Dimensional Variation of Polyurethane Foam Panel on Linear Cutting with Abrasive Water Jet Technology

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Abstract
This paper presents the results of some experiments on abrasive water jet of linear cutting into polyurethane foam panel. The abrasive water jet method can offer a suitable solution for manufacturing of polyurethane foam panel that are usually difficult to do. The main problem which occurs is the tapered shape of the linear cutting, 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 analysed the main dimensional parameters of precision to reveal the proper solution for obtaining the required quality of the process.

Keywords
linear cutting in abrasive water jet, dimensional variation

1. Introduction

These polyurethane foam panel need to be linear cutting 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 linear cutting of polyurethane foam panel are perpendicular deviation and damaged area of cutting surfaces. These defects are known as Break-IN (B-IN) and Break-OUT (B-OUT) [1, 2]. First of them is based on the analysis of the perpendicular 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 cutting it is one of the fastest most flexible manufacturing processes and most accurate methods for cutting a variety of metals and non-metals. 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 has a high flexibility due to its ability to cut most of the materials, metallic or non-metallic, regardless their hardness. [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 [1, 3].

On linear 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 [1, 3]:

- wide range of materials abrasive water jets can machine a wide range of thicknesses and materials, include metals, plastics, glass, stones 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 [1, 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 [1, 4, 5, 8, 9].

3. Run of the Experimental Tests

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

There were performed tests of machining linear cutting with three values of the thickness of polyurethane foam panel *H*, as *H* = 30 mm, *H* = 20 mm, *H* = 10 mm, Figure 2, using different strategies and values for the cutting parameters like speed rate *Va* [mm/min], and nozzle diameter *d* [mm].

Fig. 1. Linear cutting in polyurethane foam panel obtain, by abrasive water jet

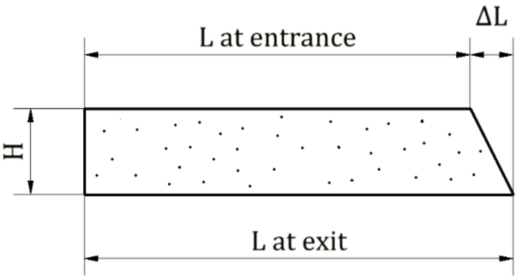

Fig. 2. Deviation ΔL results

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 [5, 6].

There were then linear cutting for each thickness *H* with three speed rate *Va* and four nozzle diameter *d* [5, 6].

To evaluate the dimensional accuracy of the parts, measure each time deviation ΔL, Figure 2, at entrance and at exit in the conditions presented above. For the polyurethane foam panel with H = 30 mm, the results are presented in Table 1, for the polyurethane foam panel with H = 20 mm in Table 2 and for the last foam panel with H = 10 mm in Table 3. Values represent the average of three measurement of deviation ΔL, at entrance and at exit of water jet.

Table 1. Mean values of the deviation ΔL for H = 30 mm

Va [mm/min]	*d* [mm]	Δ*L* [mm]
90	0.3031	0.173
128	0.3031	0.184
176	0.3031	0.215
90	0.2581	0.158
128	0.2581	0.176
176	0.2581	0.184
90	0.1750	0.144
128	0.1750	0.162
176	0.1750	0.173
90	0.1294	0.138
128	0.1294	0.152
176	0.1294	0.161

Table 2. Mean values of the deviation ΔL for H = 20 mm

Va [mm/min]	*d* [mm]	Δ*L* [mm]
90	0.3031	0.154
128	0.3031	0.161
176	0.3031	0.178
90	0.2581	0.143
128	0.2581	0.154
176	0.2581	0.165
90	0.1750	0.138
128	0.1750	0.143
176	0.1750	0.157
90	0.1294	0.128
128	0.1294	0.137
176	0.1294	0.144

Table 3. Mean values of the deviation ΔL for H = 10 mm

Va [mm/min]	*d* [mm]	Δ*L* [mm]
90	0.3031	0.147
128	0.3031	0.154
176	0.3031	0.165
90	0.2581	0.141
128	0.2581	0.146
176	0.2581	0.159
90	0.1750	0.131
128	0.1750	0.141
176	0.1750	0.155
90	0.1294	0.127
128	0.1294	0.137
176	0.1294	0.146

4. Evaluation of the Dimensional Precision

Considering the mean values in Tables 1÷3 the graphical variation of the deviation ΔL was pointed out in diagrams.

Figure 3 present the dependence of the deviation ΔL on the feed rates, at the exit and at entrance of pieces, for H = 30 mm, for nozzle diameter d = 0.3031 mm, d = 0.2581 mm, d = 0.1750 mm, d = 0.1294 mm.

Figure 4 present the dependence of the deviation ΔL on the feed rates, at the exit and at entrance of pieces, for H = 20 mm, for nozzle diameter d = 0.3031 mm, d = 0.2581 mm, d = 0.1750 mm, d = 0.1294 mm.

Figure 5 present the dependence of the deviation ΔL on the feed rates, at the exit and at entrance of pieces, for H = 10 mm, for nozzle diameter d = 0.3031 mm, d = 0.2581 mm, d = 0.1750 mm, d = 0.1294 mm.

The variation of the deviation ΔL on the nozzle diameter at the entrance and at exit of piece for H = 30 mm and feed rate Va = 90 mm/min, Va = 128 mm/min, Va = 176 mm/min is presented in Figure 6, for H = 20 mm in Figure 7, and for H = 10 mm in Figure 8.

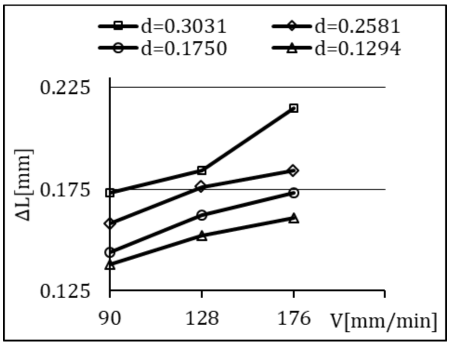

Fig. 3. The deviation Δ*L* for the nozzle diameters from the feed rate *Va*, and *H* = 30 mm

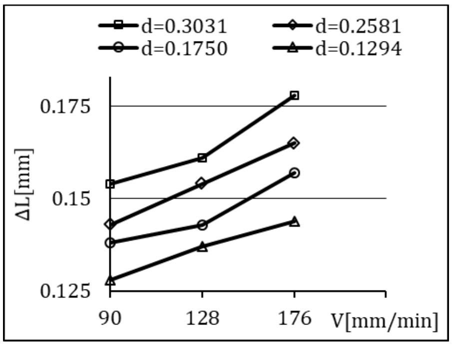

Fig. 4. The deviation Δ*L* for the nozzle diameters from the feed rate *Va*, and *H* = 20 mm

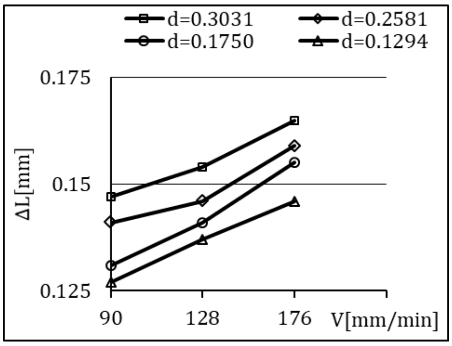

Fig. 5. The deviation Δ*L* for the nozzle diameters from the feed rate *Va*, and *H* = 10 mm

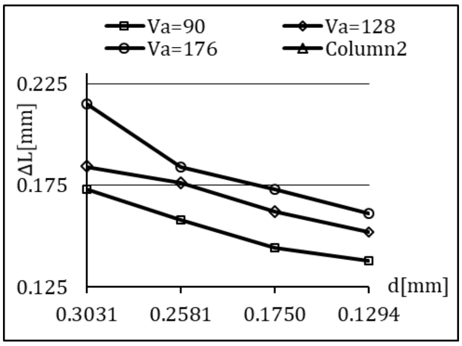

Fig. 6. The deviation Δ*L* at entrance and at the exit from the nozzles diameter at feed rate *Va* at *H* = 30 mm

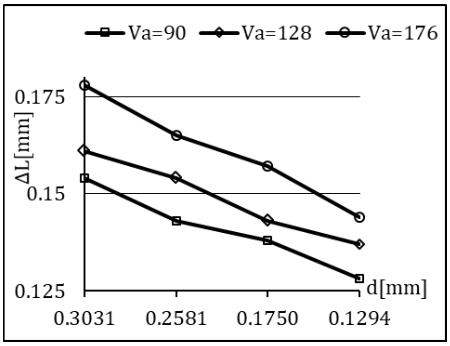

Fig. 7. The deviation ΔL at entrance and at the exit from the nozzles diameter at feed rate *Va* at *H* = 20 mm

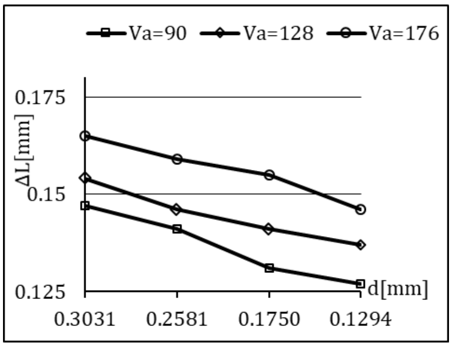

Fig. 8. The deviation Δ*L* at entrance and at the exit from the nozzles diameter at feed rate *Va* at *H* = 10 mm

The diagrams shown in Figures 3…8 point out the following statements on the parts' accuracy in terms of dimensional deviation from the main influence on the dimensional precision of the linear cutting has the feed rate, as seen in all diagrams:

- all the linear cutting has a tapered surface, wider at entrance and narrower at exit, Figures 3...5, 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 linear cutting 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 linear cutting increase with decreases of nozzle diameter as seen in Figures 3...5;
- at the exit surface, the deviation dispersal is greater than at the entrance for all linear cutting and height of pieces, Figures 3...5, 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 0.138 mm for H = 30 mm, between 0.178 mm and 0.128 mm for H = 20 mm, between 0.165 mm and 0.127 mm for and H = 10 mm;
- dimensional accuracy decreases with increasing of the nozzle diameter as shown in all diagrams;
- the significant difference between entrance and exit 0.077 mm, Figure 3, is at feed rate Va = 176 mm/min, for H = 30 mm;
- the minimal difference between linear cutting at entrance and at exit 0.127 mm, Figure 5, is at feed rate Va = 90 mm/min, at d = 0.1294 mm for H = 10 mm;
- the thickness of the part have an important influence on the dimensional precision.

5. Conclusions

Machining of foam panel is not difficult because it is a soft material. When linear cutting are needed into such materials, the abrasive water jet cutting is a very suitable method, with a reasonable cost and the required quality of the parts. The experimental tests presented in this paper proved that abrasive water jet can be used with good results for linear cutting in to 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, analysed in diagrams, Figure 3 to Figure 8, pointed out the main issue to deal with: the nonperpendicular shape of the surface 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.

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

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