CONSIDERATIONS ON THE CHOICE OF THE CUTTING METHOD AND TECHNIQUE EMPLOYED FOR THE CUTTING OF PARTS MADE OF TITANIUM ALLOYS

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Abstract

The paper analyses the various possibilities of cutting complex-shaped parts made of titanium alloy TiAl6V4 in conditions of high part precision and short production time: water jet cutting, laser cutting, plasma cutting. Each of these modern, nonconventional means of materials processing has certain benefits, but also shortcomings that need to be taken into account. On the other hand, titanium and titanium alloys are materials that, due to their specific physical and chemical properties pose special problems to the attempts to process them, even if several other of their properties certainly recommend them for a wide range of applications. The specific case of a part from the current production of a Romanian company is analysed and some recommendations are made for the correct choice of the processing parameters and of the NC equipment to be employed.

1. INTRODUCTION

Nowadays, the means and techniques employed for cutting various materials, and especially metallic materials, are very diversified, so both producers and users of cut parts are often faced with a difficult choice with regard to the right technique and machine to use for a certain application, the more so when the part has a complex shape.

The choice can become even more difficult when dealing with parts made of metallic materials with known problems concerning their behaviour under stress or at higher temperatures. Such a material is also titanium and its alloys.

The processing of these materials is not simple, especially because of the high melting point (1668°C) and the great affinity displayed by titanium versus a series of elements like oxygen, nitrogen, hydrogen, methane etc. Because of this, the casting of titanium, for example, requires the usage of special equipment and special auxiliary materials (protective atmosphere, usually based on argon, investment materials which do not allow the reaction between titanium and oxygen to take place, special melting crucibles etc.), the development of which has also increased very much in the recent years.

The processing of titanium parts by welding or cutting is also affected by the heavy oxidation of titanium, by the high temperature difference between the base metal and possible addition materials and not least by the chemical impurification or the electrochemical corrosion which might occur. Therefore, here too it is necessary to apply special procedures, such as laser welding, plasma welding or soldering with infrared radiation.

In the following, several modern options for metal cutting are presented: laser cutting, plasma cutting and abrasive jet cutting, and comments are made on their performance with the titanium alloy TiAl6V4.
2. LASER CUTTING

Laser cutting is a technology that uses a focused beam of high energy laser light to cut material by selectively burning, vaporizing and/or melting a highly localized area, while an assist gas is used to remove the molten material from the resulting cut. It is one of the fastest and most accurate methods for cutting a variety of metals and non-metals.

Both gaseous CO\textsubscript{2} and solid-state Nd:YAG lasers can be used for cutting. In each case, several subvariants can be identified, such as fast axial flow, slow axial flow, transverse flow, and slab lasers for CO\textsubscript{2} lasers. The type of gas flow can affect the cutting performance. For example, transverse flow lasers circulate the gas mix at a lower velocity, requiring a simpler blower, while slab or diffusion cooled resonators have a static gas field that requires no pressurization or glassware for protection.

Figure 1 presents an overview of a laser cutting machine (Mazak NTX-48 Champion) and a detail of the working area of the machine.

![Figure 1 An overview of a laser cutting machine (Mazak NTX-48 Champion) (a) and a detail of the working area of this machine (b).](image)

The main advantages of laser cutting over other cutting methods can be summarised as follows:
- it can cut a variety of metals and non-metals;
- it can produce part accuracies better than 0.08 mm;
- it can cut thinner metals at over 170 mm/s;
- it produces a narrower heat affected zone than plasma;

However, there are also several disadvantages to be considered:
- high cost of the equipment;
- the thickness of materials that can be cut is very limited (10-20 mm at best);
- the cutting of metals with highly reflective surfaces (such as aluminum, but also titanium, to some extent) can cause problems for the equipment (especially for the focusing lens);
- it can cause micro-fracturing in some materials;
- variations in the material's quality can affect the cutting results;
- the maintenance of the cutting equipment requires advanced knowledge;
- depending on the material being cut, noxious fumes can be produced during the cutting process.

In the case of titanium and titanium alloys, one of the big problems is also the afore-mentioned affinity for various gases at higher temperatures, so there needs to be employed a protection gas throughout the cutting process.

3. PLASMA CUTTING

The plasma cutting process is based on the superheated gas plasma jet created via a controlled electrical arc between the work head and the part to be processed. This electrically conductive, ionized gas plasma is hot enough to easily cut through a variety of metals, with part accuracies better than 0.010” attainable with the high density torch designs.
The principle of plasma cutting is presented in fig. 2.

![Figure 2. Principle of plasma cutting](image)

The main advantages of plasma cutting over other cutting methods can be summarised as follows:

- it can cut a variety of metals and non-metals;
- the cutting speed is higher than that of abrasive jet cutters;
- the plasma cutting equipment's price is only about a third that of a laser cutting system;
- the handling of the plasma cutting equipment can be learned relatively quickly;
- the equipment's maintenance is simple.

However, there are also several disadvantages to be considered:

- plasma cutting is generally not as accurate as laser cutting;
- the thickness of parts that can be cut is limited (up to 120-160 mm);
- the consumables in the cutting head deteriorate with use, affecting the quality of the cut;
- the heat induced in the cut part can lead to undesired side-effects, such as microfractures in some materials;
- depending on the material being cut, noxious fumes can be produced during the cutting process;
- the heat-affected zone may be rather large.

In the case of titanium and titanium alloys, the same problem occurs as with laser cutting, namely due to the titanium's affinity for various gases at higher temperatures, there needs to be employed a protection gas throughout the cutting process.

4. ABRASIVE JET CUTTING

The waterjet cutting process uses a thin stream of water brought to very high pressures by passing it through a narrow nozzle. When mixing a small amount of abrasive into the water, the process is called abrasive jet cutting. While water jet cutting systems can be employed only for the cutting of soft materials at efficient speeds, abrasive jet cutters can handle virtually any material.

The general structure of an abrasive jet cutting head is presented in figure 3 (OLSEN 2007).
The main advantages of abrasive jet cutting over other cutting methods can be summarised as follows:
- it can cut a variety of metals and non-metals;
- it can produce part accuracies better than 0.12 mm;
- it can cut even through relatively thick parts;
- it doesn't lead to a heating of the part or cause microfracturing;
- it produces minimal kerf widths (0.65 to 1.3 mm);
- the abrasive jet cutting equipment's price is only about half that of a laser cutting system;
- the handling of the abrasive jet cutting equipment can be learned relatively quickly;
- the equipment's maintenance is simple;
- no noxious fumes are produced during the cutting process.

However, there are also several disadvantages to be considered:
- it is very slow compared to other processing types;
- it is very noisy;
- the consumables in the cutting head (jewel, mixing tube) deteriorate with use, affecting the quality of the cut;
- the heat induced in the cut part can lead to undesired side-effects, such as microfractures in some materials.

For parts made of titanium or titanium alloys, this processing method would be ideal, as it does not require the reaching of high temperatures, nor does the surface finish play a significant role, even though the process' slowness is a big inconvenient. However, the major problem encountered here is that, due to the relative novelty of the method and the investment costs implied by the acquiring of the adequate equipment, in Romania there are still relatively few abrasive jet cutting systems in use. Therefore, the subsequent researches were carried out using just laser cutting and plasma cutting.

5. OXYFUEL CUTTING

Oxyfuel cutting is the "classical" cutting method among those discussed. It uses the chemical reaction of oxygen with the base metal at high temperatures generated and maintained by means of a flame obtained from the combustion of a specified fuel gas (most commonly acetylene) mixed with pure oxygen.

Common oxyfuel cutting applications are currently limited to carbon and low alloy steels. The method is especially appliable to parts of medium and large thickness, another disadvantage being that the heat-affected zone is rather large. Therefore, for the scientific and experimental purpose of this paper, this cutting method has been considered as not being adequate.
6. EXPERIMENTAL RESULTS

In order to be able to better assess and compare the parameters of the various cutting methods described above, a test was set up consisting in the manufacturing of the same part on two different cutting machines: a NTX-48 Champion laser cutting machine manufactured by Mazak (Japan) and a Samson CNC plasma cutting machine. The laser cutting machine used a CO₂ laser with a maximal power output of 1.5 kW.

The experiments were done on sheets with a thickness of 12 mm. They involved in a first stage the cutting, on both machines, of simpler shapes, such as rectangles and disks, with five different feed rates of the cutting heads.

One conclusion of these tests was that the machines’ NC equipment can play a significant role in determining the final part quality and accuracy. Therefore, in the case of these machines, efforts are needed for optimising the NC programming.

7. CONCLUSIONS

The present paper has analysed three modern methods for the cutting of metallic materials and focused on their possible usage with parts made of titanium or titanium alloys. Of the available modern cutting machines, the laser cutting system was the more accurate one, although the limited material thickness for which this machine can be employed, and the dimensional and position errors that occurred on this machine at some processing speeds indicate that efforts are needed for improving the technology, especially with regard to adjustments to the NC unit.

LITERATURE REFERENCES
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