from plasma to work-piece/electrode depends upon parameters such as temperature of ions, Debye length, number of ions striking the work surface etc. which can be controlled according to specific need by adjusting magnetic, electric field and aforementioned plasma factors without making any dimensional change to the machine. Through plasma welding, defects such as gas porosity, formation of oxide films, tungsten and other inclusions, hot and cold cracks, lack of fusion defects and cavities are reduced. Plasma welding/ cutting process is applicable to a broad range of samples from very small to large sized components by restricting to a set of parameters suited to them [9].

Sagar S. Pawar, Dr. K. H. Inamdar reviewed factors affecting quality of plasma arc cutting process and described now a day's metal cutting process demands high quality cut surfaces and good dimensional accuracy with no further processing. Plasma arc cutting process employs a high temperature and high velocity constricted arc through a quantity of gas between the electrode and the work material to be cut. There are various process parameters such as arc voltage, arc current, gas pressure, cutting speed, standoff distance and gas flow rate that affect the quality characteristics of plasma cut like kerf generated, chamfer (bevel angle), heat affected zone (HAZ) and surface finish. Other factors such as bore diameter of nozzle and gap between electrode and nozzle are also important which limits the cutting parameters. It is very important to have a good knowledge of process to get better quality cut. This paper highlights recent research work and results obtained by using plasma arc cutting process based on experiments and various optimisation techniques that have been used for optimisation of plasma cutting process [10].

3. PRINCIPLE OF PLASMA ARC MACHINING

When the high velocity jet of plasma is directed on the workpiece surface by means of a plasma arc cutting torch, the metal from the workpiece melts which results in to the machining of the workpiece. The continuous attack of electrons on the workpiece which transfer the heat energy of plasma on the workpiece causes the workpiece to melt. In this process, the material of the workpiece melts similar to gas flame cutting operation. The melting occurs due to:

a. Convective heat transfer from high temperature plasma
b. Direct electron bombardment of an electric arc

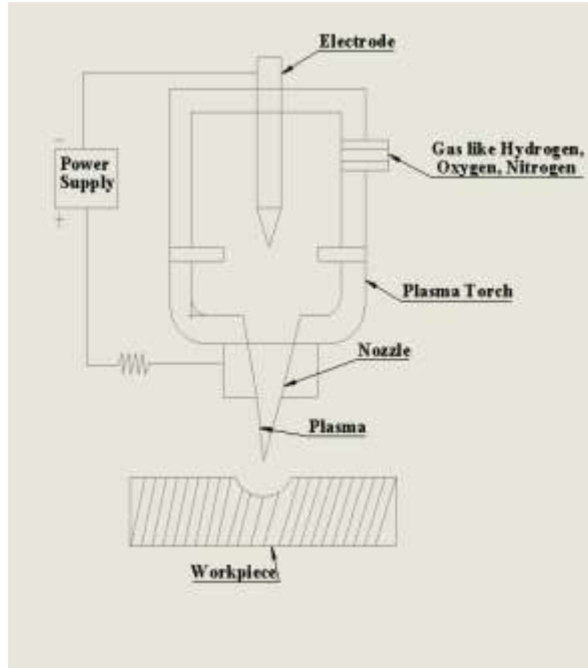

Figure 1: Setup of Plasma Arc Machining

4. SET-UP OF THE PROCESS

The setup of the process consists of:

1) Plasma cutting torch: a plasma cutting torch carries a tungsten electrode fitted in a small chamber. At other end of the torch is a small converging orifice called as nozzle. One side of the torch provides a passage for supply of gas into the torch.
2) Tool and workpiece: the electrode is connected to negative terminal of D.C. power supply and therefore acts as a cathode. The nozzle is made anode by connecting to the positive terminal of the power supply through a suitable resistor. This resistor limits the current through the nozzle to about 50 A. The workpiece to be machined is also connected to the positive terminal of the supply. The anode and cathode are separated by an insulator.
3) Gas supply unit: it consists of gas cylinder, regulators and gas supply hoses. The commonly used gases are argon or nitrogen or the mixture of two. For certain useful purposes, a percentage of hydrogen may be added. The choice of the gas depends upon the material to be cut, economics and the quality of the cut edge desired. The flow rate of the gas varies directly with the thickness of the workpiece. Typical gas flow rate is 2 to 11 m^3/hr.
4) Cooling system: a provision is made for circulating the water around the torch so that the electrodes and the nozzle both remains water cooled.
5) Power supply: a D.C. power supply of 400 V, 200 KW and upto 10000 A is supplied to the nozzle. When supply is made ON, a strong arc is struck between the

electrode and the nozzle and then gas is forced into the chamber. When the gas molecules collide with the high velocity electrons of the arc, plasma is formed. This plasma is forced through the nozzle (anode) onto the workpiece. The heat produced from this jet of plasma is sufficient to raise the workpiece temperature above its melting point and high velocity gas stream effectively blows the molten metal away.

5. CONTROLLING PARAMETERS

1) Stand-off distance: increase in the stand-off distance reduces the depth of penetration and hence narrows the cut width at the bottom. The stand-off distance depends on the thickness of the metal to cut. The typical value of the stand-off distance varies from 5 mm to 10 mm.
2) Cutting speed: increase in the cutting speed reduces the depth of immersion of the plasma jet, leading to narrowing of the cut in the lower portion. Decrease in the cutting speed will cause the opening of the cut at the bottom of the workpiece. For example, the typical cutting speed for aluminium at 80 KW power and 4 mm orifice diameter is 8 mm/sec.
3) Gas: the gas flow rate is directly proportional to the thickness of the material. The selection of a particular of a particular gas depends on the quality of cut and the economics.

6. ADVANTAGES OF PAM

1) The rate of cutting is high.
2) It is used to cut any metal irrespective of its hardness and even to non-conducting material like concrete.
3) It can cut carbon steel-up to 10 times faster than oxy-fuel cutting.
4) The process id finding ever increasing application because it gives the highest temperatures available for many practical sources.

7. DISADVANTAGES OF PAM

1) Protection of noise is necessary.
2) Heat affected zone is more.
3) High initial cost of the equipment.
4) Safety precautions are necessary for the operator and those in the nearby area.

8. APPLICATIONS OF PAM

1) For stack cutting, plate bevelling, shape cutting and piercing.
2) In manufacturing of automotive and rail road components.
3) It can cut hot extrusion extrusions to desired length.

9. CONCLUSION

Plasma arc machining (PAM) is one of the widely used unconventional machining method that is capable of producing the complex shapes. There are certain process parameters such as gas pressure, cutting speed, arc voltage, arc current, standoff distance and gas flow rate that affect the quality distinctiveness of plasma cut like bevel angle, heat affected zone (HAZ), kerf generated and surface finish. PAM and its assisted processes as well as optimization techniques, which made some new research scopes in the PAM. Developments in modeling techniques have made new research scopes in the PAM and improves the performance of PAM process.

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