Numerical Analysis of Thermal Profile in Plasma Arc Cutting

Ali. Moarrefzadeh

Abstract— **Plasma arc cutting (PAC) is a process that is used to cut steel and other metals of different thicknesses (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. The thermal effect of Plasma Arc that specially depends on the plasma, gas type and temperature field of it in workpiece, is the main key of analysis and optimization of this process, from which the main goal of this paper has been defined. Numerical simulation of process by ANSYS software for gaining the temperature field of workpiece, the effect of parameter variation on temperature field and process optimization for different cases of plasma Arc are done.**

***Keywords*–** Numerical Analysis, Plasma Arc, PAC, ANSYS, Temperature Field and Workpiece

I. INTRODUCTION

Plasma cutting is a process that is used to cut steel and other metals of different thicknesses (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.

The HF Contact type uses a high-frequency, high-voltage spark to ionize the air through the torch head and initiate an arc. These require the torch to be in contact with the job material when starting, and so are not suitable for applications involving computer numerical controlled (CNC) cutting.

The Pilot Arc type uses a two cycle approach to producing plasma, avoiding the need for initial contact. 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 25,000 °C (45,000 °F).

Plasma is an effective means of cutting thin and thick materials alike. Hand-held torches can usually cut up to 2 inches (51 mm) thick steel plate, and stronger computer-controlled torches can cut steel up to 6 inches (150 mm) thick. 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.

Plasma cutters use a number of methods to start the arc. In some units, the arc is created by putting the torch in contact with the work piece. Some cutters use a high voltage, high frequency circuit to start the arc. This method has a number of disadvantages, including risk of electrocution, difficulty of repair, spark gap maintenance, and the large amount of radio frequency emissions [1]. Plasma cutters working near sensitive electronics, such as CNC hardware or computers, start the pilot arc by other means. The nozzle and electrode are in contact. The nozzle is the cathode, and the electrode is the anode. When the plasma gas begins to flow, the nozzle is blown forward. A third, less common method is capacitive discharge into the primary circuit via a silicon controlled rectifier. The plasma arc cutting process shows in Fig. 1.

II. ARC CONSTRICTION

In the early 1950's, it was discovered that the properties of the open arc, i.e., Tig welding arc, could be greatly altered by directing the arc through a water-cooled copper nozzle located between an electrode (cathode) and the work (anode). Instead of diverging into an open arc, the nozzle constricts the arc into a small cross section. This action greatly increases the resistive heating of the arc so that both the arc temperature and the voltage are raised. After passing through the nozzle, the arc exits in the form of a high velocity, well collimated and intensely hot plasma jet as shown in Fig. 2.

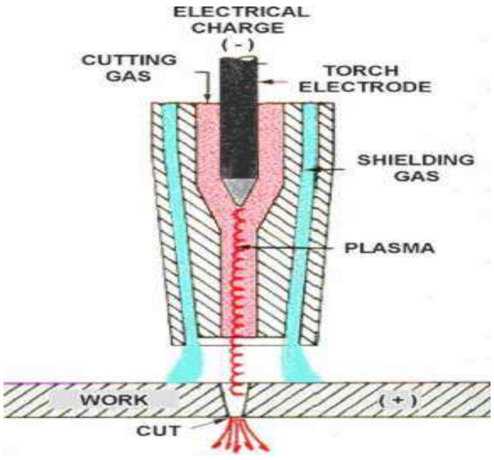

Fig. 1. Plasma Arc Cutting Process

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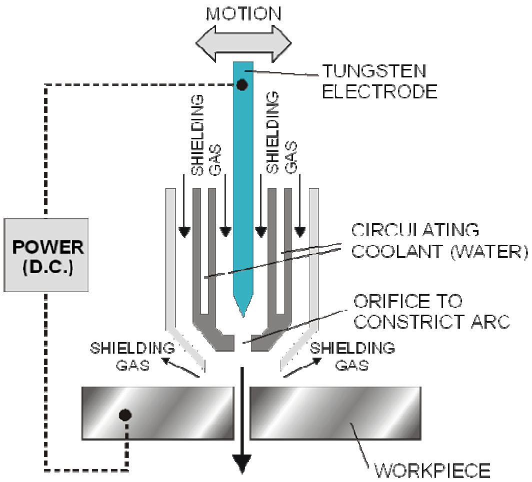


Fig. 2. Plasma jet

III. NUMERICAL SIMULATION

Finite elements simulations are done in 3 steps with the main pieces:

1- Modeling by FEMB
2- The thermal study and processing
3- Post-Processing result of analysis by ANSYS software for results discussion

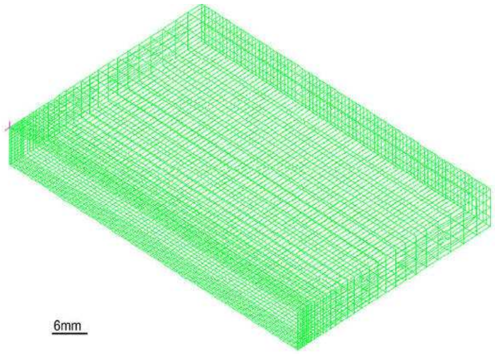
Finite-Element techniques:

1-Finite elements modeling, types and properties for model different parts.
2-The definition of material properties
3-parameter definition

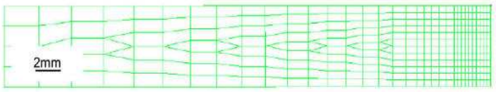
Finite-Element Modeling of SAW shows in Fig. 3.

IV. CONVENTIONAL PLASMA ARC CUTTING

The plasma jet that is generated by conventional “dry” arc constriction techniques can be used to sever any metal at relatively high cutting speeds. The thickness of plate can range from 1/8 inch to a maximum thickness depending on both the current capacity of the torch and the physical properties of the metal. A heavy duty mechanized torch with a current capacity of 1000 amps can cut through 5 inch thick stainless steel and 6 inch thick aluminum. However, in most industrial applications the plate thickness seldom exceeds 1-1/2 inch. In this thickness range, conventional plasma cuts are usually beveled and have a rounded top edge.



(a) Three-dimensional grids



(b) Cross section

Fig. 3. Finite-Element modeling

Beveled cuts are a result of an imbalance in heat input into the cut face. As shown in Fig. 4, a positive cut angle will result if the heat input into the top of the cut exceeds the heat input into the bottom. One obvious approach to reduce this heat imbalance is to apply the arc constriction principle described in Fig. 1: increased arc constriction will cause the temperature profile of the plasma jet to become more uniform and, correspondingly, the cut will become more square. Unfortunately, the conventional nozzle is limited by the tendency to establish two arcs in series---electrode to nozzle, and nozzle to work. This phenomenon is known as “double arcing” and can damage both the electrode and nozzle.

Conventional plasma cutting can be cumbersome to apply if the user is cutting a wide variety of metals and plate thickness. For example, if the conventional plasma process is used to cut stainless steel, mild steel and aluminum, it will be necessary to have three different cutting gases on hand if optimum cut quality is to be obtained. This requirement not only complicates the process, but necessitates stocking expensive cutting gases such as 65% argon - 35% hydrogen.

V. “DUAL FLOW” PLASMA CUTTING

The Dual Flow technique, developed around 1965, is a slight modification of the conventional plasma cutting process. Essentially it incorporates the same features as conventional plasma cutting except that a secondary shield gas is added around the nozzle (Fig. 4). Usually the cutting gas is nitrogen and the secondary shielding gas is selected according to the metal to be cut. Secondary shield gases typically used are: mild steel either air or oxygen; stainless steel--CO2; aluminum--argon--hydrogen mixture.

Cutting speeds are slightly better than with conventional cutting on mild steel; however, cut quality is inadequate for many applications. Cutting speed and quality on stainless steel and aluminum are essentially the same as with the conventional process. The major advantage of this approach is that the nozzle can be recessed within a ceramic shield gas cup as shown in Fig.5, thereby protecting the nozzle from double

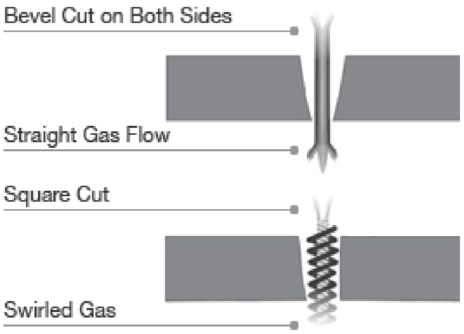


Fig. 4. Positive angle

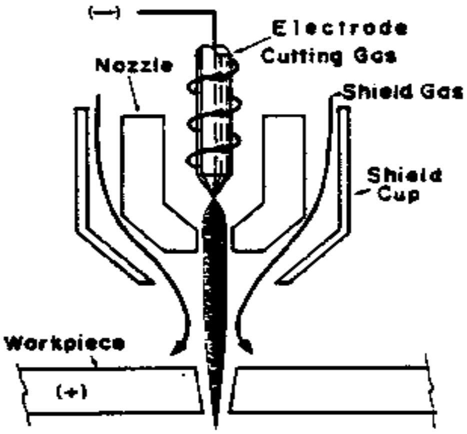


Fig. 5. Dual Flow Plasma Cutting

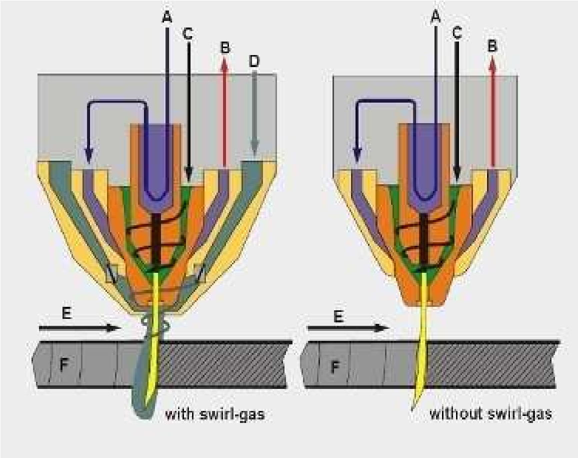


Fig. 6. Direction of cut

arcing. If no shield gas were present, the ceramic shield gas cup could deteriorate because of the high irradiative heat load produced by the plasma jet.

Water Shield plasma cutting is similar to Dual Flow except that water is substituted for the shield gas. Cut appearance and nozzle life are improved because of the cooling effect provided by the water. Cut squareness, cutting speed and dross tendency are not measurably improved because the water does not provide additional arc constriction.

Unlike the conventional processes described earlier, optimum cut quality is obtained on all metals with just one cutting gas---nitrogen. This single gas requirement makes the process more economical and easier to use. Physically, nitrogen is ideal because of its superior ability to transfer heat from the arc to the workpiece. As illustrated in the equation below, the heat energy, Eh, absorbed by nitrogen when it dissociates, is relinquished when it recombines at the workpiece.

$$N_2 + E_h = N + N \qquad (1)$$

Mass continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r) + \frac{\partial}{\partial z}(\rho\upsilon_z) = 0 \qquad (2)$$

Despite the extremely high temperatures generated at the point where the water impinges the arc, less than 10% of the water is vaporized. The remaining 90% of the water exits from the nozzle in the form of a conical spray which cools the top surface of the workpiece. This additional cooling prevents the formation of oxides on the cut surface.

Little water is evaporated at the arc because an insulating boundary layer of steam forms between the plasma and the injected water. This steam boundary layer, usually referred to as a "Linden frost Layer", is the same principle that allows a drop of water to dance around on a hot skillet rather than immediately vaporizing.

Nozzle life is greatly increased with the Water-injection technique because the steam boundary layer insulates the nozzle from the intense heat of the arc, and the water cools the nozzle at the point of maximum arc constriction. The protection afforded by the water-steam boundary layer also allows a unique design innovation: the entire lower portion of the nozzle can be ceramic. Consequently, double arcing from the nozzle touching the workpiece- the major cause of nozzle destruction--is virtually eliminated.

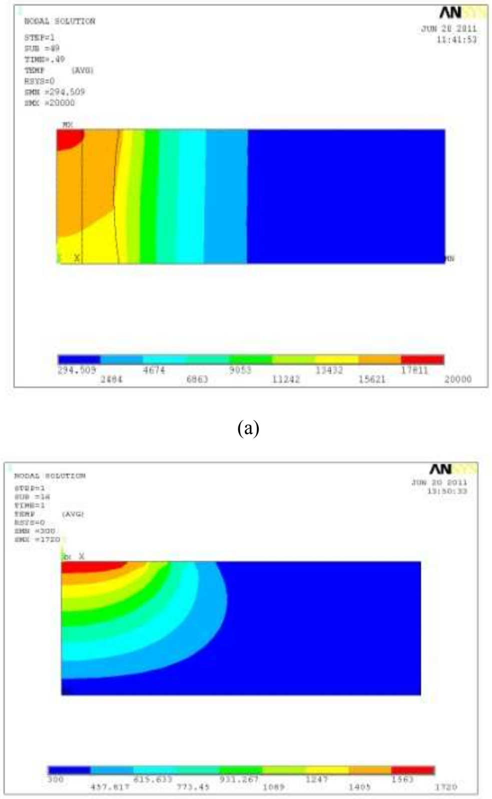
An important property of these cuts is that when viewed in the direction of the cut, as shown in Fig. 6, the right side of the kerf is square and the left side of the kerf is slightly beveled. This feature is not caused by Water-injection; rather, it results from the cutting gas which is swirled in a clockwise direction, causing more of the arc energy to be expended on the right side of the kerf. This same asymmetry exists in conventional "dry" cutting when the cutting gas is, swirled; however, the difference in cut angle is not so evident because of excessive bevel and rounding of the top edge. In shape cutting applications, this means that the direction of travel must be selected to produce a square cut on the production part.

VI. CONCLUSION

Conclusions for workpiece temperature field, showing the heat transfer way between shielding gas and environment with temperature and velocities is completely shown in Fig.7. Water-injection plasma cutting is capable of cutting virtually all metals ranging from 1/8 inch to 3 inches thick. In this thickness range, Water-injection plasma cutting offers some distinct advantages over both conventional plasma cutting and the process variations that are available. These advantages are: relatively square cuts at high cutting speeds; smooth, clean cut face; dross free cuts on most materials including mild steel; increased nozzle life since the ceramic bottom piece insulates the nozzle, thereby preventing double arcing; use of one cutting gas, nitrogen, for all metals. The cut angle on the high quality side will usually be within two degrees of square and will seldom require machining or finishing. The most widespread application of Water-injection Plasma Cutting has been multiple torches cutting of mild steel. The high cutting speeds achievable with Water-injection plasma cutting, together with the capabilities of N/C cutting machines, enable the user to greatly increase his productivity. Cutting costs are typically 1/2 to 1/4 that of oxy-fuel cutting.

The conventional "dry" cutting mode allows the cutting plate in the 3 to 6 inch thickness range. In this mode of operation the injection water is used for nozzle cooling only; arc constriction is achieved purely by the nozzle.

A gas mixture os 65% argon and 35% hydrogen is used instead of nitrogen because it develops a deep penetrating plasma jet necessary for cutting heavy plate. This capability is ideal for steel service center applications and nuclear vessel fabricators.



(a)

(b)

Fig. 7. Conclusions for temperature field: (a) Steel temperature field, (b) Aluminum temperature field

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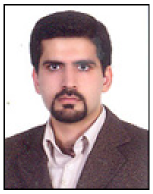

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