COMPARATIVE ANALYSIS OF SURFACE ROUGHNESS IN PLASMA CUTTING OF METALLIC MATERIALS

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ABSTRACT: This paper presents a comparative analysis of the surface roughness obtained by plasma cutting of various metallic materials, aiming to highlight the influence of technological parameters on the quality of the cut. The study is based on experimental measurements performed on steel, aluminium and stainless-steel samples. The results emphasise the importance of optimising cutting parameters to improve precision and surface quality in plasma processing applications.

KEYWORDS: plasma cutting,, surface roughness, metallic materials

1. INTRODUCTION

In metal processing industries, cutting operations represent a critical stage that directly influences the quality of the final product, the efficiency of the manufacturing process, and the associated production costs. Selecting the optimal cutting method depends on factors such as material type, thickness, and the specific requirements of industrial applications. Among the most frequently used techniques are plasma cutting and guillotine cutting, each offering distinct advantages and limitations. Recent studies have analysed these processes in detail, emphasising their effects on surface roughness and the hardness of the cutting zone.

2. MATERIALS AND METHODS

2.1 MATERIALS USED IN THE STUDY

Six different metallic materials were analysed, each with a specific thickness, in order to cover a wide range of industrial and engineering applications. The selection includes both ferrous and non-ferrous alloys with distinct properties adapted to different technological processes.

2.1.1. C125W2 Tool Steel - ISO 4957 (M1)This material is a high carbon steel (1.4%), being unalloyed and mainly used for cold working applications. The chemical composition is as follows: Fe 96.43%, C 1.4%, Si 1%, Mn 0.55%, Mo 0.281%, Cu 0.157%, Ni 0.084% and Cr 0.068%. This type of steel, with a significant content of silicon and manganese, is characterized by high hardness, being used mainly for the manufacture of cutting tools and dies. However, due to the lack of significant alloying elements, it is not recommended for applications at extreme temperatures or speeds. In the test, a thickness of 5 mm was used.

2.1.2. C90U Tool Steel - ISO 4957 (M2)
C90U steel is a material with a carbon content of approximately 0.9%, with additions of manganese and chromium in small quantities, but without a significant content of molybdenum. Its composition gives it good hardness and wear resistance, being used mainly for tools intended for cold processing, such as cutting blades and industrial knives. This material is not suitable for use at high temperatures or speeds, but it is distinguished by its high hardness. The thickness used in the test was 5 mm.

2.1.3. 11SMn30 Steel - ISO 683-9 (M3)
11SMn30 steel is a resulfurized and rephosphorized material, intended for applications where high machinability is an essential criterion. It is frequently used in the manufacture of mechanical components that require operations such as cutting or threading. The chemical composition includes: Fe 98.64%, C 0.9%, Mn 0.99%, S 0.3%, P 0.1% and Mo 0.0033%. This unalloyed carbon steel has a relatively high sulfur content, which significantly improves its machinability. A thickness of 10 mm was used in the test.

2.1.4. Structural steel S235JR- ISO 630 (M4)
S235JR steel is a low carbon unalloyed carbon steel with the following composition: Fe 99.47%, C 0.08%, Mn 0.35%, Cu 0.074%, Ni 0.056%, Cr 0.044% and Mo 0.0044%. Due to the low carbon content, this material has good ductility and weldability, being used in widely used in construction and metal structures. S235JR steel is not intended for applications requiring high hardness, but rather for those where general mechanical properties and the ability to be easily processed are important. The thickness used in the test was 2 mm.

2.1.5. Stainless steel X5CrNiMo17-12-2- ISO 4954 (M5)
This material is an austenitic stainless steel, characterized by a high content of chromium (16.55%) and nickel (10.06%), which gives it good corrosion resistance. Its chemical composition is: Fe 69.01%, C 0.07%, Cr 16.55%, Ni 10.06%, Mo 2.032%, Mn 1.30%, Cu 0.44%, Co 0.40%, V 0.113% and W 0.093%. Due to these properties, X5CrNiMo17-12-2 steel is used in applications requiring resistance to corrosive environments and high mechanical stability. In the test, a thickness of 8 mm was used.

Fig.1 Materials used

2.1.6. Aluminum alloy Al99.0 - ISO 209 (M6)
The M6 material is a high purity aluminum alloy (99.10%), with small additions of other elements to improve mechanical properties. The chemical composition includes: Al 99.10%, Fe 0.377%, Mn 0.232%, Zn 0.075%, Cu 0.065%, Ti 0.06%, Cr 0.047%, Sb 0.016%, Sn 0.011%, Ni 0.008%, Pb 0.0048% and Zr 0.0013%. This alloy is used in applications

where a combination of low weight and good machinability is required. The thickness used in the test was 6 mm.

The selection of tested materials, fig. 1, was made in such a way as to include materials with varied properties, from hard tool steels to light aluminum alloys. The study allowed highlighting the characteristics of each material in relation to its specific applications, thus facilitating the optimal choice according to the technological requirements of the manufacturing process.

The paper presents a comparative analysis of the surface roughness obtained by plasma cutting of metallic materials. The experiments were carried out using a CNC plasma cutting installation, varying the main process parameters: cutting current (from 60 A to 120 A), feed speed (1000–2500 mm/min), nozzle–part distance (1.5–3 mm) and plasma gas pressure (4–6 bar).

2.2 ANALYSIS OF THE ROUGHNESSES OF THE CUT SURFACES

The roughness measuring device was a portable roughness meter. It is a super compact, mobile precision instrument. Easy to handle, the device provides measurement results quickly even in production departments. The device (fig.2) can measure horizontal, vertical or inclined surfaces.

Fig.2. Portable digital roughness meter, positioning the feed unit on the workpiece

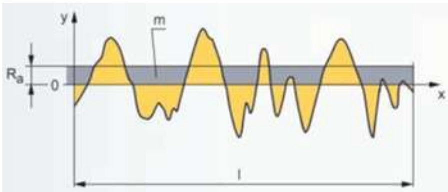


Fig.3 Determination of roughness Ra

With this device, seven important parameters of surface roughness can be evaluated. These parameters include Ra, Rz, Rq, Rpm, and others, which are determined based on the roughness profile (R profile). The parameter Pt is calculated based on the primary profile. For the evaluation of these parameters, a reference distance called Lm, defined according to DIN 4768, is used. This distance is divided into five equal portions, denoted Le ($Le = \frac{Lm}{5}$). The length of these portions corresponds to the cut-off wavelength (lc or CUT OFF) of the selected filter.

Ra – Arithmetic mean value of roughness

Ra represents the arithmetic mean value of the absolute deviations of the roughness profile from the mean line, fig.4. This value is calculated using the relation (1):

$$Ra = \frac{1}{L}\int_0^L |f(x)|\, dx \ (\mu m) \quad (1)$$

where L is the measuring length. According to ISO 4287/1, the measuring distance must be five times the CUT OFF value (for JIS, it must be three times). An advantage of the Ra parameter is that minor impurities or imperfections on the surface of the part have little effect on its value.

Rq – Root Mean Square Roughness

Rq (also known as RMS – Root Mean Square) is a measure of roughness that takes into account the squared deviations of the roughness profile from the mean line. This value is calculated using the relation (2):

$$Rq = \sqrt{\frac{1}{L}\int_0^L f(x)^2\, dx} \ (\mu m) \quad (2)$$

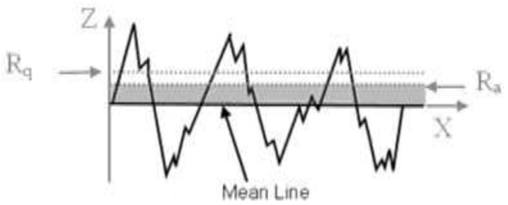


Fig.4 Determination of roughness Ra and Rq

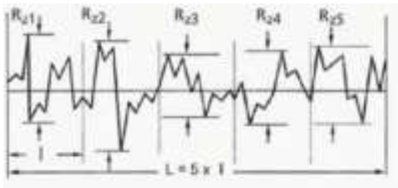


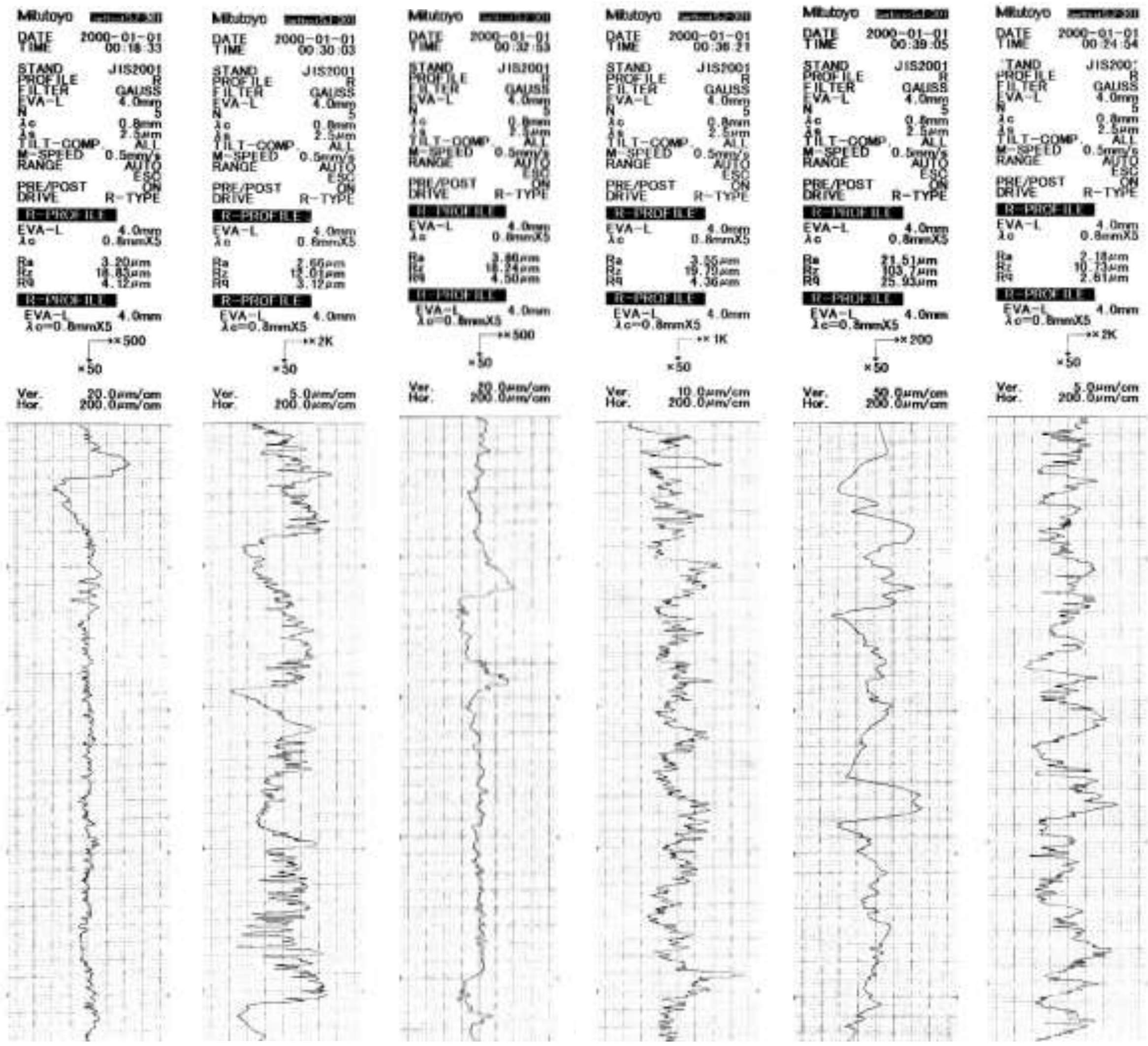
Fig.5 Determination of roughness Rz

The parameter Rq is more sensitive to the extreme peaks and valleys of the roughness profile compared to Ra, providing a broader picture of surface irregularities.

Rz – Average roughness depth

Rz is defined as the arithmetic mean of the maximum roughness depths (Zi) of the five measurement segments, relation (3):

$$Rz = \frac{1}{5}(Z_1 + Z_2 + Z_3 + Z_4 + Z_5)\ (\mu m) \quad (3)$$



a. M1 b. M2 c. M3 d. M4 e. M5 f. M6

Fig.6 Sheets with graphs of the roughness of materials cut with a guillotine

This parameter provides information about vertical cracks and pronounced surface irregularities. Unlike Ra, which is less sensitive to extreme peaks and valleys, Rz better reflects these characteristics.

Roughness analysis is an essential aspect in evaluating the quality of cut surfaces, as roughness influences the functional properties of materials, such as fatigue resistance, coating adhesion and aesthetic appearance.
In the present study, roughness is measured using three main parameters: Ra (arithmetic mean roughness), Rz (maximum profile height) and Rq (root mean square roughness). Below is a detailed analysis of roughness for guillotine cutting and plasma cutting.
Table 1 presents the roughness of the materials in the plasma cutting area.

Table 1 Roughness in the plasma jet cut area

Materials/Roughness	M1	M2	M3	M4	M5	M6
Ra [µm]	3,20	2,18	2,66	3,86	3,55	21,51
Rz [µm]	18,83	10,73	12,01	18,24	19,79	103,7
Rq [µm]	4,12	2,61	3,12	4,50	4,36	25,93

The roughness parameters are:
- Ra: varies between 2.18 µm and 21.51 µm.
- Rz: varies between 10.73 µm and 103.7 µm.
- Rq: varies between 2.61 µm and 25.93 µm.

The roughness is significantly higher in the case of plasma cutting, especially for the M6 (P6) material, where Ra = 21.51 µm, Rz = 103.7 µm and Rq = 25.93 µm. This is due to the thermal effects of the plasma cutting process, which can lead to partial melting of the material and the formation of asperities.

3. CONCLUSIONS

The comparative analysis of the roughness of the surfaces obtained by plasma cutting revealed significant differences between the tested materials, influenced by their chemical composition, thickness and thermal conductivity. The average values of the roughness Ra ranged from 2.18 µm to 21.51 µm, with the best results obtained for tool steels (C125W2 and C90U), and the highest values for the aluminum alloy Al99.0, due to the partial melting of the surface during cutting.
The parameter Rz (average roughness depth) recorded values between 10.73 µm and 103.7 µm, confirming that non-ferrous materials are more sensitive to the thermal effects of the plasma jet.
A direct correlation was observed between the cutting current and the increase in surface roughness: higher current values (above 100 A) cause excessive melting and the formation of pronounced asperities.
The feed rate inversely influences the roughness — a moderate increase in the cutting speed reduces the time of exposure to heat and leads to a smoother surface.
For all materials analyzed, optimizing the process parameters (current, speed, pressure and nozzle-to-part distance) is essential to obtain superior cut quality and reduce secondary thermal effects.
The results obtained confirm that plasma cutting, although generating higher roughness compared to mechanical cutting (guillotine), offers major technological advantages: increased processing speed, flexibility in relation to material thickness and acceptable precision for common industrial applications.

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