

SURFACE ROUGHNESS AT PLASMA CUTTING

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ABSTRACT: Distinct cutting methods could be applied to separate parts from a plate workpiece. Nowadays, among such methods, the thermal plasma allows obtaining a relatively narrow slot, a high cutting speed and a cut surface appreciated as acceptable in certain situations. Essentially, the thermal plasma is generated by sending a gas through the electric discharge developed between the central electrode and the nozzle, as components of the plasma generator. The analysis of plasma cutting process showed that there are some groups of actors able to affect the heights of asperities generated by the cutting process on the cut surface. A full factorial experiment with three independent variables at two levels was designed and achieved by considering some of process input factors whose values could be easier modified, to investigate their influence on the value of the *Ra* surface roughness parameter. By processing the experimental results, a power type function was determined. The analysis of this empirical mathematical model and of the elaborated graphical representations highlighted the influence exerted by the cutting speed, plate workpiece thickness and current intensity on the *Ra* surface roughness parameter.
KEYWORDS: plasma cutting, surface roughness, influence factors, experimental research, empirical mathematical model, cutting speed, workpiece thickness, current intensity

1. INTRODUCTION

Plasma could be considered as a forth state of matter, together with the solid state, liquid state and gas state. In a certain extent,the physical properties of plasma are similar to those of gas state, but there are also distinct properties and this fact determined the physicists to consider plasma as a different state in comparison with the gas state. Essentially, the plasma could be obtained by increasing the gas temperature, by generating electrical discharges in gases and by irradiation.

Within the field of machining processes, the plasma is obtained by electrical discharges. As a processing tool, the plasma could be applied in order to materialize processes characterized by material removal from workpiece (plasma beam cutting, drilling etc.), by material addition to the workpiece and without mass changing of the workpiece (for example, heat treatments by means of plasma).The plasma beam cutting is used in order to separate parts from plate type workpieces [7, 9, 10]. In comparison with other cutting processes applicable in similar situations (for example, laser beam cutting, oxygen flame cutting, abrasive water jet cutting etc.), the plasma beam cutting ensures a relatively narrow kerf, a higher cutting speed, a lower surface roughness of the obtained surfaces. A possible disadvantage is generated by the thickness of heat affected zone, generally higher in the case of plasma cutting, compared with other cutting methods.

Bhuvenesh et al. investigated the roughness of surfaces obtained by manual plasma arc cutting[3]. They noticed an inverse proportional relation between the values of the *Ra* surface roughness parameter and the values corresponding to the material removal rate. They highlighted also that the dimensions of the dross offers a certain information concerning the roughness of the surfaces resulted by applying manual plasma arc cutting.

The results of an experimental research concerning the quality of surfaces obtained by plasma cutting were published by Begic et al. [2]. They took into consideration the influence exerted by the cutting speed and plasma gas pressure on the *Ra* surface roughness parameter in the case of test pieces made of low alloy steel. One of the study conclusions highlights that the values of the *Ra* surface roughness parameters diminish when the plasma gas pressure increases and only a low variation of the *Ra* surface roughness parameter is generated when the cutting speed has higher values.

Akkurt compared the results obtained by applying distinct cutting methods in the case of test pieces made of AISI 304 stainless steel [1]. He especially revealed that compared with the abrasive water jet cutting, the plasma cutting methods determine continuous changes in hardness values and the heat affected zone is wider. An increase of the surface roughness is considered as inevitable when the cut depth is higher.

In investigations developed in the “Gheorghe Asachi” Technical University of Iași (Romania), researches concerning the performances of plasma cutting applied to test pieces made of distinct steels were considered [5-8]. Some of the researches highlighted the influence exerted bysome process input factors (cutting speed, test piece thickness, current intensity) on the values of the *Ra* surface roughness.

The objective of the research presented in this paper was to identify the main factors able to exert influence on the surface roughness parameter *Ra* and to investigate the character of this influence, for a certain interval of changing the values of the process input factors.

2. PREMISES FOR AN EXPERIMENTAL REASEARCH

In the case of plasma cutting, the plasma state is obtained in a plasma generator, as a consequence of an electrical discharge developed between the central electrode and the anode - nozzle, the both components being included in a generator body (fig.1).

The central electrode and the nozzle are included in an electric circuit where there is also a voltage source *S*, so that an electrical discharge is generated between the central electrode and the nozzle. One could consider an intensity *I* of the electric current passing through electrical discharge. A gas jet is sent in the space between central electrode and nozzle. The gas passes through the electrical discharge, being affected by a dissociation process; in this way, a plasma beam leaves the nozzle as a plasma column.The temperature is higher near the plasma column axis; usually, in the cutting process, the plasma temperature could be of about 10,000 – 30,000 °C.

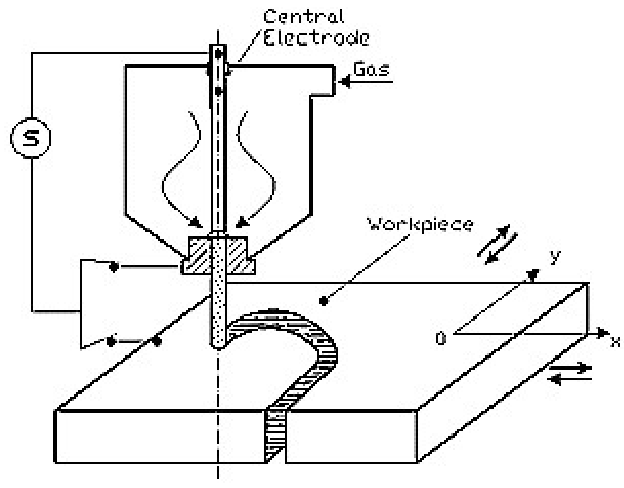

Figure 1. Scheme of plasma beam cutting

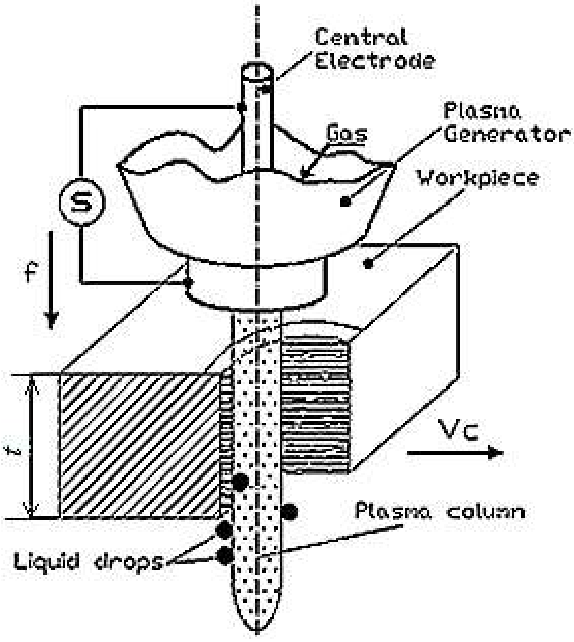

Figure 2. Surface generation during plasma beam cutting

The plasma column is directed to the workpiece found in a relative movement to the plasma generator. Due to high temperature of the plasma column, the workpiece material is melted and even vaporized. The plasma pressure determines the fast evacuation of the melted and vaporized material from the zone of contact between the plasma column and workpiece, so that a cavity is generated in a short time interval. If there is the relative movement between the plasma column and workpiece, a slot is thus continuously generated, determining finally the separation of a part from the plate type workpiece (fig. 2).

The small variations of the plasma pressure together with other dynamic phenomena corresponding to the flow of melted and vaporized material of workpiece develop a surface characterized by narrowed channels placed ones near the others on the surface generated by plasma cutting process.

On the other hand, due probably to the diminishing of the plasma column temperature and pressure along the plasma column when the distance from the nozzle frontal surface increases, the channels generated on the cut surface get a curve shape.The users of the plasma beam cutting processes are interested in obtaining a low roughness of the cut surface, in order to diminish the number of subsequently processes necessary when low values of the roughness are prescribed in the mechanical designs.

The factors able to affect the values of the roughness parameters corresponding to the surface obtained by plasma beam cutting could be included in some groups:

- the workpiece material: it is expected that workpieces materials characterized by higher melting and boiling temperatures are difficulty cut by means of plasma beam, this meaning a decrease of the workpiece thickness and a possible worsening of the roughness;

- the thickness t of the plate type workpiece: the higher the workpiece thickness is, the higher the surface roughness could be;

- the intensity of the electric current used in generation of the electric discharges between central electrode and nozzle. A worsening of the surface roughness is expected for high value of the electric current intensity, due to more intense melting phenomena;

- the speed of the relative movement between plasma column and plate type workpiece. When the cutting speed is higher, an increase of the roughness could be highlighted;

- the distance between the frontal surface of the nozzle and the workpiece;

- the pressure of the gas used to generate the plasma etc.

In order to highlight the influence of some main factors able to affect the values of the surface roughness parameters, an experimental research was designed and materialized. As main such factors, the workpiece thickness t, the cutting speed v_c and the current intensity I were considered.

If a monotone variation of the surface roughness parameter Ra is expected for certain intervals of plasma cutting process parameters variation, power type empirical models could be considered:

$$Ra = C_o v_c^{C_1} t^{C_2} I^{C_3}, \tag{1}$$

where the values of the coefficient C_0 and exponents C_1, C_2 and C_3 could be determined on experimental way.

3. EXPERIMENTAL CONDITIONS

The test piece was made of carbon steel 1C45, which is a material widely applied in the field of machine manufacturing and sometimes is used as etalon material, to compare the behaviour of various materials with the results obtained in the same conditions on the steel 1C45. In normal state (when it is not affected by the result of a hardening operation), the average hardness of this material is of 235 HB. A Kompact 3015-HPR130 type equipment was used to get slots in a test piece having a thicknesses of 4 and 10 mm.

The equipment is commanded by a computer numerical controlled subsystem, so that the trajectories of relative movements between the plasma generator and test piece could be accurately established and achieved. Subsequently, the values of the roughness corresponding to surfaces obtained by plasma cutting were measured by using a surface roughness meter type Handysurf E-35A/B.

A full factorial experiment with three independent variables (cutting speed v_c, plate workpiece thickness t and current intensity I) at two levels was designed and applied.

One considered only two experimental levels appreciating that, as above mentioned, in the intervals defined by the considered limits of independent variables, the dependent variable (Ra surface roughness parameter) will have a monotone variation.

Thus, as proper values for independent variables, one considered v_{cmin}=1000 mm/min and v_{cmax}= 1800

Table 1. Experimental conditions and results obtained in the case of workpiece made of steel 1C45

Experiment no.	**Process input factors**						**Surface roughness parameter *Ra*, µm**
	Cutting speed v_c, mm/min		**Workpiece thickness, *t*, mm**		**Current intensity *I*, A**		
	Level	Value	Level	Value	Level	Value	
Column no. 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	1	1000	1	4	1	80	1.30
2	1	1000	1	4	2	130	1.68
3	1	1000	2	10	1	80	1.20
4	1	1000	2	10	2	130	1.62
5	2	1800	1	4	1	80	2.25
6	2	1800	1	4	2	130	1.30
7	2	1800	2	10	1	80	1.83
8	2	1800	2	10	2	130	0.98

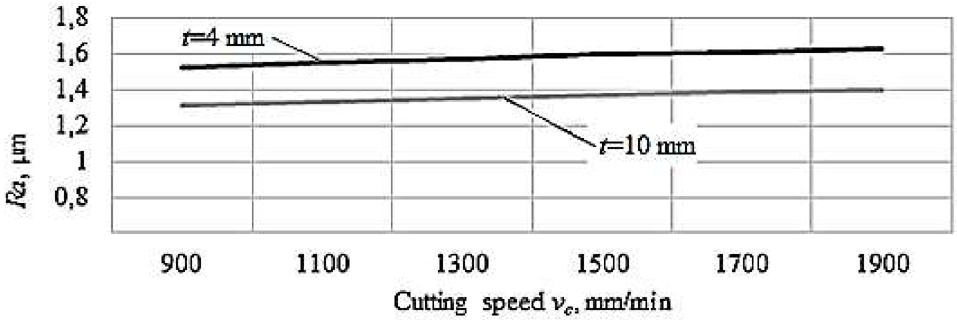

Fig.3. Influence exerted by the cutting speed on the *Ra* surface roughness parameter at plasma beam cutting (test piece made of steel 1C45, current intensity *I*=105 mm)

mm/min, t_{min}=4 mm and t_{max}=10 mm, I_{min}=80 A and I_{max}=130 A.

The values of the process input factors and the experimental results were included in the table 1.

4. PROCESSING AND ANALYSING OF EXPERIMENTAL RESULTS

The experimental results presented in table 1 were processed by using a software based on the method of least squares [4]. As indicator of adequacy of the empirical mathematical model to the experimental results, the Gauss's criterion could be used.As a consequence of the mathematical processing of the experimental results, the following power type empirical mathematical model was determined:

$$Ra = 4.540 v_c^{0.0899} t^{-0.165} I^{-0.317},$$

the Gauss's criterion having the value S_G=0.1481012.

On the base of this empirical mathematical model, the graphical representations from figures 3, 4 and 5 were elaborated.

Analysing the power type empirical mathematical model, some remarks could be formulated.In this way, one can notice that the maximum absolute value of the exponents attached to the independent variables included in the relation (1) correspond to the current intensity *I* (C_3=-0.317). This means that the current intensity *I* is the process input factor able to exert the maximum influence on the *Ra* roughness parameter of the surfaces resulted by applying the plasma cutting.

A lower influence is exerted by the test piece thickness *t*, while the influence of the cutting speed v_c is negligible in the studied interval. One may notice also that in accordance with the empirical model corresponding to the relation (1), the increase of the test piece thickness *t* and of the current intensity *I* has as a result a decrease of the *Ra* surface roughness parameter, while the increase of the cutting speed v_c determines a low increase of the *Ra* surface roughness parameter.

5. CONCLUSIONS

The plasma cutting is a machining method able to ensure possibilities of separating parts from a plate type workpiece. Essentially, the plasma is obtained by an electrical discharge developed in a plasma generator between a central electrode and a nozzle; the plasma gas sent through the space between the central electrode and nozzle leaves the generator as a plasma having a high temperature. As result of the contact of the plasma beam and plate workpiece, the material is melted or even vaporized and removed from the cutting zone. Due to relative movements

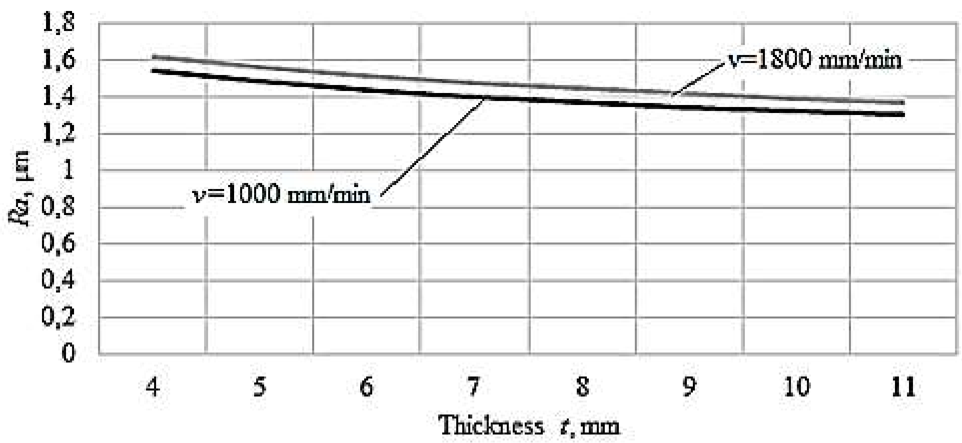

Fig.4. Influence exerted by the test piece thickness *t* on the *Ra* surface roughness parameter at plasma beam cutting (test piece made of steel 1C45, current intensity *I*=105 mm)

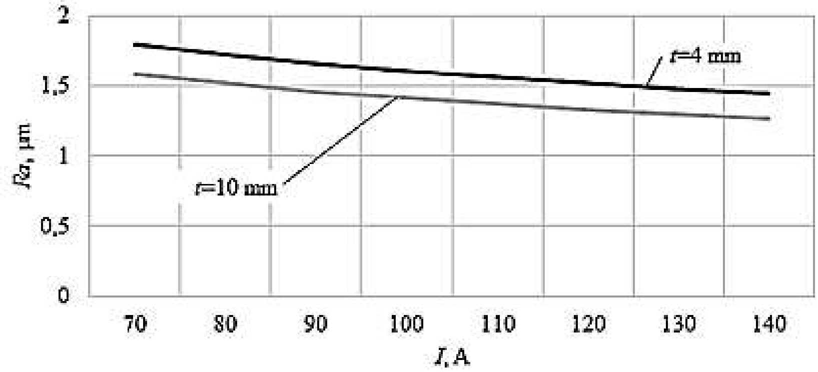

Fig.5. Influence exerted by the current intensity *I* on the *Ra* surface roughness parameter at plasma beam cutting (test piece made of steel 1C45, current intensity *I*=105 A)

between the plasma generator and plate workpiece, a slot develops gradually in the plate workpiece. There are many groups of factors able to affect the quality of surface layer generated by the plasma cutting process. An experimental research was designed and achieved to evaluate the influence exerted by the cutting speed v_c, test piece thickness *t* and current intensity *I* on the surface roughness evaluated by means of the *Ra* parameter. The experimental research developed in accordance with the requirements of a full factorial experiment with three independent variables at two levels. By mathematical processing of the experimental results, a power type empirical model was determined. The analysis of the mathematical empirical model and of the graphical representations elaborated on the base of the empirical model showed that for the considered experimental conditions, the most important influence is exerted by the current intensity. One noticed that the increase of the cutting speed determines a relatively low increase of the *Ra* surface roughness parameter, while the increase of the test piece thickness *t* and current intensity *I* has as a result a decrease of the values corresponding to the *Ra* surface roughness parameter. In the future, there is the intention to extend the experimental researches on other test pieces materials, to evaluate how distinct materials behave as a consequence of applying a plasma cutting process.

6. REFERENCES

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