PLASMA ASSISTED MILLING

Rahul T L

Student of Department of Mechanical Engineering, Siddaganga Institute of Technology Tumakuru, Karnataka, India

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Abstract - *The term Thermal Enhanced Machining refers to a conventional cutting process in which an external energy source is used to enhance the chip-generation mechanism. The work presented here analyzes the basic aspects and the experimental results obtained when applying an assisting plasma jet to the milling process. The study under these conditions has shown an excellent performance of the whisker reinforced ceramic tools. In fact, cutting speeds as high as 970 m/min and large radial and axial depths of cuts are possible, driving to a cost-effective machining process. The absence of changes in the metallurgical structure of the alloys after applying the PAM process is also addressed.*

Key Words: Plasma, Milling, Alloy, PAM, Chips.

1. INTRODUCTION

The objective of the assisted machining techniques is to improve the cutting process by acting on the chip removal mechanism. Nowadays, there are two most expanded techniques due to their feasibility and industrial expectations: Jet Assisted Machining (JAM) and Thermal Enhanced Machining (TEM).

In Thermal Enhanced Machining (TEM) the cutting process takes place at temperatures ranging from 400º to 700ºC, and therefore the shear strength of the material is significantly lower than the room temperature strength, resulting in considerably lower cutting forces. The technique is economically feasible only when the machinability of the material being processed is limited and therefore the cutting parameters (depth of cut, feed per tooth and cutting speed) are very low. This is the case of the heat resistant alloys, such as the Ni-base alloy Inconel 718 and the Co-base alloy Haynes. These materials maintain their mechanical properties as well as an excellent corrosion resistance even over 600ºC. Because of these properties, above materials have been used in the manufacturing of turbine components of both commercial and military airplane engines.

In this research work, a plasma jet has been applied to the milling of Haynes 25, Inconel 718 and Ti6Al4V.

2. FUNDAMENTALS OF THE TECHNOLOGY OF PLASMA ASSISTED MILLING

Figure 1 shows a schematic drawing of the plasma-machine system layout. The nozzle is focused at a distance of about 8-10 mm ahead of the milling tool in the direction of the feed; this distance is high enough to prevent the tool body from being directly affected by the plasma jet. The nozzle is placed at a height of 5-6 mm over the workpiece, and thus the electric arc responsible for the ionization of the channel (known as transferred arc) can be activated. The diameter of the heated spot is about 4-5mm. The spot must be located just exactly at the material to be removed, avoiding the zones of the workpiece previously machined, as shown in Figure 1.

The temperature of the ionized gas (Argon) is well over 15,000 K. The velocity of the plasma jet about 5 mm away from nozzle is 400 m/s; this is the speed at which the plasma jet impacts on the material surface. The energy is transferred by convection to the workpiece and produces the heating of the work surface at temperatures ranging from 400 to 1,000ºC. A precise model for the calculation of the heating of a surface exposed at a plasma jet can be found in this work, it is stated that the heat flow distribution transferred to the workpiece is 4,700 W for an arc intensity of 225 A, and 5,600 W for an intensity of 275 A.

Experimental measurements are carried out using an infrared camera show that there are two zones clearly identified inside the heated spot by the plasma jet: a circle of maximum heating, where the temperature is between 500ºC and 1,000ºC, and the adjacent zone, where the heat is transferred by conduction to the workpiece.

Experimental testing was carried out in a conventional machining center, equipped with a spindle with rotational speed below 10,000 rpm and maximum linear feed of 5 m/min. The geometry of the workpiece must be simple, with geometrical features that do not involve sharp changes in the feed direction, since the plasma spot must be located ahead of the tool during the whole process.

The ionized gas produces material surface heating by convection. The result is a phenomenon known as thermal softening, which is related to the reduction of the cutting forces.

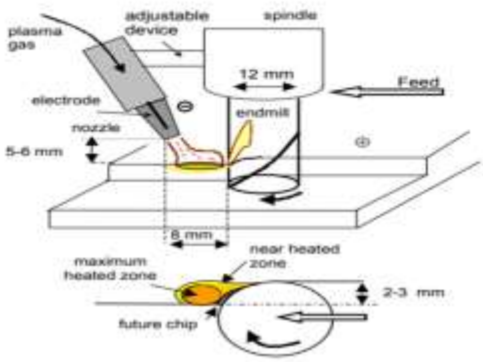

Fig. 1: Main components of the plasma assisted milling system. Below, top view of the plasma spot and the milling tool.

3. RECOMMANDED MATERIALS FOR PAM

Plasma assisted milling is recommended for the machining of low-machinability alloys, and especially those whose mechanical properties decrease only over a certain temperature. In these materials a high mechanical strength is related to a high shear strength, and therefore machining is difficult. The Ni-base and Co-base alloys are considered to be amongst the materials with lowest machinability. This low machinability depends mainly on the following factors:

• The cutting forces and the temperature at the cutting zone are extremely high. This is due to the heat generated by the high deformation energy, as well as to the low thermal conductivity of these materials.

• Ductility: The machining of ductile alloys requires very sharp cutting edges, for the operation to be a cutting process rather than a plowing action. However, these materials must be machined with strong tools because of their high specific cutting energy. The high ductility is responsible of some frequent chip type named "chip foot", when the tool exits from the workpiece; at this point the material is stretched rather than cut. This produces an uncontrolled chipping of the tool edge.

• Strain hardening: This phenomenon is caused by the cold working of the material during the plastic deformation. In order to reduce it, very small feed, high cutting speed and worn tools must be avoided. Cold working of the machined surfaces (related to the increase in hardness) makes future operations more difficult, causing premature notch wear of the tool at the point of the edge intersecting the work surface.

4. EXPERIMENTAL SETUP

Testing has been carried out in a conventional machining center and a maximum rotational speed of 6,000 rpm. The NC unit controls the machining toolpaths and the basic operation of the plasma power generator, using specially programmed miscellaneous functions. Thus, the pilot and the transferred arcs can be switched on/off.

The plasma power equipment is a commercial welding one, providing transferred arcs (direct current) at a maximum intensity of 250 A. The plasma torch is a copper nozzle of 2 mm diameter. Tungsten electrodes (cathodes) with 30º taper angle are used. The nozzle serves as anode when used with non-conductive materials, while the arc is transferred to the work piece in the case of conductive pieces the plasma gas is Argon with a flow of 0.5 l/min, while the shielding gas is a mixture of Argon and 5% of Hydrogen, with an approximate flow of 11 l/min. The heating of the workpiece depends primarily on two operating parameters: the intensity of the transferred arc I and the translational velocity of torch over the work surface.

In milling, because of the location of the nozzle fixed with respect to the milling tool, that velocity is equal to the machine-tool linear feed.

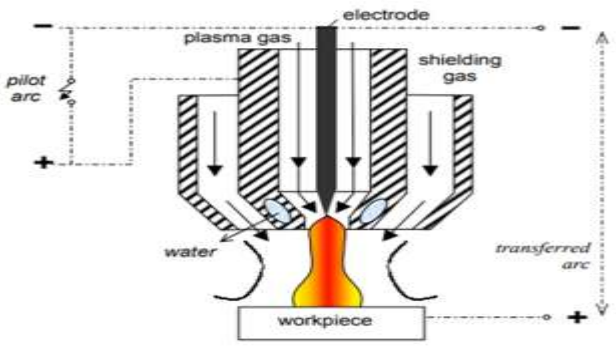

Fig.2: Plasma torch.

Fig. 3: Experimental equipment of PAM. (a) Inconel 718 or Haynes 25, (b) milling tool, (c) plasma torch, (d) Kistler 9255B force measuring device, (e) plasma generator, (f) 3 axes vertical machining center, (g) torch positioning system (2 axes)

An infrared camera Nikon Laird-S270 has been used to measure the maximum heating of the work surface just after being exposed to the plasma jet. The camera has a range of – 10 to 1,200ºC (with two different lens), and accuracy of ±2%. The scanning frequency is 2 images per second. Figure 4 shows a snap image taken by the infrared camera during machining, together with a CCD camera equipped with a luminosity filter. Determination of the target emissivity was done by placing atop the workpiece surface a piece of thin black electrical paint (ε=0.95). After several minutes the temperature of both the workpiece surface and the tape are similar, and the emissivity of workpiece is calculated by an inverted procedure. This method for emissivity determination is proposed by the camera manufacturer and also used in Medaska et al. Its main advantage is that one can be sure that the calculated emissivity corresponds to both the same material and texture surface that is going to be PAM'ed.

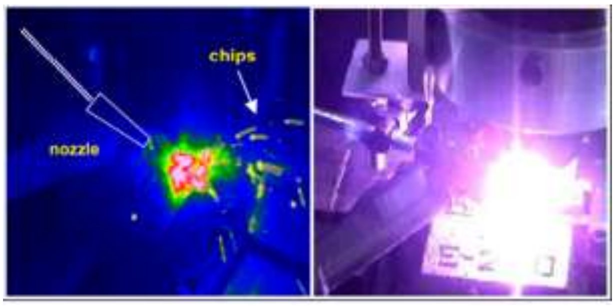

Fig. 4: Left-infrared image of the PAM process, nozzle drawn in. Right- the same image taken using a CCD camera with a luminosity filter.

5. RESULTS

•Heating of the alloy- The first objective was the evaluation of the temperature in the material just after the plasma heating. If we go deeper into the material below the work surface, the temperature decreases rapidly

•Tool wear- Flank wear has been measured during the cutting tests, as shown in. These tests have been performed using a cutting speed of 70 m/min. When conventional milling, tool wear after a cut length of 500 mm is 0.5 mm, some of the teeth showing chipping.

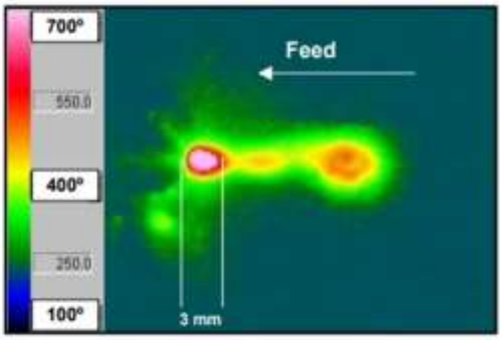

Fig. 5: Temperature at the plasma spot after switching off the transferred arc (Haynes 25). Spot diameter is approximately 3 mm (60A and 650 mm/min).

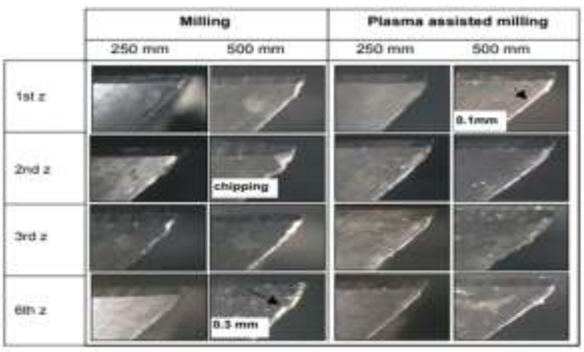

Fig. 6: Flank wear in four teeth, with and without assisting plasma (the tool has seven teeth). When no plasma is used, chipping appears.

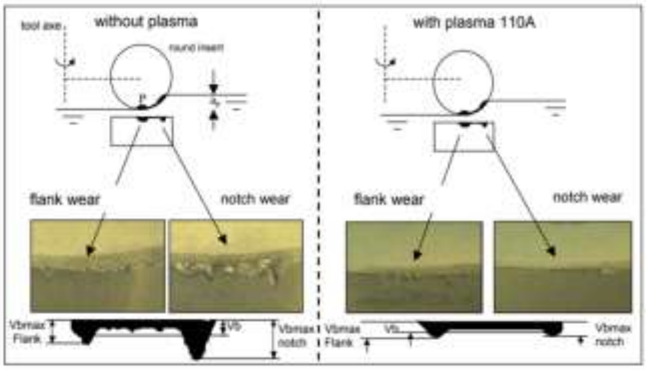

Fig. 7: Comparison of wear patterns for the same cutting conditions with and without plasma assistance.

6. ADVANTAGES, DISADVANTAGES AND APPLICATIONS

ADVANTAGES

- Faster rates of productions.
- Very hard and brittle materials can be machined.
- Small cavities can be machined with good dimensional accuracy.

DISADVANTAGES:

- Initial cost is very high.
- It is uneconomical for bigger cavities to be machined.
- Inert gas consumption is high.

APPLICATIONS:

- Welding of Aerospace and High Temperature Corrosion Resistant Alloys.
- Nuclear submarine pipe system.
- Welding steel rocket motor case.
- Welding stainless steel tubes.
- Welding titanium plates up to 8mm thickness.

7. CONCLUSIONS

It has been identified that the use of PAM for Inconel 718 using whisker reinforced ceramic tools (Al2O3 +CSiw) leads to an increase in the tool life of approximately 200%. The reason is that notch wear, which is the most important wear mechanism in conventional milling, nearly disappears. Flank wear is reduced but it cannot be entirely eliminated from the axial lower point of the inserts. The reduction in the cutting forces is about 40%. The cutting speed is close to 970 m/min, and the material removal rate is 12.3 cm3 /min. Therefore, the process should be recommended for roughing operations, given its high productivity.

If the process is to be industrialized, other aspects should be considered in more detail, namely the security devices with which the machine should be fitted, which should allow the operator to watch the process without any risks, and the design of a controlled orbital device in order to make the torch rotate around the tool, controlled from the NC. Solutions for these aspects can be easily designed.

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