DIMENSIONAL VARIATION OF POLYURETHANE FOAM PANEL ON CIRCULAR CUTTING WITH ABRASIVE WATER JET TECHNOLOGY

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Abstract. The abrasive water jet method can offer a suitable solution for manufacturing of polyurethane foam panel that are usually difficult to do. This paper presents the results of some experiments on abrasive water jet cutting of circular holes into polyurethane foam panel. The main problem which occurs is the tapered shape of the hole, due to the mechanics of the process and the control of the surface produced by the abrasive water jet. The experiments considered several values of the main process parameters like the feed rate and nozzle diameter which have a direct influence on the part cutting process. After measuring the parts, there were analyzed the main dimensional parameters of precision to reveal the proper solution for obtaining the required quality of the process.

Keywords: circular cutting in abrasive water jet, dimensional variation of cut diameters

1. Introduction

These polyurethane foam panel need to be drilled and a high quality are demanded than those elements are placed in key components of the aircrafts.

The defects that can be produced in the dry drilling of polyurethane foam panel are diameter deviation and damaged area of cutting surfaces. These defects are known as Break-IN (B-IN) and Break-OUT (B-OUT) [1]. First of them is based on the analysis of the diameter deviation. Second procedure is based on the damaged area. The parameters have been measured making use of image analysis techniques.

2. Abrasive water jet cutting

2.1. The principle of abrasive water jet cutting

Abrasive water jet machining is one of the most flexible manufacturing processes known today. It is based on forcing a high pressure water jet to flow into a small orifice. The jet is then mixed with abrasive into a chamber and guided through a mixing tube. The high speed of the jet like over twice the speed of sound is able to cut holes into the workpiece. The method has a high flexibility due to its ability to cut most of the materials, metallic or non-metallic, regardless their hardness. It is one of the fastest and most accurate methods for cutting a variety of metals and non-metals [2,8].

Any of the cutting models is intended to be used, usually it is very difficult to implement it into the machine software. So, in most times, there is used the original model of the machine, because the possibilities of adjusting the working parameters is very limited [3].

On circular cutting in abrasive jet machining technology for polyurethane foam panel depends on cutting parameters show above.

The main advantages of abrasive water jet cutting over other cutting methods can be summarised as follows [3]:

- wide range of materials abrasive water jets can machine a wide range of thicknesses and materials, include metals, plastics, glass, and ceramics;
- it can produce part accuracies better than 0.08 [mm];
- it can cut thinner metals at over 30 mm/s;
- it produces a narrower heat affected zone than plasma;
- quality finish materials machined by the abrasive jet have a smooth, satin-like finish, similar to a fine sandblasted finish;
- no heat in machining process, abrasive jets abrade material at room temperatures. As a result, there are no heat-affected areas or structural changes in materials with low melting points;
- environmentally friendly, abrasive jets use garnet as an abrasive. Garnet is a reddish natural crystal, with a hardness of 800 HV to 1100 HV, no noxious gases or liquids are used in abrasive jet machining, nor are there any oils used in the machining process;
- a wide range of conventional processes can be performed with this single tool;
- drilling, broaching;
- gear cutting, profile milling;
- punching, slitting;
- spline cutting, blanking.

However, there are also several disadvantages to be considered [3]:

- high cost of the equipment;
- the thickness of materials that can be cut is limited at 1-30 mm;
- 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.

2.2. Abrasive water jet cutting machine

The experiments were realized in the laboratory of Advanced Technologies, using a water jet machine type Maxiem, with 20 HP at a maximum power of 50,000.00 psi having following specifications:

- rate speed Va [mm/min];
- nozzle diameter d [mm];
- water jet velocities W_{jv} = (520…710) m/s;
- pressure at nozzle P = (345…255) Mpa;
- mixing tube diameter D_{mt} = 0.832 mm;
- abrasive flow rate A_{flr} = 0.3401943 kg/min;
- abrasive size A_s = 80 μm.

The cutting head was a usual one, without the possibility of automatic tilt, to compensate the taper surface [4, 5, 8].

3. Run of the experimental tests

The aim was to obtain, by abrasive water jet cutting holes in polyurethane foam panel Figure 1.

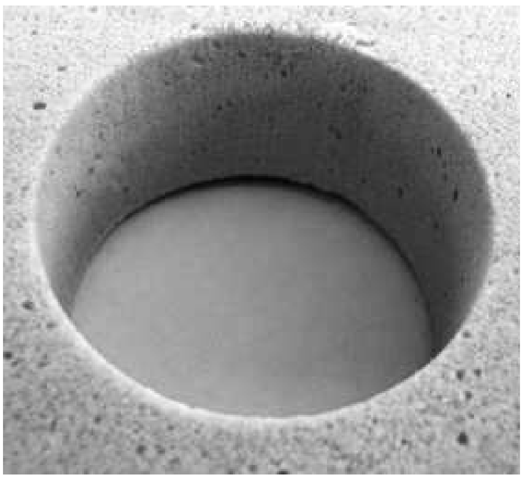

Figure 1. Hole in polyurethane foam panel obtain, by abrasive water jet

There were performed tests of machining circular holes with two values of the nominal diameter D, as D = 40 mm, D = 20 mm, in the foam panels of two different heights G, the first with G = 20 mm, and the second with G = 12 mm, Figure 2, using different strategies and values for the cutting parameters like speed rate Va [mm/min], and nozzle diameter d [mm].

In the present case, the polyurethane foam panel used was not found in the list of materials, so it was manually added the machinability strategies with Va = 90 mm/min, Va = 128 mm/min, Va = 176 mm/min, nozzle diameters d = 0.1294 mm, d = 0.1750 mm, d = 0.2581 mm, d = 0.3031 mm. These values proved to be correct and the holes were cut in good conditions [5, 6].

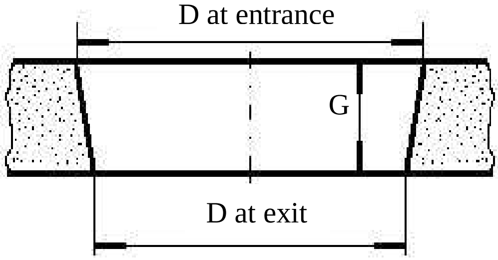

Figure 2. Diameters results at entrance and at exit of material

Table 1. Mean values of the deviation on the hole diameter, D = 40 mm for G = 20 mm

Va [mm/min]	d [mm]	D = 40 mm	
		at entrance	at exit
90	0.3031	-0.155	-0.173
128	0.3031	-0.164	-0.184
176	0.3031	-0.172	-0.215
90	0.2581	-0.135	-0.158
128	0.2581	-0.153	-0.176
176	0.2581	-0.166	-0.184
90	0.1750	-0.125	-0.144
128	0.1750	-0.132	-0.162
176	0.1750	-0.146	-0.173
90	0.1294	-0.114	-0.138
128	0.1294	-0.122	-0.152
176	0.1294	-0.133	-0.161

Table 2. Mean values of the deviation on the hole diameter, D = 40 mm for G = 12 mm

Va [mm/min]	d [mm]	D = 40 mm	
		at entrance	at exit
90	0.3031	-0.153	-0.162
128	0.3031	-0.160	-0.173
176	0.3031	-0.170	-0.184
90	0.2581	-0.138	-0.146
128	0.2581	-0.151	-0.163
176	0.2581	-0.163	-0.172
90	0.1750	-0.128	-0.131
128	0.1750	-0.134	-0.153
176	0.1750	-0.145	-0.164
90	0.1294	-0.113	-0.127
128	0.1294	-0.125	-0.146
176	0.1294	-0.137	-0.155

Table 3. Mean values of the deviation on the hole diameter, D = 20 mm for G = 20 mm

Va [mm/min]	d [mm]	D=20 mm	
		at entrance	at exit
90	0.3031	-0.123	-0.154
128	0.3031	-0.145	-0.161
176	0.3031	-0.154	-0.178
90	0.2581	-0.122	-0.143
128	0.2581	-0.140	-0.154
176	0.2581	-0.149	-0.165
90	0.1750	-0.120	-0.138
128	0.1750	-0.132	-0.143
176	0.1750	-0.146	-0.157
90	0.1294	-0.114	-0.128
128	0.1294	-0.122	-0.137
176	0.1294	-0.133	-0.144

Table 4. Mean values of the deviation on the hole diameter, D = 20 mm for G = 12 mm

Va [mm/min]	d [mm]	D = 20 mm	
		at entrance	at exit
90	0.3031	-0.115	-0.134
128	0.3031	-0.134	-0.148
176	0.3031	-0.146	-0.154
90	0.2581	-0.108	-0.125
128	0.2581	-0.121	-0.138
176	0.2581	-0.138	-0.146
90	0.1750	-0.098	-0.116
128	0.1750	-0.107	-0.127
176	0.1750	-0.115	-0.134
90	0.1294	-0.084	-0.101
128	0.1294	-0.098	-0.126
176	0.1294	-0.114	-0.132

There were then holes cut for each nominal diameter D and height G with three speed rate Va and four nozzle diameter d [5, 6].

To evaluate the dimensional accuracy of the parts, measure each time diameter D, Figure 2, at entrance and at exit in the conditions presented above. For the holes with nominal diameter D = 40 mm, the results are presented in Table 1 for the polyurethane foam panel with G = 20 mm and in Table 2 for the second foam panel with G = 12 mm. For the holes with nominal diameter D = 20 mm, the results are presented in Table 3 for the first foam panel with G = 20 mm, and in Table 4 for the second with G = 12 mm. Values represent the average of three measurement of diameter D, at entrance and at exit.

4. Evaluation of the dimensional precision

Considering the mean values in Tables 2÷4 the graphical variation of the hole diameter was pointed out in diagrams. Figure 3 present the dependence of the hole diameter D = 40 mm on the feed rates, at the exit and at entrance of pieces, for G = 20 mm, nozzle diameter d = 0.3031 mm and in Figure 4 for d = 0.1294 mm.

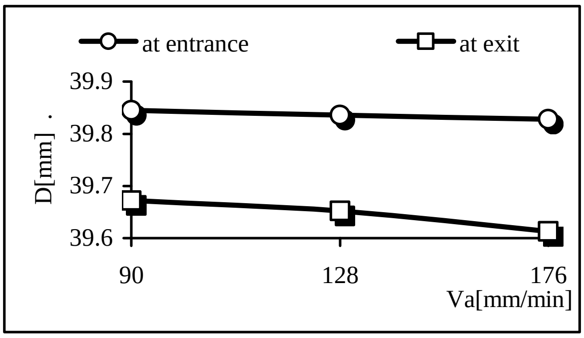

Figure 3. The diameter variation at entrance and at the exit from the feed rate Va, for D = 40 mm, d = 0.3031 mm and G = 20 mm

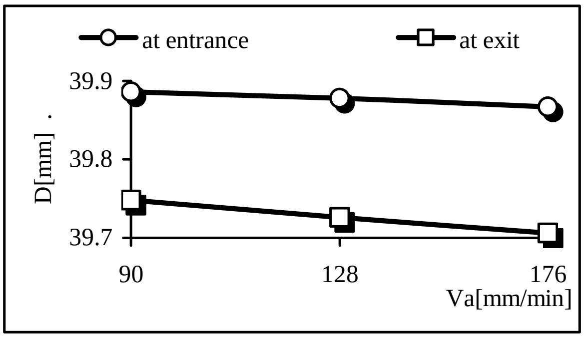

Figure 4.The diameter variation at entrance and at the exit from the feed rate Va, for D = 40 mm, d = 0.1294 mm and G = 20 mm

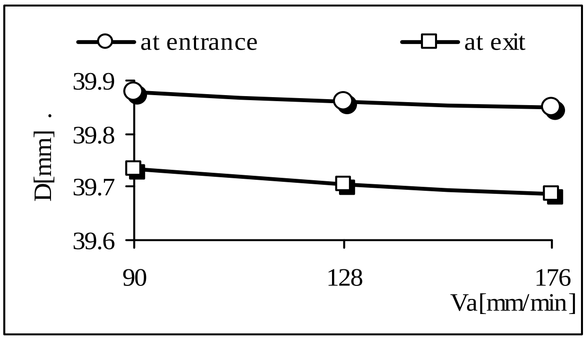

Figure 5. The diameter variation at entrance and at the exit from the feed rate Va, for D = 20 mm, d = 0.2581 mm and G = 20 mm

Diagrams in Figure 5 present the dependence of the hole diameter D = 20 mm on the feed rates Va, at the exit and at entrance of pieces with G = 20 mm, for nozzle diameter d = 0.2581 mm and for d = 0.1750 mm, and G = 12 mm, in Figure 6.

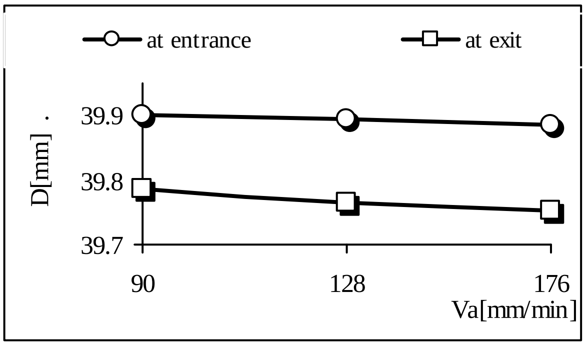

Figure 6. The diameter variation at entrance and at the exit from the feed rate Va, for D = 20 mm, d = 0.1750 mm and G = 12 mm

The variation of the diameter, D = 40 mm, on the nozzle diameter at the entrance and at exit of piece for G = 20 mm and feed rate Va = 90 mm/min is presented in Figure 7.

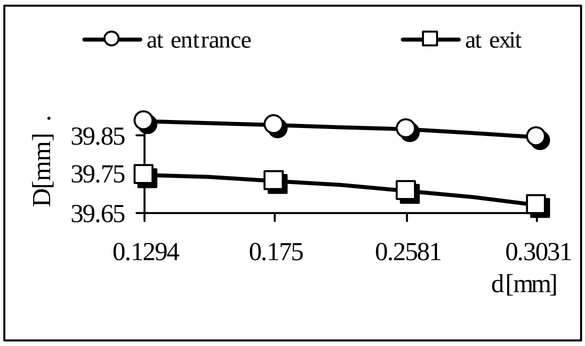

Figure 7. The diameter variation at entrance and at the exit from the nozzles diameter at feed rate Va = 90 mm/min, for D = 40 mm, and G = 20 mm

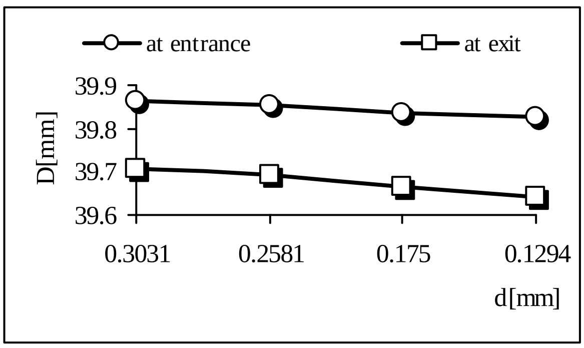

Figure 8. Show the diameter variation at entrance and at the exit from the nozzles diameter at feed rate Va = 6 mm/min, for D = 40 mm and G = 12 mm

The variation of the diameter D = 40 mm from the nozzles diameter at the entrance and at exit of foam panel for G = 12 mm at feed rate Va = 176 mm/min is presented in Figure 8 and for D = 20 mm in Figure 9.

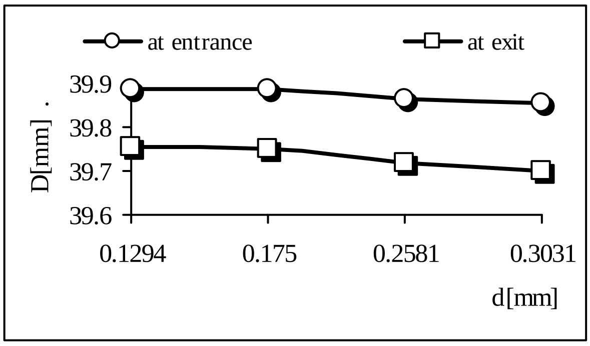

Figure 9. Show the diameter variation at entrance and at the exit from the nozzles diameter at feed rate Va = 176 mm/min, for D = 20 mm and G = 12 mm

The variation of the diameter, D = 20 mm, on the nozzles diameter at the entrance and at exit of piece for G = 20 mm and feed rate Va = 176 mm/min is presented in Figure 10.

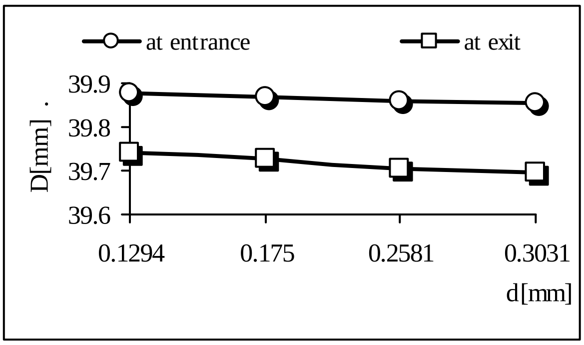

Figure 10. Show the diameter variation at entrance and at the exit from the nozzles diameter at feed rate Va = 176 mm/min, for D = 20 mm and G = 20 mm

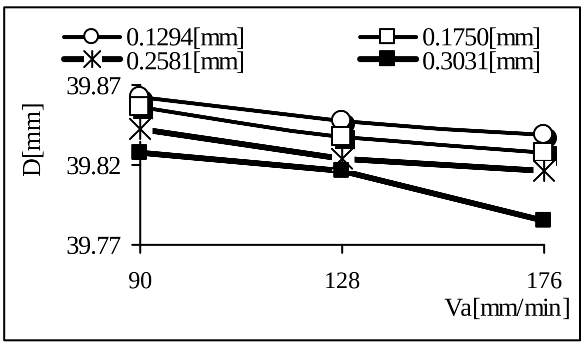

Figure 11. Show the diameter variation at entrance from feed rate on different nozzles diameter, for D = 40 mm and G = 20 mm

The variation of the diameter D = 40 mm from feed rate, at entrance with G = 20 mm for different nozzles diameter is presented in Figure 11 and the diameter at exit of piece in Figure 12.

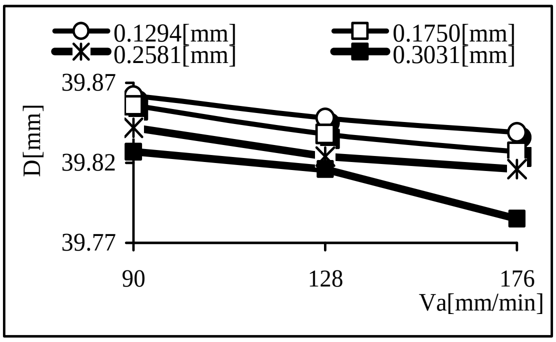

Figure 12. Show the diameter variation at the exit from feed rate on different nozzles diameter, for D = 40 mm and G = 20 mm

The variation of the diameter D = 20 mm from feed rate at exit of piece with G = 12 mm on different nozzles diameter is presented in Figure 13.

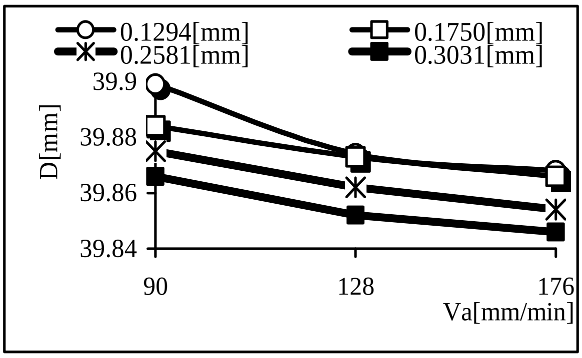

Figure 13. Show the diameter variation at the exit from feed rate on different nozzles diameter, for D = 40 mm and G = 12 mm

The diagrams shown in Figures 3…13 point out the following statements on the parts' accuracy in terms of dimensional deviation from the main influence on the dimensional precision of the circular holes has the feed rate, as seen in all diagrams:

- all the circular hole has a tapered surface, wider at entrance and narrower at exit, Figures 3...13, looking at the direction of the abrasive water jet; this is a general effect of a much longer contact with the jet at the entrance surface compared to the exit one;
- the precision of the cut diameters increase with decreases of the feed rate, as seen in diagrams; this can be explained by a longer time contact with the abrasive water jet when the feed rate is smaller;
- the precision of the diameters increase with decreases of nozzle diameter as seen in Figures 8...10;
- at the exit surface, the deviation dispersal is greater than at the entrance for all diameter and height of pieces, Figures 3...6, probably because of the uncontrollable dispersal phenomenon of the abrasive water jet in contact with the particles already cut from the workpiece;
- the deviation field spreads between 0.215 mm and 0.114 mm for D = 40 mm, G = 20 mm, between 0.184 mm and 0.113 mm for D = 40 mm and G = 12 mm, between 0.178 mm and 0.114 mm for D = 20 mm and G = 20 mm, between 0.15 mm and 0.94 mm for D = 20 mm and G = 12 mm;
- dimensional accuracy decreases with increasing of the nozzle diameter as shown in all diagrams;
- the significant difference between entrance and exit 0.043 mm, Figure 3, is at feed rate Va = 176 mm/min, at d = 0.3031 mm for D = 40 mm and G = 20 mm;
- the minimal difference between diameter at entrance and at exit 0.007 mm, Figure 3, is at feed rate Va = 90 mm/min, at d = 0.1294 mm for D = 20 mm and G = 12 mm;
- the height of the part have an important influence on the dimensional precision, Figure 2 and Figure 4, but it has an indirect influence as it determines the values of the feed rate, chosen to assure a complete penetration of the hole.

5. Conclusions

Machining of foam panel is not difficult because it is a soft material. When circular holes are needed into such materials, the abrasive water jet cutting is a very suitable method, which assures a reasonable cost and the required quality of the parts. The experimental tests presented in this paper proved that abrasive water jet may be used with good results for cutting circular holes into foam panel materials. The main challenge is to find the proper values of the working parameters to obtain the required surface accuracy.

The results of the experiments, analyzed in diagrams, Figure 2 to Figure 4, pointed out the main issue to deal with: the conical shape of the surface of the hole should be minimized when the precision required.

One method to minimize the taper is the use of an automatic tilt head, but this is not always cost effective. Other method, proposed in this paper, is to adjust the feed rate at such a value which assures a minimum taper, but is able to cut through the hole as required.

Further research is encouraged to establish the cutting conditions in other cases of part's shape and other alumina ceramic materials.

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Received in November 2014