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PLANNING EXPERIMENTS FOR WATER JET CUTTING OF THE PARTS OBTAINED FROM "LIQUID WOOD"

BY

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Abstract. In the context of the technological developments of the last decades the scientific community and the world economic reality required the development and optimization of new processes and technologies that enable the sustainable production of recyclable modern materials, biocompatible and biodegradable from renewable natural resources. One of these resources is certainly the vegetable material such as *lignin*. As a result of increasing demand for biodegradable materials, it has developed a new material with the trade name "*liquid wood*" (100% biodegradable), by a team of German researchers (Technical Institute of Chemistry of Fraunhofer with the company Tecnaro GmbH). This material meets all the above conditions and is consistent with chemistry and "green" engineering also. "Liquid wood" can be found in three different forms: "Liquid Wood" named ARBOFORM®, wood with plastic composite named ARBOBLEND®, wood with composed biopolymer named ARBOFILL® (Nagele *et al*., 2014). The paper aims planning experiments using the Taguchi method for water jet cutting of the pieces obtained by injection from liquid wood.

Keywords: liquid wood; water jet cutting; Taguchi method; plastic injection; Quality of the cutting surface.

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1. Introduction

The main challenges in obtaining and industrial conversion for materials from bio resources are durability, sustainability, compatibility and accessibility to such new material. Environmental integrity and social equilibrium is attained when an enduring developments happened and this meet the basic human needs (Nagele *et al*., 2014; Shah *et al*., 2008).

"Liquid wood" is a thermoplastic material of high quality, that can be processed like any plastic (injection moulding, extrusion, calendering, blow moulding, thermoforming or pressing to obtain semi-finished products, sheets, films or profiles), non-polluting the air and does not affect the human health. This material decays (breaks down) in water, humus and carbon dioxide, as well as the natural wood, which makes it more eco-friendly than plastics materials which by combustion releases a lot of toxic gases (Shah *et al*., 2008; Eggins and Oxley, 2001). Also, since lignin is a residue - product of paper industry can be used from this source and thus is not necessary to cut other trees to get this natural material.

Considering the special properties of "liquid wood" (mechanical, physical, electrical, structural, thermal) using of this type of material has expanded in many fields, successfully substituting the conventional plastic materials. Thus, we find using this material in automotive industry, construction, electronics, large consumer goods and others (http://www.tecnaro.de). In recent years they developed some research on the behaviour of liquid wood (Nedelcu *et al*., 2016; Nedelcu *et al*., 2013a; Nedelcu *et al*., 2013b; Nedelcu *et al*., 2015a; Nedelcu *et al*., 2015b; Constantin, *et al*., 2015; Plăvănescu, 2014) but lacks research on the processing of liquid wooden parts.

Water jet cutting is, undoubtedly, the most spectacular and modern cutting process. This technology, included among unconventional technologies, is less used in our country and as a result, researches in this area are relatively modest.

This technology relies on the use of concentrated energy of a high pressure water jet or a water jet with abrasive particles and allows machining of every contour on one machine at any surface quality requirements.

Water jet cutting machines is a tool that achieves high precision: 0.01mm. The maximum size of the material is cut up to 300x1500x200 mm.

Water jet cutting technology is the latest technology, enjoying the advantages that ensure the needs of the most demanding customers: excellent quality of cut surface, the possibility of cutting the three-dimensional shapes and lack of deformations (Hashish, 2002; http://www.grafex.ro).

This paper summarizes the process of issues implementation of water jet machining for liquid wood parts, presenting considerations on technological parameters and economic issues depending on the type and the thickness of the cutting material.

2. The Principle of Processing

Processing principle is based on the particular mode of behaviour of materials under stress from shock. In these situations it is essential that strikes at high-speed body another body. Water is sent, in this case, the material at high speed and it the moment of impact, a material becomes “stiff” more “tough” than the material to which it is sent and can thus produce penetration (Fig. 1, Mistodie *et al*., 2007).

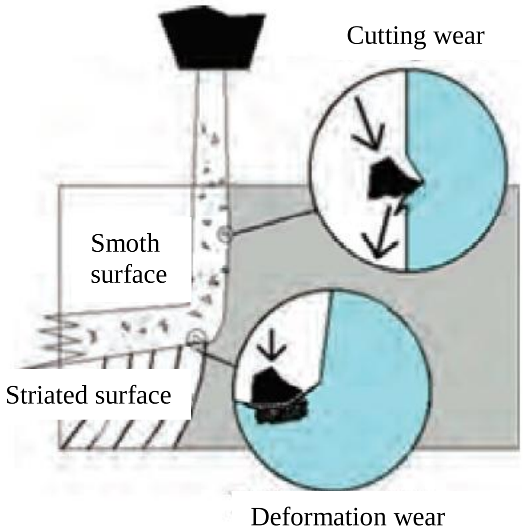

Fig. 1 – Working principle of water jet cutting process.

Compared to laser cutting, can be seen that the cuts with water jet are made from two to three times wider, but still narrow and especially with a constant width. As a result, scheduling the numerical control equipment with a correction radius equal to half width of the cut, can be achieve very precise contours.

The basic elements of a water jet cutting machines are (Fig. 2): the water jet cutting machines with CNC command, the cutting head, control panel, recirculation water reservoir; high-pressure pump; abrasive supply hopper; drying facility for abrasive; spent abrasive collector.

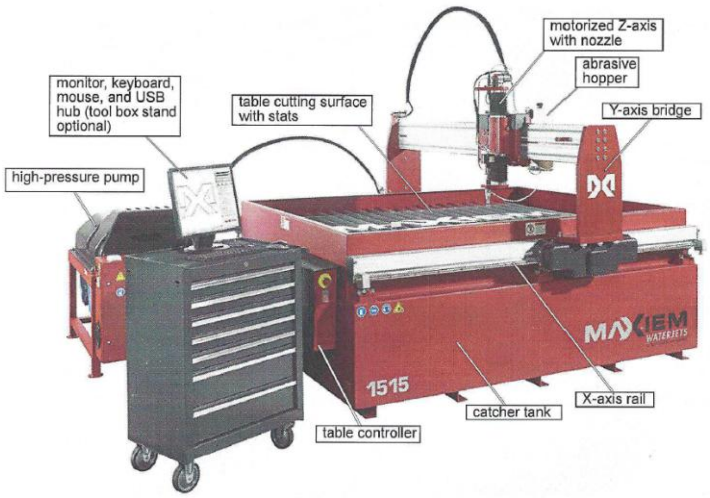

Fig. 2 – The components of the water jet cutting machine.

The experimental results will be made on either a water jet cutting machine produced by the American company OMAX Corporation as shown in Fig. 3.

Fig. 3 – Water jet cutting machine MAXIEM 2030.

The equipment contains three main parts of operation: the MAXIEM table of the machine with: Z, Y and Z system of axes; nozzle and abrasive recovery tank system and cutting table surface; control bench with monitor, keyboard, mouse, USB port and Soft Basic Intelli-MAX; MAXIEM pump group: with high-pressure pump and load pump.

The cutting head (Fig. 4, Mistodie *et al.*, 2007) for abrasive water jet is more complex from construction point of view, using materials such as ruby, sapphire and diamond in its construction. Sapphire is the most often used in pure water jet cutting, because of his low price (15-30) $ lasting life of 50-100 h. For abrasive water jet cutting is used Ruby, this having the same lasting life but higher price, and Diamond that has a lifetime of 800-2000 h and a price of 20 times higher than Sapphire, so it can by used intensively for 24 h. The cutting headwear depends on the work mode and also on the quality of water and abrasive materials. For this reasons it was complex surveyed to establish the correlations between all involved factors. The abrasive used is sand, tough and very fine grain.

3. Quality of the Surfaces Obtained by Abrasive Water Jet Cutting

The surfaces quality processed with this technological process is given by several factors as: material thickness; physico-chemical properties and in-process machine parameters (pressure, cutting speed, range correction, the technical condition of equipment and special nozzle).

Generally, by using this method are obtained very good quality of the cutting surface in comparison with the other cutting methods. A very important aspect is that the taper of the cutting area, how relates to the inclination at edges of the material obtain during the water jet or abrasive water jet cutting process. Because this method naturally occurring erodes the processed material, leads to the appearance of a taper in the cutting area, because the peaks of the material are exposed to the water jet for different periods of time.

There are different types of taper from cutting shown in Fig. 5, (Mistodie *et al.*, 2007).

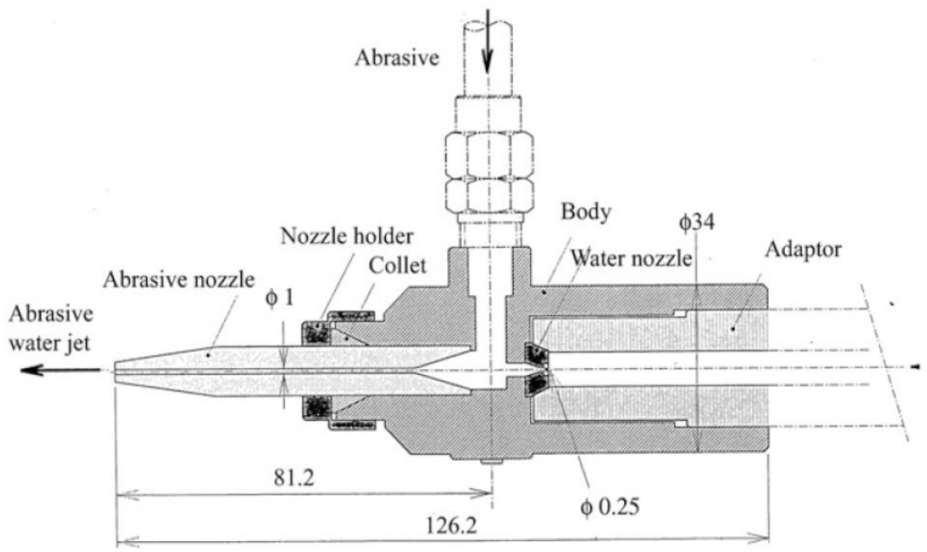

Fig. 4 – The cutting head.

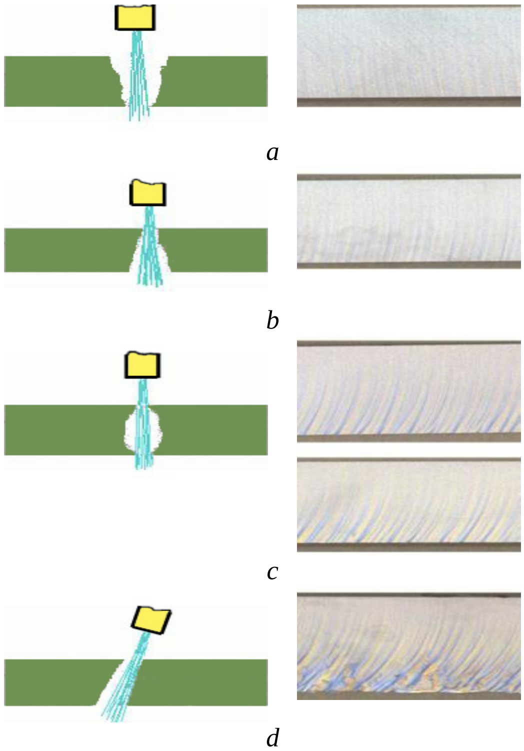

Fig. 5 – Different Types of jet. The quality of the cut surface.

Tapered V shape (Fig. 5*a*), occurs where the tip of the cut is wider in the jet penetration area than in the base of the material. This is happened when the jet spending enough time in an area to erode the material more than the base. The jet tends to erode the margins.

The inverse conical shape (Fig. 5*b*), occurs where the tip of the cut is narrower than the base. This tends to happen with soft materials when the material is quickly eroded or when cutting is very slow.

Tapered barrel shape (Fig. 5*c*), result when the middle of the cut is wider than the top or bottom. This form tends to occur in very thick materials.

Tapered diamond or trapezoidal shape (Fig. 5*d*), is actually tapered V which was tilted because the nozzle is not at right angles to the material. This conical shape is actually very small, very little is visible to the naked eye. Its occurrence is by increasing cutting speed or in the case of thin materials by stacking them.

All the five qualities obtained by water jet cutting are presented in Table 1, (Mistodie *et al.*, 2007): Q5, it is the highest-quality, the piece is smooth, ribbed with great accuracy; Q4 is a very good quality with very fine striations; Q3, is a good quality, but streaking appear at the bottom; Q2, is a poor quality that accentuates the ribbed bottom, the exit jet area; Q1, poor quality, high ribbed over the entire cutting.

Table 1
Quality Classes of Surfaces

Material thickness	Inclination		Deviations from the straight line	
	Q5	Q3	Q5	Q3
0.12	0.002	0.005	+/-0.003	+/-0.005
0.25	0.0035	0.0075	+/-0.005	+/-0.005
0.5	0.003	0.01	+/-0.007	+/-0.005
0.75	0.0035	0.012	+/-0.010	+/-0.020
1	0.004	0.014	+/-0.015	+/-0.030
1.5	0.006	0.016	+/-0.020	+/-0.040
2	0.008	0.018	+/-0.025	+/-0.045
3	0.01	0.02	+/-0.030	+/-0.050

It follows from the presented show that the cut surface quality is variable depending on the chosen cutting regime. In terms of industrial use, state of wear of the nozzles should be closely monitored and observed their lifetimes. We intend in the future to investigate how wear changes the shape of the water jet and how this affects the quality of the cut surface.

This study involves shooting ultrafast the abrasive jet, while monitoring the operating parameters.

In this sense we use modern equipment of shooting at high-speed synchronous for measurement of parameter involved in the cutting process.

4. General Aspects Looking at Planning Experiments

Optimizing cutting regime parameters is very important to get a quality-cost report as good. This is done taking into consideration the most about significant factors how influencing the cutting process. Optimisation is making so that the surface quality to be the best in terms of high cutting speeds, suitable thickness of parts and materials and obtain a minimum cutting widths. Analysis of the results is done by statistical methods or plans experiences. The main parameters that can influence the process of abrasive water jet cutting are presented in Fig. 6 (Patel *et al.*, 2015).

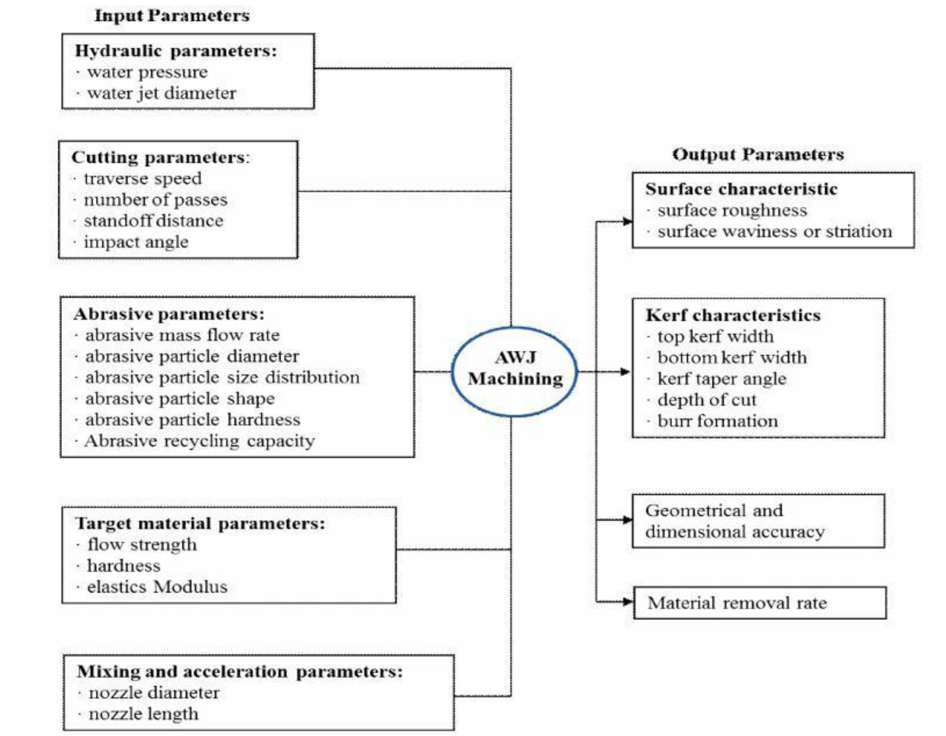

Fig. 6 – Process parameters that can influence the abrasive water jet cutting.

The process parameters include the hydraulic parameters related to the abrasive, mixture of water and abrasive for the quality of the cut. The parameters that must be highlight correlated are: water jet pressure; cutting speed; abrasive flow; the particle size of the abrasive; abrasive nature; the mixing room parameters and the number of passes.

In the experimental research will consider the following input parameters: advance (mm/min); pressure (bar) and abrasive flow rate (g/min) and next, as output parameters: roughness; depth and speed of material removal. During the tests is considered one variable at a time, while other variables are kept fixed. It can be study these issues on the output parameters: speed crossing effect; jet pressure effect; abrasive flow effect and stand-off distance effect. The values of some influence factors are presented in Table 2.

To reduce the number of experimental determinations, needed for verification, and rapid and accurate interpretation of the results of a theoretical model, it has resorted to methods of planning the experiments.

Table 2
Values of Factors Influence

Coded values	Water pressure [bar]	Abrasive Flow [g/min]	Cutting speed [mm/min]	Distance nozzle – material [mm]
1	2000	60	500	1.0
2	2500	100	1000	1.5
3	3000	150	1500	2.0
4	3500	200	2000	2.5
5	4000	250	2500	3.0

In the experimental research will be used Taguchi method. The method is well known and used mainly having the advantage of providing the best accuracy using a reduced number of experimental tests. The experimental plan is presented in Table 3 type Taguchi L27 (3^{13}) for a process expressed by an equation defined by Eq. (1):

$$Y=M+A+B+C+D+AB+AC+AD+BC+BD+CD \quad (1)$$

Table 3
Experimentation Plan

Crt. No.	Factors	Materials tested					No. attempt
		1	2	3	4	5	4x5=20
1	Water jet pressure, [bar]	2000	2500	3000	3500	4000	A
2	Abrasive flow, [g/min]	60	100	150	200	250	B
3	Cutting speed, [mm/min]	500	1000	1500	2000	2500	C
4	Distance nozzle – material, [mm]	1.0	1.5	2.0	2.5	3.0	D
Total attempts							80

Taguchi method requires also the checking of orthogonality and the number of freedom degrees and finis with assigning independent factors columns.

5. Conclusion

The method of using water jet cutting allows a very good quality of the cutting surface than other cutting processes. In the process, parameters are interrelated and should highlight the pressure jet of water; cutting speed; abrasive flow and the distance nozzle – material, factors that will be considered in the plan experimental propose in the paper. It will be studied both independent factors influences and interactions of these factors on roughness, depth of cut and on the rate of material removal.

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PLANIFICAREA EXPERIMENTELOR
LA TĂIEREA CU JET DE APĂ A PIESELOR DIN ,,LEMN LICHID”

(Rezumat)

În contextul evoluților tehnice din ultimile decenii, comunitatea științifică și realitatea economică mondială a necesitat dezvoltarea și optimizarea de noi procese și tehnologii, care să permită producția durabilă de materiale moderne reciclabile, biocompatibile și biodegradabile din resurse naturale regenerabile. O astfel de resursă o reprezintă materialele vegetale, precum *lignina*. Ca urmare a cererii tot mai mari de materiale biodegradabile, a fost dezvoltat un nou material, cu numele comercial de ,,lemn lichid” (100% biodegradabil), de către o echipă de cercetători germani (Institutul Tehnic de Chimie din Fraunhofer împreună cu compania Tecnaro GmbH). Acest material, îndeplinește toate condițiile de mai sus fiind în concordanță cu chimia și ingineria ,,verde”. ,,Lemnul lichid”, se poate găsi sub trei forme diferite: „Lemn lichid” ARBOFORM®, compozit plastic cu lemn ARBOBLEND®, compus biopolimeric ARBOFILL® (Nagele *et al.*, 2014). Lucrarea își propune planificarea experimentelor utilizând metoda Taguchi la tăierea cu jet de apă a pieselor din lemn lichid obținute prin injecție.