EFFECTS OF PROCESS PARAMETERS IN PLASMA ARC CUTTING ON STAINLESS STEELS AND STRUCTURAL STEEL

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Abstract: *Plasma arc cutting is a non-conventional manufacturing process that has potential for modern day metal cutting demands with good dimensional accuracy and high-quality surfaces without any extra operation. In this experimental study, AISI 304, AISI 430 and EN S235JR sheet materials having 5 mm. thicknesses, has cut with plasma arc cutting. Each material has cut with 6 different variations. Current, cutting speed, arc voltage, gas pressure and gas flow rate have been changed as process parameters. The quality of the cut has been monitored by measuring the edge roughness, the hardness of the heat-affected zone (HAZ) and the results has compared.*
Keywords: STAINLESS STEEL; STRUCTURAL STEEL; PLASMA ARC CUTTING; HEAT-EFFECTED ZONE (HAZ)

1. Introduction

Modern manufacturing processes are widely employed for harder, stronger, and tougher materials those are known as “difficult to cut”. Moreover these methods are capable to produce complex geometries with high dimensional and surface accuracies. Plasma cutting is a modern manufacturing method which can be applied for cutting wide range of materials. The inert gas is blown with high speed out of a nozzle; at the same time, an electrical arc is formed through that gas from the nozzle to the surface, reaching high temperatures that are ionizing atoms to plasma form. The formed plasma melts the material being cut and swiftly moves blowing molten metal away from the cut [1-4].

‘Plasma’, as a term, had been used firstly in 1920s, it was firstly realized in 1950s that material can cut with it. Cutting with plasma arc, one of the thermal cutting methods has been improved as an alternative method for mostly stainless steel, aluminium and non-ferrous metals being cut with oxy-acetylene. Plasma cutting of the workpiece is the result of melting/vaporizing of material through a very hot cylindrical (theoretical) plasma beam which burns and melts through the material (Fig. 1).

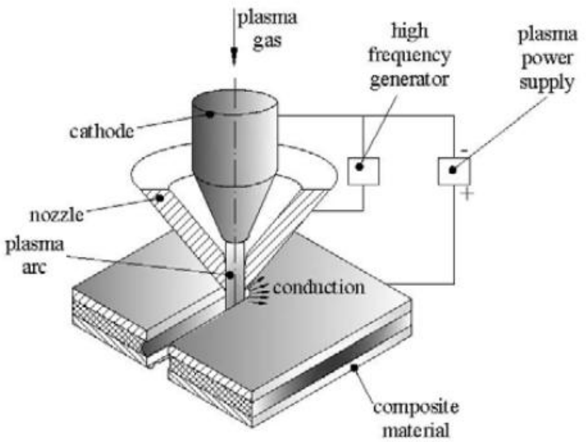

Fig.1. *Plasma cutting [2]*

One of the most important problems occurring as result of heat transfer from plasma column to the workpiece is the deformation of the cut edges after the material is cut and then cooled. During the cut operation, many physical phenomena occur in this process: heat conduction, convection, radiation effects, mechanical deformation, phase transition etc. The principle of plasma cutting means to focus a lot of power on a small area of workpiece surface, in this way producing an intense surface heating [2].

Nowadays, with the increasing of stainless steel, aluminium and metal and non- metal materials’ consumption in industry, the importance of rapid, cheap and delicate cutting for these materials have scaled up. At initial application of plasma cutting, generally, argon and 35% hydrogen mixture was used as a plasma gas. However, this mixture is expensive and cutting operation will be costly. Reducing operation costs would be reached by changing mixture of gas to air as a plasma gas. Simply, plasma can be identified as a state of matter. The differences between states of matter is the energy that they have. For the transition from a state to another, it is required to supply energy and reverse transition is also possible [5]. The solid material can be turned into fluid state by supplying energy, the fluid material can be converted to gas with energy and gaseous material can be ionized and converted to plasma by supplying energy.

The plasma cutting technology is sometimes compared to laser and waterjet cutting methods. This technology seems providing more advantages over both cutting methods such as lower operation costs, widely used in cutting high-alloy steel and aluminium materials in medium and larger thickness, excellent performance in small and medium-sized thickness of steel (30 mm), high cutting speeds, high automation, etc [3-7].

Stainless steel is identified ferrous alloys having at least 10,5% chromium (Cr). The thin but dense chromium oxide layer on surface of stainless steel provides high resistance against corrasion and inhibits oxidation to move deeper [8,9].

There are five different types of stainless steels which are ranked from completely austenitic to completely ferritic varying in regard to additives that they contain. These are respectively:
Austenitic Stainless Steel
Ferritic Stainless Steel
Martensitic Stainless Steel
Dual phase Stainless Steel
Precipitation-hardened Stainless Steel

Austenitic Stainless Steel includes 200s and 300s quality series and 304 quality is the most commonly used which its basis element is chromium nickel. Ferritic Stainless Steel is an alloy that cannot be hardened and 405,409,430,422 and 446 quality stainless steels are Ferritic Stainless Steel. Martensitic Stainless Steel has almost the same chemical properties, yet it has high incidence of carbon and less chromium that’s why they can be hardened with heat treatment. 403,410,416 and 420 qualities are Martensitic Stainless Steel. Dual phase Stainless Steel is obtained by forming a microstructure having almost equal austenite and ferrite and it definitively contains %24 chromium and %5 nickel. It doesn’t include any of quality series from 200s, 300s and 400s.

Various studies have been reported regarding the application of plasma cutting in stainless steels using different process parameters [10-15]. These studies have provided useful and applicable parameters, however, more efforts have been required to understand the process better.

In this experimental study, the plasma method is selected to cut some commonly used metals (AISI 304, AISI 430 and EN S235JR). CNC plasma cutting machine is used The selected cutting parameters were current, cutting speed, arc voltage, gas pressure and gas flow rate and the effects of these parameters on edge roughness, the hardness of the heat-affected zone (HAZ).

2. Experimental Study

In this experimental study, AJAN CNC 2x6m PP260A plasma cutting bench was used (Fig. 2.). 6 different experiment scenarios having different parameters were applied (Table 1.). 3 different materials shown in Table 2. having same thickness of 5mm were subjected to these experiments.

Fig. 2. *AJAN CNC 2x6m PP260A plasma cutting*

The materials were cut flat sided oval shape having 90mm length and 40mm width. Totally, 18 cutting operations were performed, yet it was not accomplished to cut S235JR material in 5st scenario.

Table 1. *Parameters of Experiment Scenarios*

	CURRENT (A)	PLASMA GAS	GAS PRESSURE (BAR)	GAS FLOW RATE(Lpm)	MATERIAL THICKNESS(mm)	VOLTAGE(V)	CUTTING SPEED (mm/min)
1. SCENARIO	30	O2	4,56	18,3	5	120	750
2. SCENARIO	40	O2	4,8	5,4	5	114	1300
3. SCENARIO	80	O2	6,53	9,6	5	120	3700
4. SCENARIO	130	O2	4,49	16,4	5	111	4500
5. SCENARIO	45	N2	5,51	9,7	5	129	1050
6. SCENARIO	80	AIR	6	28	5	151	2200

Table 2. *Materials subjected to the experiment*

	C%	Cr%	Ni%	Mn%	P%	S%	Si%
S235JR	0.17	-	-	1.4	0.035	0.035	-
AISI 304	0.08	18	8	2	0.045	0.03	0.75
AISI430	0.12	16	0.75	1	0.045	0.03	1

The surface roughness (R_z) of cut materials was measured with Mitutoyo SJ201P equipment. Then by, the materials were divided into 3 sections by bandsaw bench branded Mossner. The middle sections of materials is rubbed with P240 emery sheets by using Netkon and Forcipol 2V grinders. The hardness of material which its surfaces were polished and the hardness of heat affected zone(HAZ) were measured with HMV Sumadzu Micro Vickers Hardness test device.

3. Results and Discussion

3.1. Surface Roughness

Surface roughness is one of the major process outputs when metal is cut. This value will affect the dimensional accuracy as well as surface quality. In surface roughness measurement, for S235JR material, the least roughness was experienced in the 4th experiment scenario (2,385µm). The highest roughness value (6,7975 µm) was beheld in the 6th experiment scenario.

For AISI304 stainless steel, the least roughness (2,3175 µm) was seen in the 5th experiment scenario. The highest roughness value (41,125 µm) was experienced in the 1st experiment scenario. For AISI430 stainless steel, the least roughness (1,6925 µm) was met in the 5th experiment scenario. The highest roughness value (38,2725 µm) was observed in the 1st experiment scenario.
The surface roughness of 3 different materials resulted by 6 different experiment scenarios are indicated in Fig.3.

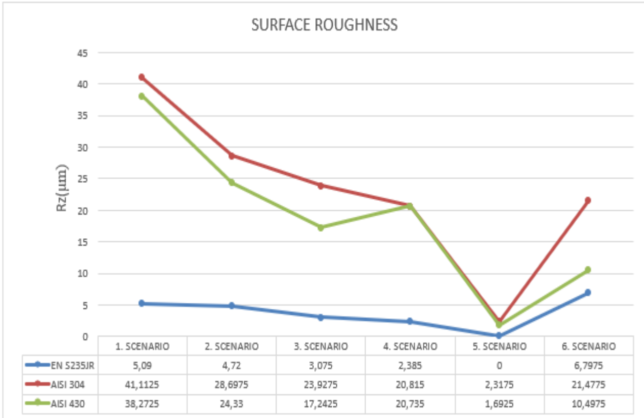

Fig.3. *Surface roughness of material after plasma cutting*

3.2. Hardness

The hardness of cut sections in plasma cutting application is examined and the results have been presented in Fig 4. The obtained minimum and maximum hardness results for the materials after plasma cutting operations are as follows:
For 235JR, between 130HV-150HV
For AISI304, between 190HV-225HV
For AISI 430, between 340HV-395HV

It was noticed that the hardness value has not changed with using different cutting conditions. The hardness of cut sections were similar in all cutting conditions.

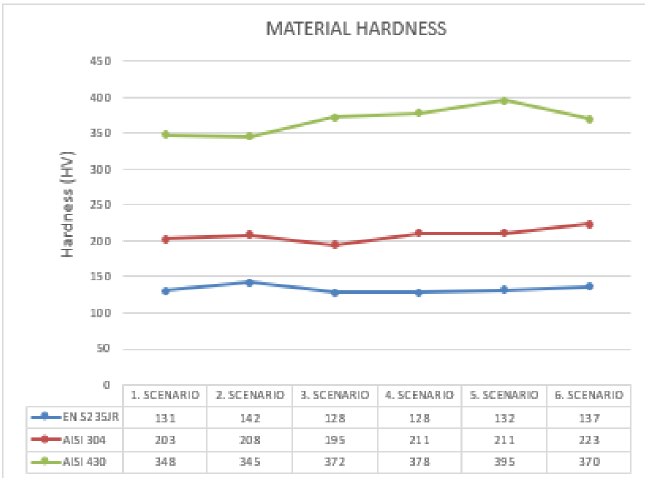

Fig.4. *Material hardness after plasma cutting*

3.3. Hardness of Heat Affected Zone (HAZ)

The Heat-Affected Zone (HAZ) presents to a non-melted area of cut metal that has experienced changes in its material properties as a result of exposure to high temperatures. The HAZ is identified as the area between the cut and the main metal. These areas can vary in size and severity depending on the plasma cutting parameters.

The height hardness for 235JR material was obtained in 6th experiment scenario and the least one was sought in 4th experiment. When it is compared roughness of HAZ and of the material, it is realized that HAZ roughness is higher than the one that the material has.

For the austenitic AISI 304 stainless steel, after the 6th experiment scenario, the highest hardness value was occurred.
The lowest hardness value was obtained after 4th experiment scenario. The HAZ hardness is higher than the one that material has.

Comparing to ferritic AISI 430 stainless steel, highest value was experienced in 3rd experiment scenario and the lowest value was observed after 6th experiment scenario. Contrast to other materials, the HAZ roughness is less than the roughness of material.

The Heat Affected Zone (HAZ) hardness of the materials cut with plasma cutting are shown in Fig. 5.

During plasma cutting operations, the depth of the HAZ is related to cutting speed, material properties, and material thickness. It is known that plasma cutting process that operates at high temperatures and slow speeds produce large HAZs. Furthermore, cutting processes that operate at high speeds tend to reduce the width of the HAZ.

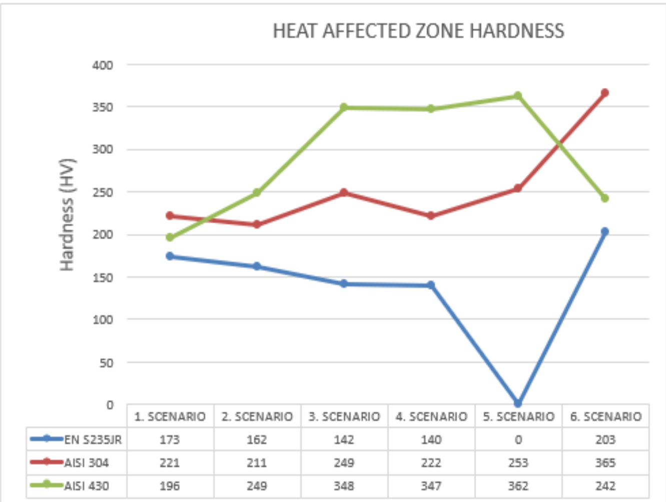

Fig.5. *HAZ hardness after plasma cutting*

Note: Due to that S235JR couldn't be cut with 5th experiment scenario, HAZ hardness was not measured.

4.Conclusion

Plasma cutting is one of the modern cutting methods that is applied for various materials. The process has different cutting parameters and these are should be examined to find optimum industrial application. In this experimental study, 5mm thick austenitic and ferrite stainless steels were cut by plasma method. The selected cutting parameters on surface roughness, hardness and HAZ were examined. The following conclusions are obtained:

- When oxygen was used as plasma cutting gas, the surface roughness value was higher than the other applications with different gases.
- The lowest surface roughness value (1,6µm) was observed when nitrogen is used
- The HAZ hardness of austenitic stainless steel increased after plasma cutting, whereas HAZ hardness of ferritic stainless steel decreased.

Industrial application of plasma arc cutting process presents many unique advantages and cost effective technology comparing to other cutting methods. It should be noted that more efforts put to optimize the process parameters in any industrial application of material cutting.

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