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WATER JET CUTTING OF THE PARTS OBTAINED FROM "LIQUID WOOD" - METHODS AND TECHNOLOGIES

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Abstract: Human society has used and continues to widely use plastic materials because of their extensive versatility, low cost and manufacturing process. However, the widespread use of plastics has become a significant concern due the negative impact on the environment; specifically, the sources from which plastics are derived (petroleum and its components) and their biodegradability. Thus, there is an immediate need to develop non-petroleum- based and sustainable feed stocks, and this has predominantly shifted the attention of many researchers, academic and industrial, towards biobased and biodegradable plastics. Tecnaro Company meets this need by developing a biodegradable material and known as "liquid wood". This material is available in three different versions: Arboform - Liquid wood (based on lignin, organic additives and natural fibers), Arboblend plastic composite with wood (its content is based on biopolymers degree, e.g.: lignin, starch, natural resins, wax and cellulose), Arbofill - biopolymeric composite (polymers and natural fibres-based compound provided with natural cork aspect). "Liquid wood" granules can be processed like any other plastic materials by different procedures, i.e. injection moulding, extrusion, calendering, blow molding, deep drawing or pressing into moulded parts, semi-finished products, sheets, films or profiles.
The goal of this paper is to present some aspects of research concerning the water jet technologies of plastic materials referring at "liquid wood" manufacturing. Water jet technology is a method able to cut a wide variety of materials and shapes using a very high-pressure jet of water. This technology use two basic methods: with water jet or a mixture of water and an abrasive substance. The experimental planning used Taguchi methodology in order to manufacture parts from "liquid wood". For this research six input parameters will be utilized: water flow, pressure, part thickness, angle inclination of jet, velocity movement of injection head and abrasive granulation. Each factor had two variation levels.
This method, water jet and abrasive jet, is used in various industries for cutting, shaping, and reaming metallic and nonmetallic materials.

Key words: water jet, abrasive jet, plastic materials, liquid wood, manufacturing.

1. INTRODUCTION

The plastics materials fall into the category of most important materials for the industry and for our consumer society because of their many forms in which it may be processed and also because the low costs of manufacturing. With a major impact on our daily life, renewable resources and their modifications are involved in a variety of important processes, [1]. It is well known that the extensive use of plastic materials (non-biodegradable materials) has a negative impact on the environment because of the sources from which plastic is derived - the fossil resources. Green composite made of natural fibers such as agricultural residues, kenaf, hemp, wood and bioplastics provide a sustainable and environmentally friendly alternative to synthetic materials, composites, reinforced fiberglass and are 100% biodegradable. The use of bioplastics and biocomposites contributes to fostering and restoring the ecological balance, and is tending, in the near future, to become a healthier alternative for our planet to petroleum-based plastics, [2].
The viable solution to solve the environmental pollution is bioplastics, which are biodegradable materials obtained from renewable raw materials, of a degradable polymer type, originating from agricultural resources. Bioplastics started to be recognized as a positive and important invention of chemical industry and plastics, offering numerous and varied opportunities. The new category of bio-plastics and plastic biodegradables are of a real interest in almost all sections of society and industry, [3].
Plastic processing aims at turning them into semi-finished or finished parts. Processing itself is preceded by mixing and homogenizing the resin with other constituents and shall be carried out in blenders or mixers. The choice of the processing technology depends on the nature of the plastic material (heat-reactive, thermoplastic), the status of raw materials (dry, viscous or smooth) and the shape of the finished

products (sheets, tubes, bars or parts). As a result the plastic materials can be processed through pressing, casting under pressure (injection), extrusion, calendaring systems, drawing, expansion, welding, soldering and by mechanical processes, [4].

As a result of the need for urgent development of biodegradable materials, researchers of the academic and industrial environments engaged in solving this problem. Fraunhofer Institute for Chemical Technology ICT, Pfinztal and the Tecnaro Company, Germany, meet this problem by developing a new material, namely "liquid wood ", which is to be the fundamental raw material in the future.

This new material is available in three different versions: Arboform based on lignin, organic additives and natural fibers, of 100 % renewable raw materials and is completely biodegradable; Arboblend - a composite biopolymer whose content is based on biopolymers such as: lignin, starch, natural resins, wax and cellulose and Arbofill composed of polymers and natural fibers [5]. Figure 2 presents some "liquid wood" products.

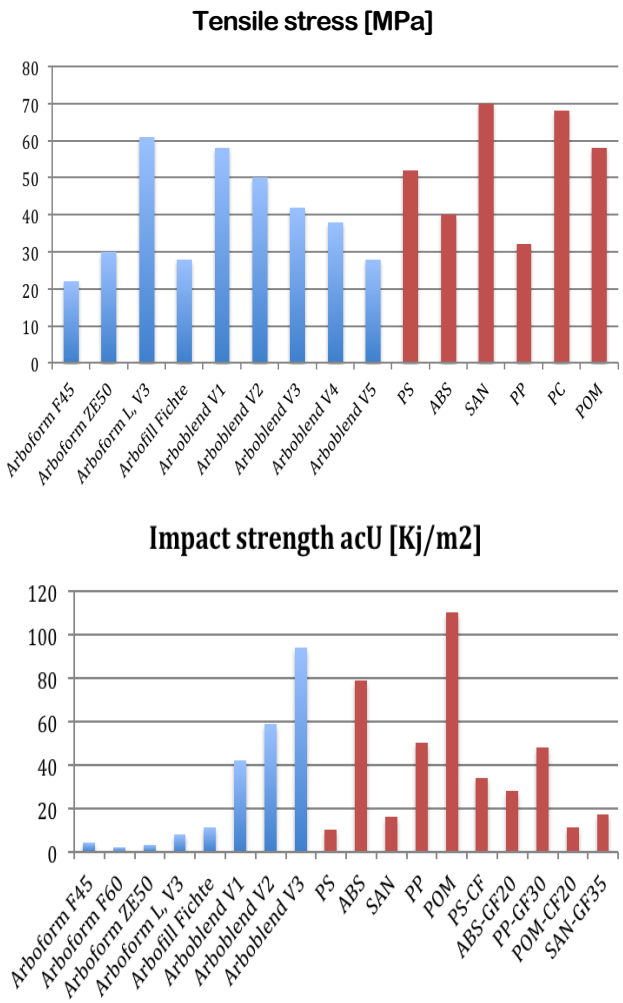


Fig. 1. "Liquid wood" vs. conventional plastic, [5]: ABS = Acrylonitrile butadiene styrene; SAN = Styrene-acrylonitrile resin; PP = Polypropylene; PC = Polycarbonate; POM = Polyoxymethylene

a b c

Fig. 2. Various products made from the three versions of "liquid wood" [5]: a - Arboform, audio enclosures; b - Arbofill, consumer goods; c - Arboblend, packaging items

The matrix of the liquid timber contains more than 50% lignin, plus wood fiber wax, flax, and chemical additives.

Due to its outstanding properties similar to the plastics and especially due to the fact that it is environmentally friendly, the liquid wood will become in the future an real alternative to all plastic products that are currently existing. Toys, cases, bottles, food dishes of any shape, watches, keyboards, brushes and helmets, furniture and even car bodies will be produced. As one of the newest environmentally friendly material, it presents a very important property – i.e. it can be reused several times without destroying its properties.

Even if the price of liquid wood is greater than that of the polypropylene one can say that in a short period of time it will become the most sought for material because of its capacity of not polluting the environment, as it is a biodegradable material. Although it is heavier than plastic which is present in almost all the products sold worldwide, it has the advantage of a 100% natural product, without the side effects against human health, [6].

The grains of liquid wood can be processed using the same equipment used in the manufacturing of plastic. The grains are placed in a tank and heated until melted, and then the content is poured into a mold and subjected to extreme pressures. Once cooled, it behaves much better than plastic, being tougher but at the same time more flexible and shock resistant, [7].

Thus "liquid wood" can be processed as any other plastic material by various processes, namely: injection molding, extrusion, calendaring systems, blowing, press in molded parts, semi-finished products, sheets, or profiles, using the same equipment, not needing additional costs, at the same time it can successfully replace plastic materials due to its versatility and ability to be used in many areas.

2. WATER JET PROCESSING METHODS AND TECHNOLOGIES

At present, the cutting methods and devices used along the years in the industry are beginning to lose

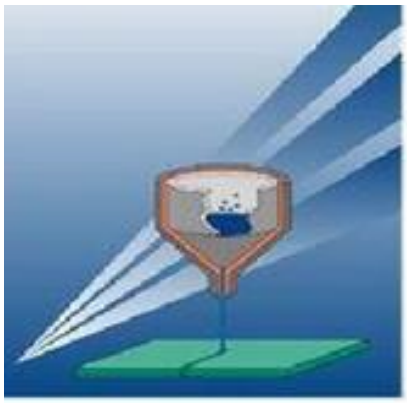
their ground thanks to the development and the moving forward of the materials used, and as such, the machines used for their processing needed an upgrade or an innovation.
Traditional (conventional) methods of molding and cutting proved to consume more and more time; they have become difficult but especially expensive, failing to satisfy production. The necessity of efficient, fast, affordable and reliable processing witnessed the birth of water jet cutting, [8].
Abrasive water jet cutting is one of the newest unconventional technologies in material processing. For the first time the water jet was used on exploitation of coal, in Russia and New Zealand. In 1979 Dr. Mohamed Hashish invented cutting with abrasive water jet by adding abrasive material to the water jet, in 1980 he used the abrasive water jet cutting machine to cut glass, steel, concrete, [9].
Cutting with a jet of water means cutting a wide variety of materials with the help of a very high pressure of water. Basically the method presents two versions: with a jet of water (the power of erosion of a high-speed water jet is used) and with a hydro abrasive jet (water jet is mixed with abrasive additives, thereby substantially increasing the erosion power).

2.1 Processing with water jet without abrasives

This process is suitable for processing the following materials: textiles, elastomer, fiber, plastic, food, paper, and other. Normal water pressure is 6500bar, at a speed of approximately (800-1000)m/s, the water being forced to pass through a small hole (a diameter of one-tenth of a millimeter) made from a precious stone to form a strong chipping jet. Therefore potential energy W will be converted into kinetic energy, and the water will become so fast that it can cut any type of material (figure 3). Also in the figure 3 are presented materials that can be processed and the thickness that can be cut using this process.

2.2 Processing with abrasive materials

For the materials that are not suitable for processing with a jet of pure water, abrasive material is used. In this process, an agent composed of fine particles is added to the water. The combination of water, air and abrasive material is done in a mixing chamber to accelerate the process. The result is a powerful shot, which can cut, separate or drill materials of different thicknesses and densities, like metals, natural stones or safety glass, plastics, and more. The principle diagram for processing with a jet of water with abrasives is shown in figure 4 and in figure 5 we have a detail of the actual equipment. The main parts of a water and abrasive jet cutting equipment are, [10], (figure 6): hydraulic pump driven by an electric engine or an internal combustion engine; hydraulic amplifier raises water pressure delivered by the hydraulic pump (2000-4000) bar; the connecting pipes which may be rigid or flexible; the cutting head with a jet of water and abrasive composed of the mixing chamber, the nozzle and the abrasive supplying system.



Processed material	Thickness of material catting at the pressure of 4000 bar [mm]
Rubber	over 80mm
Textiles	over 30mm
Leather	over 30mm
Wood	over 35mm
Stratified plastics	over 35mm

Fig. 3. Processing with a jet of pure water, [9]

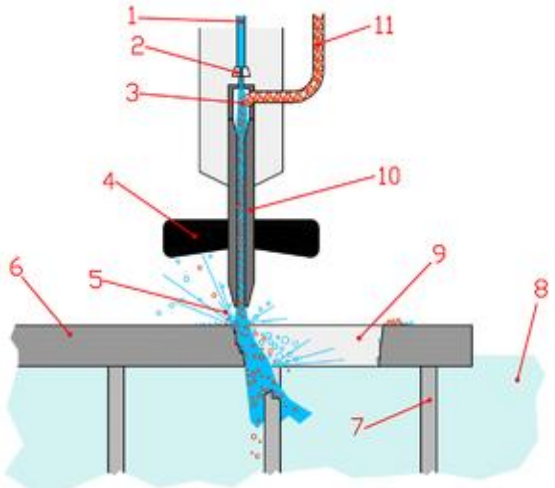
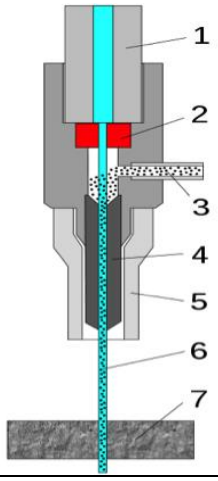


Fig. 4. Scheme of equipment for abrasive water jet cutting (injection): 1 - abrasive water jet; 2 - nozzle; 3 - mix room; 4 - shields; 5 - hydro abrasive jet; 6 - workpiece; 7 - lattice support for workpiece; 8 - water tank; 9 - piece cut; 10 - combination tube; 11 - abrasive particles

The following materials can be processed with this method (figure 7): metal: alloy steel and non-alloy steels, stainless steel, aluminum, brass, bronze, cobalt, copper, gold, alloys of nickel, silver, titanium,



Processed material	Thickness of material cutting at the pressure of:	
	4000 bar [mm]	6000 bar [mm]
Stainless steel	Over 180 mm	Over 300 mm
Steel	Over 180 mm	Over 300 mm
Titanium	Over 250 mm	Over 350 mm
Aluminum	Over 300 mm	Over 400 mm
Wood	Over 300 mm	Unknown

Fig. 5. Detail of the actual equipment and the processed materials scheme, [8, 9]: 1 - the high-pressure valve for water supply; 2 - Ruby or diamond; 3 - abrasive material (garnet);4 - mixing pipe; 5 - conducting wall; 6 - abrasive jet (water abrasive suspensions); 7 – work piece

wrought iron, zinc, etc.; plastic materials: PVC, polypropylene, polyethylene, polystyrene, teflon, thermoplastics, polycarbonate, plexiglas, ABS, etc.; glass, ceramics (floor tiles, stoneware tiles, porcelain); stone: granite, marble, travertine, limestone, onyx, etc.; other materials: carbon fiber, cardboard, concrete, glass fiber, foam, graphite, kevlar, linoleum, rubber, silicone, wood, tego, nylon, leather, composite materials.

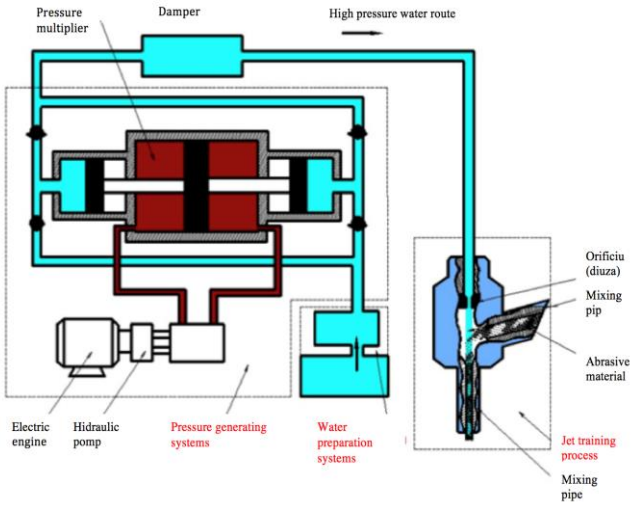


Fig. 6. The design of the abrasive water jet cutting machine, [10]

The technology is widely used in the aviation industry, automotive, construction etc., being used with high accuracy and minimal loss of material in about any application, [11].

For the purposes of experimental research we will use the water jet cutting machine Maxiem Waterjets of the company Self Trust LTD from Iasi (figure 8). The benefits of cutting the parts with a jet of water are: the hydro jet can easily cut a wide range of materials and thicknesses (metal, plastics, ceramic, marble, glass, etc.); a cutting machine with a jet of water performs the work of four other machines in less time. Cutting machines with a jet of water were designed for cutting of a higher quality, being faster and easier to use; the possibility of manufacturing any contour on a single machine to a surface quality that meets any requirement. Ideal for complicated filigree contours; the water jet does not affect the heat and does not distort the processed material. It does not produce heat during the processing, because it is used water and a mild abrasive (in the case of tougher materials), the material is not significantly heated during the cutting process.

This causes the system of cutting with a jet of water to be ideal for materials which are affected or deformed by heat; the process does not use toxic gases, liquids or oils to blotch, affect or discolor the cut surfaces of material; the cutting quality can be adjusted so that the resulted part does not require operations for correction (high precision); the software used for operating the machine allows optimizing of marks in such a way that the amount of residue resulting from processing is kept to a minimum; the cutting table dimensions are 3200 x 1650 mm; it is ecological, protects the environment, and does not produce toxic vapors during processing.

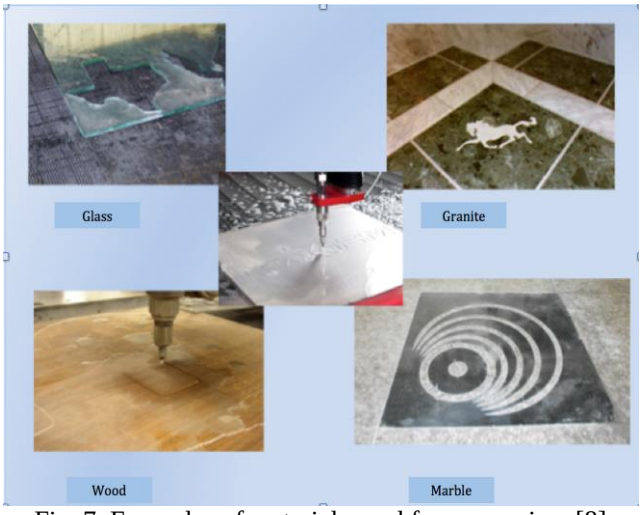


Fig. 7. Examples of materials used for processing, [8]

This technology also has some disadvantages and we can list the following aspects: the operating life of nozzles is relatively short; continued forming of

waves of water; noise pollution; frequent need for refitting; high costs of technology and processing [11, 12]. The machine shown in figure 8, allows the following parameters to fluctuate: shape of nozzle, pressure, the inclination of water jet, the distance from the piece to the nozzle head and the speed of travel of the nozzle head.

Fig. 8. The Maxiem Waterjets
water jet-cutting machine, [12]

In order to ensure the cutting accuracy one should take into consideration the dependence between gap and crater (figure 9).

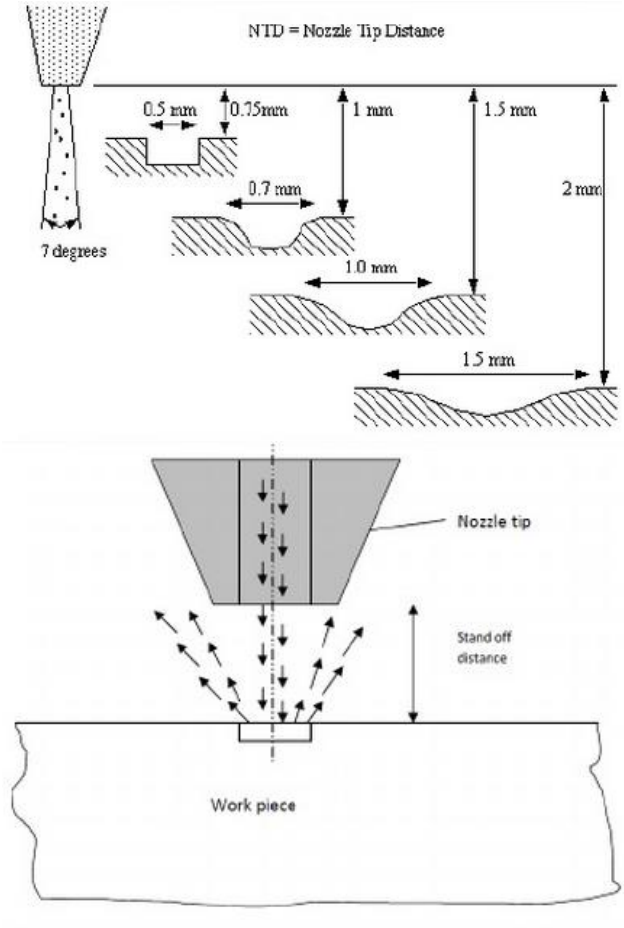


Fig. 9. The gap-crater dependency

Thus, this figure shows the crater size variation diagram according to the distance from which the abrasive water jet is pumped. The tolerance depending on the thickness of the processed mark is as follows: at a thickness between (0.5 -12)mm the tolerance is +/- 0.25mm; at a thickness of (12-50)mm the tolerance is +/- 0.50mm; if the thickness of the processed material is between (50-76)mm then the tolerance is +/- 1mm and in situations when the thickness of the material is greater than 76 mm the tolerance is 2mm.

3. CONCLUSIONS

Conclusions given the fact that the material removal is generated by the erosive action of high-pressure water (with or without abrasive particles) on the material to be processed, cutting with a jet of water is a non-conventional process of cutting. From multilayer flat glass to metals of high toughness or marble or granite, cutting with jet of water can be used in almost any application. The semi-products can be accurately cut due to the machine's performance. And because cutting with a jet of water does not cause vibrations, it does not produce heat and does not leave sharp edges, further processing and secondary post-processing are not necessary unless required. In addition, both the machine's ability to perform accurate precise cuts and the speed with which this process is carried out, optimize the execution timeframe. In the wake of the cutting process there can be obtained surfaces of a very tough quality or extremely fine depending on: the thickness of the cut work piece, the quality of the material, the applied pressure, the mixture water – applied abrasive, the quality - quantity and size of abrasive particles, cutting speed. In our workshops we use three different travel speeds, as a result we obtain three different basic qualities: basic, good and fine. The cut surface is usually sharp, indented and often harsh (due to the alternating movement of the high-pressure pump). By reducing the speed of cut, the increasing of the quantity of abrasive material in composition, it can considerably be refined the roughness of the surface, so it is possible to obtain features comparable to those of laser cut surfaces. The travel speed when cutting may oscillate in the range of 1 mm/minute up to 20m/minute. The thicknesses of material that can be cut, depending on the quality of material, are located within a very wide range (in the case of steels even exceed 150mm). The resulted slot is located within the range of (0.3–1.6)mm, which means a small loss of material after the cutting. The equipment of processing with a jet of water incorporates in a compact assembly the high pressure pump, the

cutting table, the regulating and control system (CNC), the power unit, the cutting nozzle, the collimation/mixing tube, the feeding with abrasive material unit and the noise absorption equipment. The high-pressure pumps, using the latest technologies can reach a maximum level of pressure of 6000bar. The high-pressure water jet is pumped towards the nozzle through a flexible metal pipe of (5-8)mm in diameter and thickness (1-2)mm. Through a very small notch of focusing nozzle, an extremely high travel speed of water is obtained. At the moment of impact with the surface of the work piece, the water jet can reach a speed of 3600kmh. Generally the operating desk has digital program control, usually with portal system, designed to meet the specific requirements of the hydro-abrasive cut. The working area is divided into separate segments by detachable grids. Using the CNC desk certain stages of work may be scheduled next on the machine. Depending on the quality and thickness of material and using the high performance cutting software, the cutting parameters and the necessary optimal timeframe can be determined.

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