RESEARCH ON 3D METAL SCULPTURING BY WATER JET CUTTING VERSUS CNC MACHINING

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Abstract: *Abrasive Water Jet (AWJ) has various distinct advantages over the other technologies, such as no thermal distortion, high machining versatility and small cutting forces, and has been proven to be an efficient technology for processing various engineering materials. Abrasive Water Jet technology is used in a routine manner in manufacturing industry to cut materials that are difficult to cut by other methods. AWJ technology is in a continuous development, using an abrasive jet, different parts can be milled. Milling parts using water jet cutting equipment can save time and money, eliminating an extra operation. This paper presents a comparison between classical milling and abrasive water jet milling.*

Key words: *abrasive water jet, CNC manufacturing, milling.*

1. INTRODUCTION

Abrasive water milling (AWJ) is a process that involves the entrainment of abrasive particles into a high velocity jet of water. The slurry of particles and water are used as the cutting tool (Escobar 2012).

The AWJ technology has received considerable attention from industry due to its beneficial characteristics in machining of various materials, particularly difficult-to-machine and thermal sensitive materials (Ojmertz 1997).

Abrasive water jet cutting (AWJ) has various distinct advantages over the other cutting technologies, such as no thermal distortion, high machining versatility and small cutting forces, and has been proven to be an effective technology for processing various engineering materials (Farhad, 2009).

AWJ technology proves to be in a continuous development, using an abrasive jet, different parts, made out of various engineering materials, can be cut, drilled, polished and milled. (Susuzlu, 2007).

Using water jet milling complex 3D parts can be manufactured from a variety of materials.

In this paper a comparison between abrasive water jet cutting and CNC classical milling has been made. To conduct this investigation an experiment has been made and the results were measured and analyzed.

Fig.1. Part made by AWJ milling (Omax)

2. TEORETICAL FORMULATION

Water jet milling is a process with a large number of parameters.

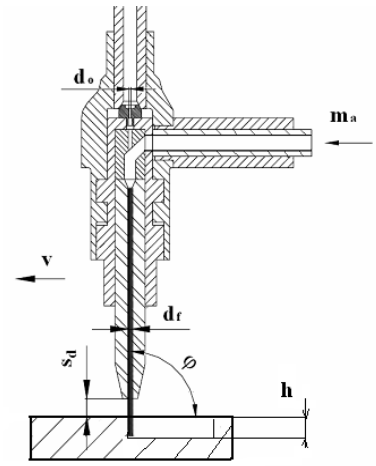


Fig.2. Water jet milling processing system

Figure 2 illustrates schematically the processing system by water jet milling. The most significant parameters of the water jet milling process are:

do orifice diameter (mm); *df* focus tube diameter (mm);*Ma* abrasive mass flow rate (Kg/min); *P* water-jet pressure (Bar); *Sd* stand-off distance (mm); *V* traverse feed rate (mm/min); *φ* impact angle (°); *h* processing depth (mm); *Ra* surface roughness (μm).
In order to obtain complex 3D parts using water jet milling was developed the algorithm shown schematically in figure 3.

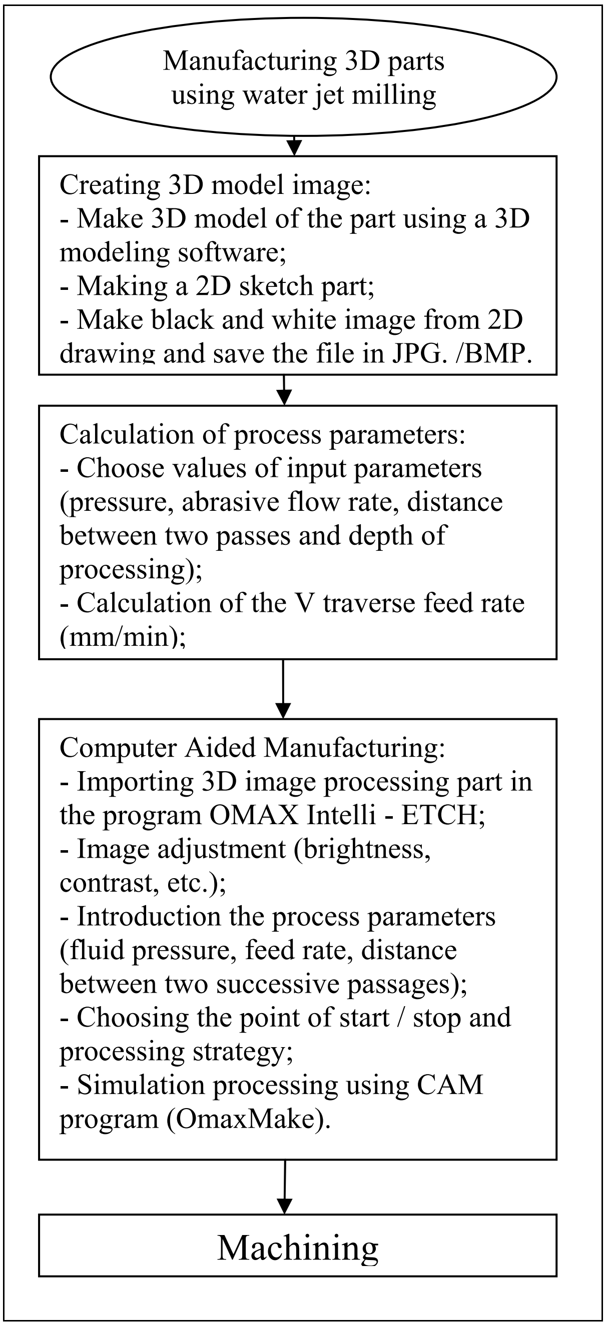


Fig.3. Processing algorithm for manufacturing 3D parts by water jet milling

The first step in processing 3D parts using water jet milling is to create the image of the 3D part. Thus, to obtain this image you start from the 3D model of the part with the help of a 3D modeling software. With this CAD software, starting from the 3D model the 2D drawing of the part is made.
The 2D sketch, saved with the DWG format is imported into Corel DRAW program. It is necessary to use a 2D sketch made in this way to obtain an image with high dimensional accuracy. CorelDraw drawing program recognizes the sketch and offers the possibility to color this sketch. Thus, depending on the geometry of the part that wants to be machined by water jet milling, the sketch is colored in shades of white and black. Minimum depth areas are colored in white and areas with maximum depth are colored in black. Intermediate depth zones are colored in gray. Black and white proportions are calculated by the algorithm presented in table 1.

Table 1. Algorithm to choose the color image

Color	The proportion of color	Traverse feed rate	Example
	0% Black / 100% White	V= 1 x Vmax mm/min	Vmax=5000 mm/min
	20% Black / 80% White	V=Vmin + 0.8 x (Vmax-Vmin) mm/min	V1=4280 mm/min
	50% Black / 50% White	V=Vmin + 0.5 x (Vmax-Vmin) mm/min	V2=3200 mm/min
	80% Black / 20% White	V=Vmin + 0.2 x (Vmax-Vmin) mm/min	V3=2120 mm/min
	100% Black / 0% White	V= 1 x Vmin mm/min	Vmax=1400 mm/min

It is important that the image to be made perpendicular to the processing surface and its quality should be as high as possible as it affects the accuracy of manufacturing. This black and white picture is saved in a .BMP or .JPEG format.
The second step of the milling processing algorithm is to calculate the parameters of the process. To obtain the process parameters we used a dedicated program to calculate these parameters. Maximum feed rate is recommended for maximum velocity of the used equipment. The minimum feed rate is calculated for maximum depth of processing. The last step in obtaining the 3D parts is programming the equipment and implementation of manufacturing. Image processing and

programming is performed using a special program developed for this application. The most complex program of this kind is the one made by American company OMAX, launched in early 2011, and entitled "Intelli-ETCH".
The program adjusts the feed rate of abrasive jet, using an algorithm for the brightness of each pixel of the processing image. Thus, low light areas are covered with low feed rate, resulting in great depth processing and high brightness areas are covered with high feed rate, resulting in a low depth processing (Omax 2012). In this way 3D parts with complex surfaces can be processed using water jet milling.
Developers of the "Intelli-etch" state that it is ideal for applications where the esthetics side of processing is important and precision is not important, such as artwork, logos, etc. Processing accuracy is low because this program allows calculating the optimal values of process parameters, depending on the processed material (Omax 2012). This problem was solved by using the software, a program developed at Technical University of Cluj-Napoca.
Thus, using this algorithm 3D part with a high engineering complexity can be processed using water jet milling.

3. EXPERIMENTAL STUDY

In this experimental study two identical parts were processed using waterjet milling and classical CNC milling.
In this first investigation a 3D part was made by water jet milling, using the algorithm proposed above. To process this part we started from the 3D model using Solid Works software. The 3D model of the part is shown in figure 4. From this 3D model, by using Solid Works a 2D sketch of the part was made, which is illustrated in figure 4.
This sketch, saved in "dwg" format, was imported into Corel DRAW drawing program. Using this software, the image was colored in shades from white to black according to the algorithm from table 1. The picture was saved with the .JPG format and is illustrated in figure 5.

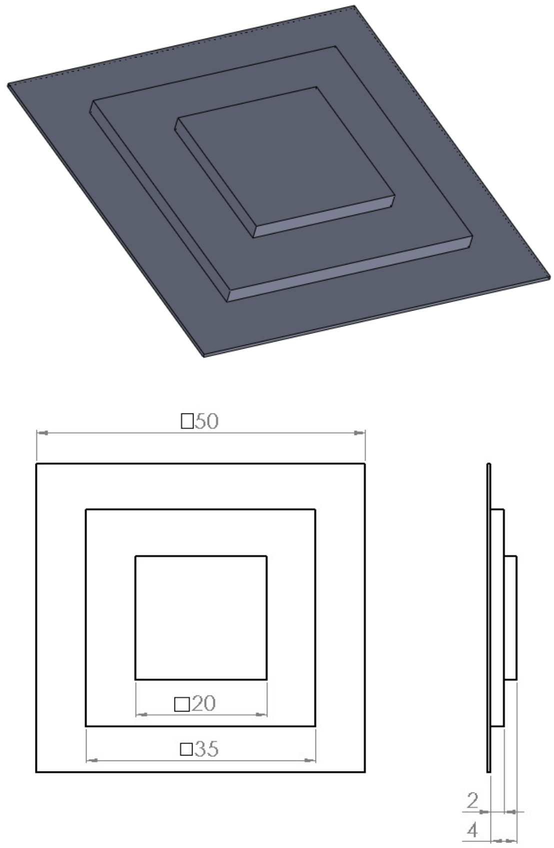


Fig.4. 3D model of the part and 2D sketch of the part.

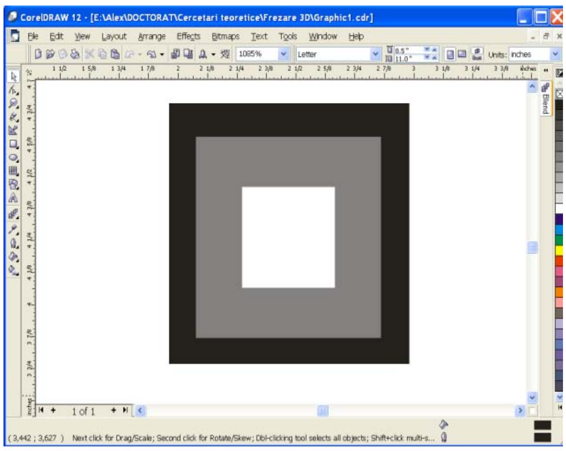
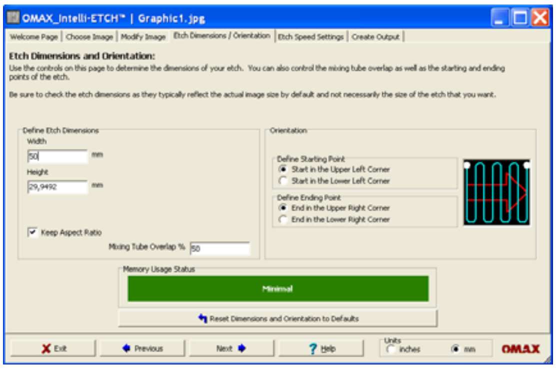
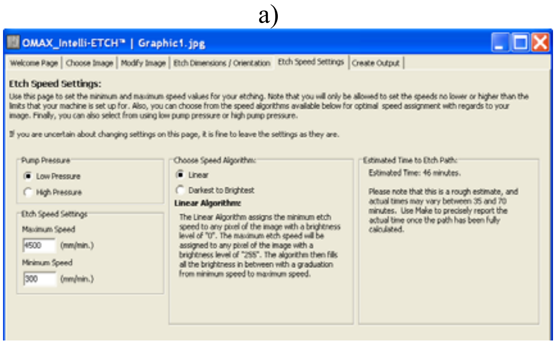


Fig.5. The 3D image of the part

Captured image using CorelDraw program was imported in the "Intelli-ETCH". The program offers a choice of start point and end point of the trajectory of the jet, the dimensions of the 3D part and the distance between two successive passages (Fig. 6).



a)



b)

Fig.6. The introduction of process parameters

Thus, for processing this part, the starting point was chosen in the top left corner of the processing sketch with the following dimensions: 50x50 mm and the distance between two successive passages was 0.38 mm.
Type of steel used in this study is 37-2k OL STAS 500, equivalent to S235JR according to EN 10025-2.
One of the disadvantages of this program is that it does not offer the possibility to calculate the process parameters. This problem was solved by using the computer software, named CAPAJETA, developed at Technical University of Cluj-Napoca for calculating the process parameters. Using this program we calculated the feed rate required to achieve the desired processing depth, 4 mm, using a pressure of 1600 bar and a flow rate of 0.45 kg / min.
Thus, having these values of process parameters, we return to the "Intelli-Etch" program. In this section of the program were introduced: the fluid pressure, the minimum and maximum feed speed. The "Intelli-ETCH" contains an algorithm that controls acceleration and deceleration of the jet at direction changes to improve the obtained surface quality and to increase processing accuracy.
The parameters of the process were: the water pressure 1600 bar; the maximum/minimum feed rate 4500/300 mm/min; the nozzle diameter 0.35 mm; the focusing tube diameter 0.76 mm; the jet impact angle 90˚; the abrasive flow rate 0.45 Kg/min; the abrasive size 80 Mesh; the standoff distance was 2 mm.
To obtain this part we used OMAX 2626 water jet machining equipment from Technical University of Cluj-Napoca.

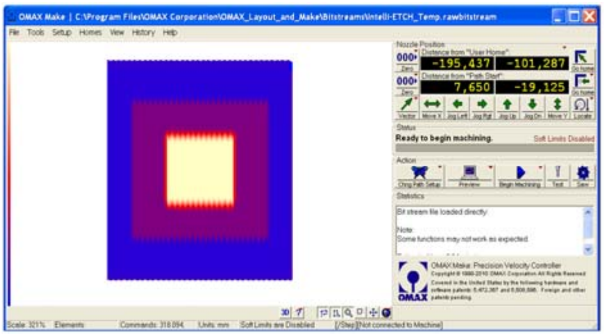


Fig.7. Simulation of the processing

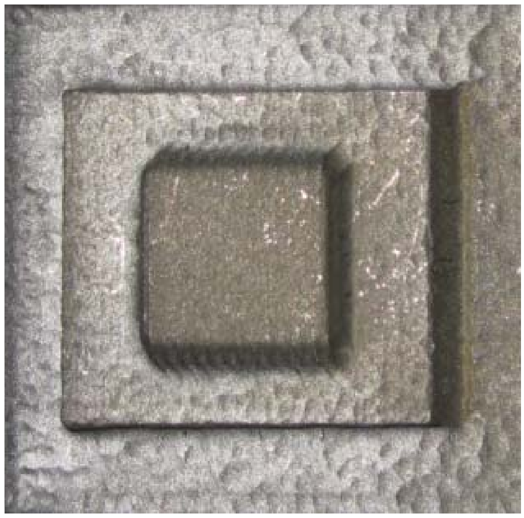


Fig.8. The part made by water jet milling

The OmaxMake simulation can offer graphical representation of feed rate variation during processing (figure 7). Thus, blue is the minimum speed, intermediate speed is red and white is the maximum speed. Using the proposed algorithm the 3D part (illustrated in figure 8) was processed by water jet milling.
In the second investigation a 3D part was made by CNC classical milling method. To process this part CAD/CAM software was used. The 3D model was opened in CAM software, SolidCam.
First processing operation was rough milling. In this process was used a carbide end mill with a 16mm diameter and 4 flutes. The process parameters were: the cutting speed 150 m/min, the feed per tooth 0.15 mm/tooth, the depth of processing up to 4 mm and 8 mm step over.
Type of steel used in this study is ST 37-2k OL STAS 500.

In figure 9 is presented the strategy for rough operation.

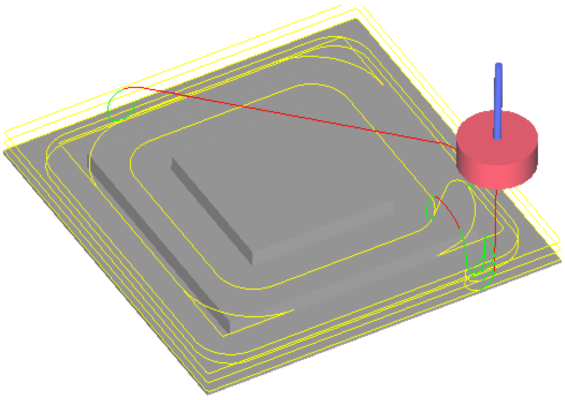


Fig.9. Roughing operation

Finishing operation was made with the same tool by using 0.03 mm/tooth feed rate (figure 10).

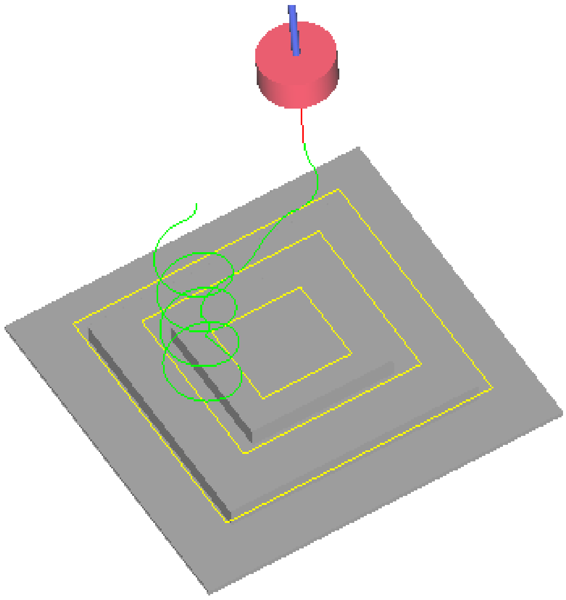


Fig.10. Finishing operation

Using the proposed strategy the 3D part, illustrated in figure 11, was processed by CNC classical milling.

Fig.11. The part made by classical milling

4. RESULTS AND DISCUSSIONS

For part measurement in this study a coordinate measuring machine manufactured by CIMCO, FIRE II model was used. We choose to use this equipment for measurement due to good measurement accuracy, ± 0.005 mm.

In the measuring process CIMCO equipment is used, model FIRE II, software DELCAM PLC, which allows the generation of a measurements bulletin.

The part was set on the measuring equipment table, and by using a detecting element the desired dimensions were measured, as shown in figure 12.

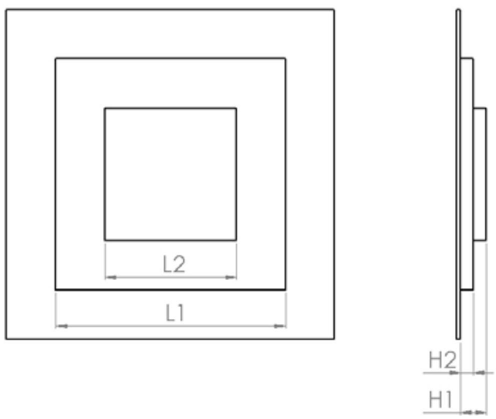


Fig.12. The part dimensions, pursued in this study

Table 2. Dimensions of the 3D milled part

	Nominal dimension [mm]	Dimensional deviation- water jet milling [mm]	Dimensional deviation- classical milling[mm]
L1	50	0.85	0.02
L2	20	0.7	0.02
H1	4	0.63	0.01
H2	2	0.31	0.01

Comparing the experimental results with the nominal dimensions a dimensional accuracy of ± 0.9 mm was obtained for water jet milling process and ± 0.02 mm for classical milling (table 2).
By analyzing the surface quality of experimental parts we obtained Ra 13.5 μm for water jet milling process and Ra 2.5 μm for classical milling. The processing time was 5 minutes for part made through water jet milling process and 5.5 minutes for the part made through classical milling.

5. CONCLUSION

Water jet milling is a solution for processing complex parts. A comparison between classical CNC milling process and AWJ milling process was made and we observed that: using classical milling we can obtain a higher dimensional accuracy and a better surface quality. By analyzing the processing time the AWJ milling process was faster.
With the developed process, complex 3D parts can be manufactured, resulting a high dimensional accuracy.

6. REFERENCES

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