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QUALITY OF PLASMA CUTTING

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Abstract: *The plasma arc cutting process severs metal by using a constricted arc to melt a localized area of a workpiece, removing the molten material with a high-velocity jet of ionized gas issuing from the constricting orifice. The ionized gas is a plasma, hence the name of the process. This paper analyzes quality of cut in plasma arc cutting. Quality of cut in plasma arc cutting is defined using standard EN ISO 9013. The correlation between quality of plasma cut Conclusions of other authors who investigated quality of plasma cut are also presented.In the second part of the paper, experimental investigation of plasma cut was presented. Samples of steel plate thickness of 15 mm were used for creating 17 cuts. Obtained experimental results are consistent with theoretical considerations, as well as previous experimental results.*

Keywords: Plasma arc cutting, experiment, quality of cut, process parameters

1. INTRODUCTION

The efficient manufacture of high-quality plate components is quite difficult task. One of the easiest methods of contour cutting steel is oxy-fuel cutting. With respect to oxy-fuel cutting, laser cutting, abrasive water jet cutting, and plasma cutting are new attractive advanced processes for contour cutting of plate. They have numerous advantages, namely, a narrow cut, a proper cut profile, smooth and flat edges, minimal deformation of a workpiece, the possibility of applying high feed rates, intricate profile manufacture and fast adaptation to changes in manufacturing programs [1].

Plasma cutting is an industrial process that is essentially controlled by the operator who uses recommendations given by the manufacturers of the cutting equipment. Those recommendations, however, reflect the point of view of the manufacturers' business, which includes not only selling the cutting torches but also the consumables. Yet, the manufacturers' recommendations usually lead to solutions that are technically sound in terms of cutting quality, but do not necessarily correspond to the most cost-effective solutions on the user's point of view [2].

As a result, the user attempts to optimize the cutting operations by trial-and-error every time it is needed to setup the existing equipment for a new different task.

This requires the development of full studies and apply theoretical and experimental researches among all the technological system's links, in order to establish (chose) the optimal processing variant.

2. PROCESS PARAMETERS

As in the case of other machining methods, at the plasma arc cutting (PAC), in order to obtain good results, it is very important to well know the process, this meaning to exactly know what are the parameters involved in the process and their influences (fig. 1).

Input parameters are those parameters that can be controlled, and their values are known and can be set by the operator. Output parameters related to the quality of the obtained surface. Factors which cannot be controlled coming from machines and work environment.

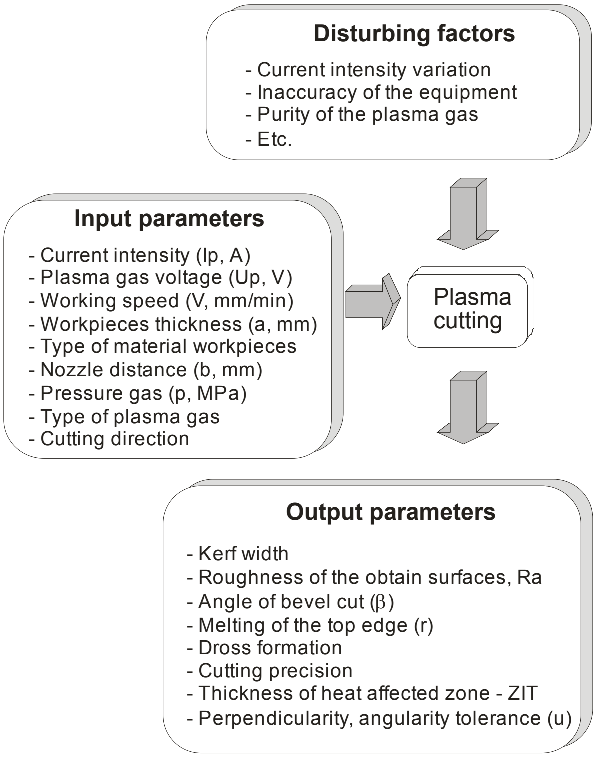

Figure 1. Parameters of plasma arc cutting [3]

3. QUALITY OF PLASMA CUTTING PROCESS

European standard "EN ISO 9013" "Thermal Cutting" defined classification of thermal cutting, contains geometrical product specification and quality. Standard applies to materials suitable for cutting with oxy-fuel (from 3 to 300 mm), plasma cutting (1 to 150 mm) and laser cutting (0.5 to 40 mm) [4], fig. 2.

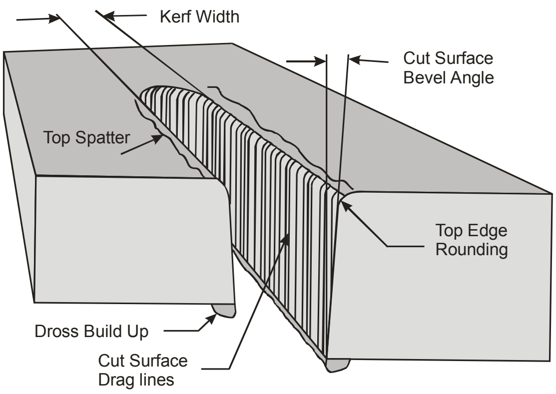

Figure 2. Quality parameters of a plasma cut *[5, 14]*

Using standard "EN ISO 9013" quality of the surface is defined by the following parameters:

- Squareness and angularity tolerance (u)
- Average peak-to-valley height (Rz5, Ra) - roughness
- Drag (n)
- Melting of the top edge (r)
- Possible formation of burrs or drops of molten metal on the bottom of the cut-edge.

This standard defines terms like: kerf width, angle of bevel cut… that can be used to define the quality of the work piece.

Squareness and angularity tolerance is defined as distance between two parallel straight lines that limit the upper and lower boundaries of the cut face profile at the teoretically correct angle, 90 degrees for square cut edges, fig. 3. Standard establishes a zone of significance for the measurement of U reduced at the the top and bottom edge by distance, Δa, related to material thickness. This measure also applies to concave and convex surfaces.

Since several works in literature highlight that the torch cutting direction and the swirling direction of the plasma gas determine a different squareness and angularity tolerance in the two sides of the cut [6], both left and right (*U*L and *U*R, respectively) were measured in order to highlight the asymmetric behaviour of the plasma beam.

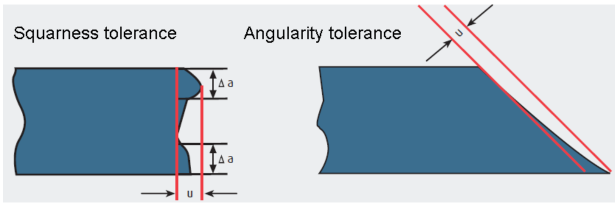

Figure 3. Squareness and angularity tolerance [5]

Surface roughness is defined cut appearance, and gives information on whether the need for further processing. Parameter surface roughness is mean height of the profile Rz5, unit is μm.

Surface roughness is influenced by more input parameters, but the most influential are: cutting speed, current and material thickness. Based on the developed mathematical model [7, 8], shows that the thickness of the material has the greatest influence on surface roughness. This is logical because current and cutting speed are functions of material thickness. Surface roughness is a function of material thickness defined by ISO 9013, based on which we can see that the thinner material have lower roughness (Fig. 4).

Roughness of the cutting edge is connected with stability of process. When the torch is too high positioning from work piece plasma arc is a long and curve. This phenomenon leads to the formation of surface waves, and lynx, and therefore to a higher Rz. When the cutting speed increases the torch moves fast and plasma arc loses stability with view to the cutting front. Therefore plasma arc can not remain perpendicular to front surface of the work piece, which is on surface cutting formed lynx. On the other side too low cutting speeds lead to excessive melting in a work zone, resulting appearance of furrows.

It is known that surface roughness of the cut is not same by depth. Experimental studies [9] showed that diameter nozzle has a larger effect on surface roughness on upper reaches of cutting (1 mm from the top edge) than in the lower zones (5 mm from the top edge). These studies demonstrated that higher values of pressure gives lower values of Rz.

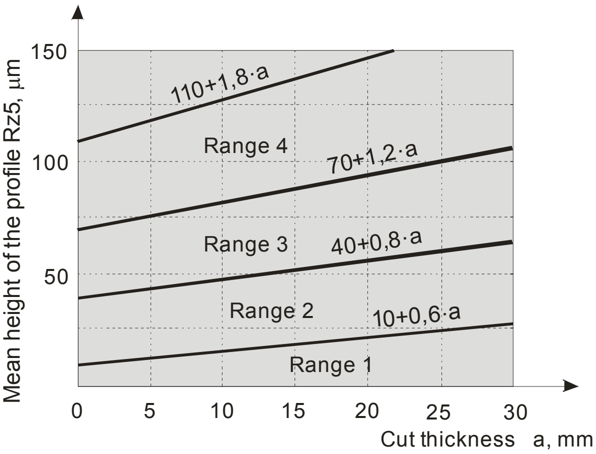

Figure 4. Influence of material thickness on Rz5 by standard "EN ISO 9013"

Surface roughness is different for the left and right sides of the cut. Surface on the right are about 25% rougher than on the left side [10].

Drag (n) is the projected distance between two edges of drag lines (lag lines) in the direction of cutting (Fig. 5.). At extremely high speeds arc becomes unstable and oscillates so the sparks and molten metal form a line in the form of a "tail" (drag lines) Fig. 5. At high speeds drag angle varies from 60 º - 80 º, while at maximum speed this angle has a value of 90 º and cut is lost. In the lower third of the cut the arc sweeps back steeply. It is probable that the hot gas, with no tendency to attach metal walls, leads the arc slightly at the bottom. Such a small amount of molten metal from the output port is not ejected.

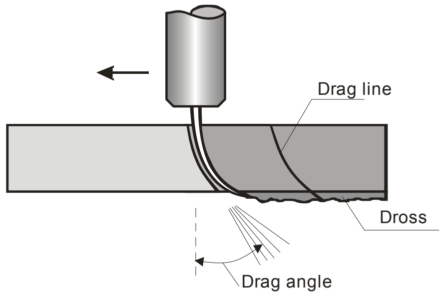

Figure 5. Dross, drag lines, drag angle [4, 11]

Melting of the top edge (r) occurs due to high cutting speeds or long distance from the nozzle to work piece. Top edge can be with overhang.

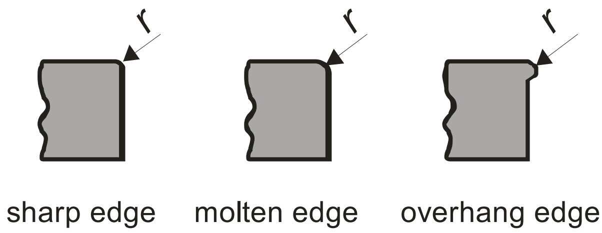

Figure 6. Melting [4]

On the top edge may appear slag spatter, accumulation of hardened metal sprayed along the edges of the cut. Basically it is easily removed. This phenomenon occurs at high speed, the large distance between the nozzle and the work piece, if the nozzle is wears. Slag spatter may also arise from the whirling motion of plasma gas. This phenomenon occurs when there is a big positive angle, because along the bevel is a difference in pressure that ejected molten metal on top.

In plasma cutting one of the biggest problems that arises is the dross (burr formation on the bottom of the kerf and spatter on the top of the kerf) Concentrations of dross will be higher in the worse side of cut. The amount of dross depends of lot parameters, but the most influential: types of materials, cutting speed and currents [7]. There are two types of molten metal on the bottom of cut-edge[12]:

- low speed dross
- high speed dross

If the cutting speed is too low plasma starts to search more material to cut. Then cut expanding to the point where more molten metal does not eject. The molten metal is accumulating along the lower edge of the large bulbous-shaped form. Thus formed molten metal are easily remove. Melted metal formed by low-speed cutting followed by the occurrence concave surface (Figure 7). It may be that the molten metal and the bottom edge forms a "bridge" over which the sectioned pieces connecting again. At extremely low speeds arc is turns off because there is not enough metal to hold arc. Increasing power or decrease distance between the nozzle and cutting objects have the same effect on appearance of molten metal. The practical counter measures for this phenomenon is removing part of the heat from the cutting zone, which is achieved by: reducing amperage or increase the distance between the nozzle and the work piece.

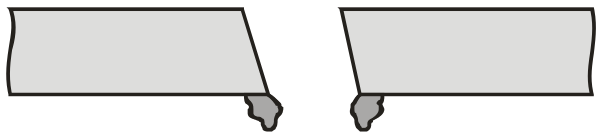

Figure 7. Low speed dross

High speed of molten metal gives a rounded tip of cut edges (Figure 8). Molten metal on the bottom edge formed into a thin line. At these speeds arc often does not penetrate into the metal and can be shut down. Long distance between the nozzle and the work piece, and a small amperage current can lead to the same phenomenon as the speed too high. Increasing the current or reducing distance between nozzle and work piece leads to more heat in the cutting zone, which the effect of drag line is reduce, effectively reduce negative consequences of high speeds.

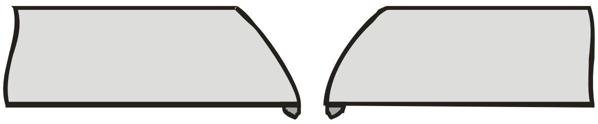

Figure 8. High speed dross

Angle of bevel cut is angle between the cut surface and the top surface of the work piece. The angle of inclination can be positive (the upper part is smaller size then the bottom) or negative (lower dimension is smaller than the upper). Plasma arc cutting will usually result in an angle on the cut surface of approximately 1 to 3° on the "good" side and 3 to 8° on the "bad" side, when using torches that swirl the plasma. With larninar-flow torches, the angle on both sides is usually about 4 to 8° [14].

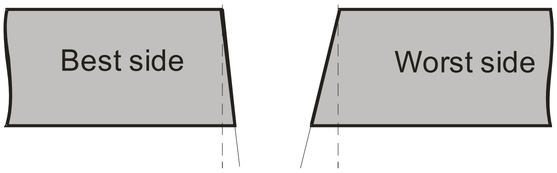

Figure 9. Positive angle of bevel cut [13]

Arc first establishes a connection with a better side of and releases heat. Cutting speed, current and distance from the work piece also have influence on angle of bevel cut.

If the cutting speed and the current have a correct value, and part have big positive angle of bevel cut, then the distance from the nozzle to work piece is too much. If the cutting speed and the current have a correct value, and distance from the nozzle and work piece is small, then angle of bevel cut will be negative. Optimal distance from the nozzle to work piece is a distance before angle of bevel cut start to appear [15].

Kerf width, the rule is that the cutting width at the plasma cutting is about 1.5-2 times bigger than the size of the nozzle exit. Cutting width is influenced by the cutting speed. If the cutting speed decreases, the cut is expanding.

4. EXPERIMENTAL EXAMINATION

In the experiment were done 17 samples. As input parameters used cutting speed V, mm/min and current intensity I, A. Steel plate material S235 JRG2 (Č0361) was 15 mm thick. Electric current of 60 A, 80 A, 100 A and 120 A was used in combination with the tablet, reduced and increased speeds value (Table 1).

Table 1. Used speeds and current intensity

samples	I, A	V , mm/min
1	60	425
2	60	530 (tablet value)
3	60	635
4	80	490
5	80	610 (tablet value)
6	80	730
7	80	870
8	80	1055
9	100	530
10	100	695
11	100	870 (tablet value)
12	100	1055
13	120	730
14	120	870
15	120	1055
16	120	1320 (tablet value)
17	120	1585

Quality of samples is defined by:

- surface roughness Ra (measured by device Talysurf 6)
- kerf width (St and Sb, defined in Fig. 10.)
- dross width (Sd) and dross higth (h), Fig. 10.
- dimension of molten metal on the bottom edge of the cut. (defined in Fig. 11.)

Ra was measured in three points: near to upper edge (g), in the middle (s), near to lower edge (d).

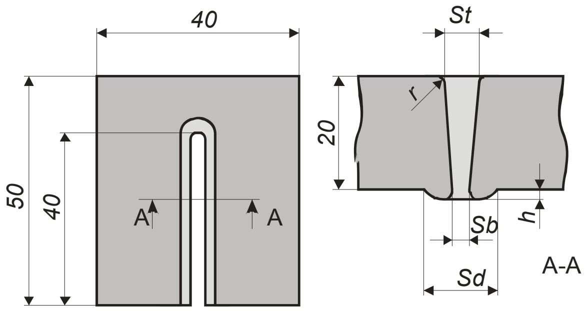

Figure 10. Measuring kerf width and molten metal on the bottom of cut

Figure 11. Measured in three points

Using a current of 60 A quality cut can be described as very poor due to large deposits of waste material to the bottom of cut. Therefore requires additional treatment, and just cutting it very slowly (Fig. 12.).

Figure 12. Cutting with 530 mm/min and 60 A

Figure 13 shows the sample which was cutting with current intensity of 80 A and speed of 610 mm/min (tablet value). The quality of the cut can be characterized as acceptable. There are waste particles on the bottom, but not on a large extent. An additional treatment section is necessary. Using a current of 80 A and a change speed, quality is approximate when used in tablet value.

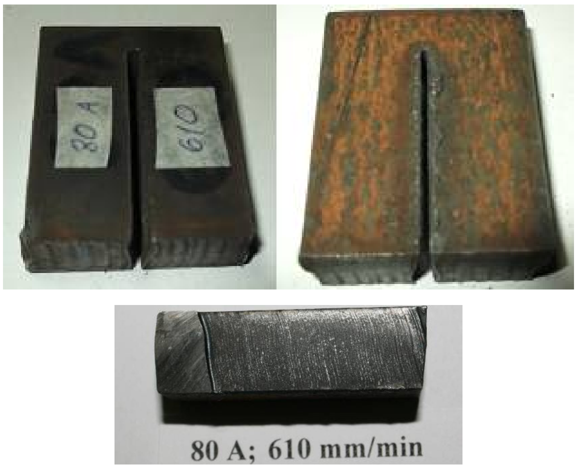

Figure 13. Cutting with 610 mm/min and 80 A

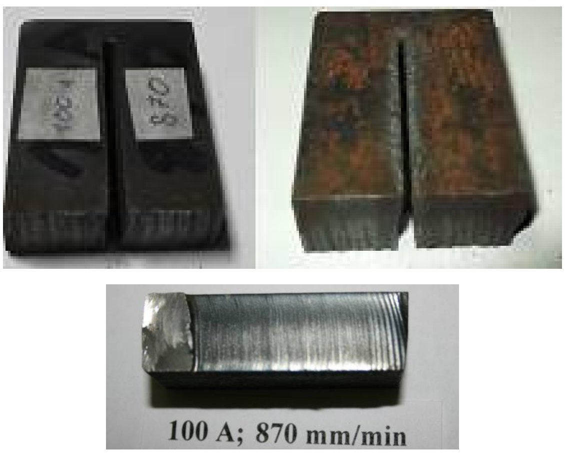

Figure 14. Cutting with 870 mm/min and 100 A

Using a current of 100 A obtained quality of the cut can be described as solid. There are waste particles on the bottom, but not on a large extent. An additional treatment section is necessary.

Using the current with intensity of 80 A the best quality is obtained by using the highest speed.

Sample of 17 is considered best combination of parameters because obtained fragment with the best quality (Fig. 15.). The best quality is obtained increasing the speed by 20% of tablet speed value.

Table 2. Measured values of Ra, kerf width and molten metal on the bottom of cut

Samples	Measur. points	Ra µm	St mm	Sb mm	h mm	Sd mm
1	g s d	10.5 17 30.7	2.14	1.2	4.78	7.12
2	g s d	12.4 21.3 40.4	2.18	1.13	5.11	7.18
3	work piece is not penetrated					
4	g s d	17.5 29.4 26.6	2.55	1.61	1.05	5.63
5	g s d	15.2 35.8 23.0	2.45	1.38	0.95	4.98
6	g s d	14.1 24.3 24.7	2.30	1.18	2.23	6.64
7	g s d	14 41 55	2,01	1,11	4,45	7,38
8	work piece is not penetrated					
9	g s d	35 19 32	2,51	1,75	3,74	10,32
10	g s d	13.0 13.0 9.8	2.54	1.54	1.16	5.21
11	g s d	12.4 8.8 13.0	2.45	1.36	0.93	7.29
12	g s d	12.0 12.4 10.1	2.36	1.23	0.93	8.40
13	g s d	16 14 18	2,68	1,82	1,15	7,58
14	g s d	17 14 20	2,46	1,67	0,80	7,83
15	g s d	10.3 11.0	2.64	1.45	0.52	3.07
16	g s d	10.8 9.9 12.9	2.55	1.29	0.66	3.24
17	g s d	8.3 10.1 9.8	2.4	1.03	not exist	-

Lower values of current are not resulted with enough heat in the cutting zone, and therefore the quality of these clips are worse. With lower currents and much higher speed than recommended may happend that clip does not penetrate, like in samples 3 and 8.

Based on of experimental results can conclude that an increase in speed reduces kerf width.

Figure 15. Cutting with 1585 mm/min and 120 A

5. CONCLUSIONS

Plasma cutting is nonconventional technology that represents the best relation between cost and quality value for money for most of the standard ports and small series production types. In addition, the processing speed is far greater than the technology of machining, and quality is comparable to the laser cutting technology.

Plasma cutting process may be used to cut any conductive material, including carbon steel, stainless steel, aluminum, copper, brass, cast metals and exotic alloys.

Obtained experimental results are consistent with theoretical considerations, as well as previous experimental results.The best quality is obtained increasing the speed by 20% of tablet speed value, which indicates that in this area have a place for further research and improvements.

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