

Research on Application of Technology Using Water Jet on Machining of Polymeric Composite Biological-Reinforced Materials

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The paper deals with a machining of polymeric composite materials reinforced with fibres from hemp, false banana (*Ensete ventricosum*) and microparticles from *Jatropha Curcas* L. seedcakes by means of a technology using a water jet (abrasive water jet AWJ, water jet WJ). A matrix of the composite material is from a structural resin used for a production of sport equipment which shows good mechanical properties, but is it very brittle and it comes to its destruction during machining. Therefore, the water jet technology was used for the research. The research was focused on the evaluation of an influence of a velocity of a cutting head movement on a kerf width inlet and outlet the composite board by means of an optical analysis and on a connected quality of the cut. The composite material based on the biological reinforcement was cut by CNS cutting machine AWJ CT 0806 at a different velocity of the cutting head movement (traverse speed), i.e. 50, 250, 750 and 1000 mm/min. The research results proved a significant difference between the technologies AWJ and WJ and also among the velocities of the cutting head movement. The cut was inhomogeneous under unsuitable conditions and it came to a significant destruction of a surface outlet of the water jet.

Keywords: abrasive water jet, cut quality, false banana, hemp, *jatropha curcas* L., water jet

1 Introduction

New advanced materials are a source of innovations for new products and services. Ceramics, composites, polymers and metals belong among these materials [1]. Materials have to be machined according to specific requirements coming from other production processes. This issue was dealt with on different materials by many researchers who optimized the machining process [2, 3, 4, 5, 6]. However, namely non-metal materials have been still developed with a used of ceramics, composites and polymers in different branches [1]. This trend of increasing use of non-metal materials is reflected in the research in the area of the production.

Composites with the polymeric matrix have been more often used, however, there is a great number of problems connected with their other processing, i.e. e.g. with cutting [7, 8]. Many research studies deal with a primary evaluation of mechanical properties depending on the reinforcing phase and the matrix. At the present, composite materials which use a potential of a biological reinforcement belong among prospective materials [7, 9, 10]. The composite materials are of relatively high purchase price, but they are very popular nowadays [9, 11]. There are namely heterogeneous materials which consist of a reinforcing phase (fibres, particles) connected with a matrix which is usually soft and brittle [10, 11]. It is obvious from above mentioned that it is not suitable to use classical machining methods as at e.g. homogeneous materials, but it is necessary to search for other prospective machining methods. AWJ machining process is well-established unconventional machining process for cutting a wide range of heterogeneous materials including the composites [8, 12]. Many researches proved an efficiency of the water jet technology use at the composites machining [7, 12]. The abrasive water jet technology proved its positives in many production branches, however, it is not still

enough information in the area of the composite materials machining [11]. Alberdi et al. draw attention that it is necessary to develop a methodology for an adaptation of cutting process parameters for each type of the composite material which enables the machining operations to be effective [11].

Hejjaji et al. refer to cutting of epoxies reinforced with fibres by means of AWJ in their paper and they explain that the cutting mechanism depends on a micro-mechanism of cutting which is evident by a presence of broken fibres or fibres pullout over the entire cutting front [12]. When using AWJ technology, the abrasive particles can negatively affect an interaction between the matrix and the reinforcement at the acting of a high-speed liquid with the abrasive on a surface of a workpiece at various velocities of cutting head movements [13, 14, 15].

This research deals with processing of polymeric composite materials with biological reinforcements on a base of the experimental testing of the optimization at the cutting process by AWJ and WJ. The surface quality was used for the optimization of the cutting process by the water jet technology of the composite materials based on the optical analysis.

2 Material and Methods

The paper deals with machining of polymeric composite materials reinforced with fibres from hemp, false banana (*Ensete ventricosum*) and microparticles from *Jatropha Curcas* L. seedcakes by means of the technology using the water jet (abrasive water jet AWJ – abrasive grains garnet MESH 80 - mechanical dosing device Bimba Flat 1, 340 ± 15 g/min, water jet WJ) at the different velocities of the cutting head movement (a traverse speed). The kerf width inlet and outlet was measured by means of the microscopical investigation on which a conicity of a cutting gap was subsequently determined.

The composite materials were made by means of a

vacuum infusion. Boards of dimensions 220 x 130 x 4 mm were made. A two-component epoxy resin LH 288 Havel Composites with a low viscosity suitable for a laminating technology including the vacuum infusion was used as the matrix. The resin was hardened with cycloaliphatic polyamine, the main component isophorone diamine. The reinforcing phase was dried at the temperature 105 °C for the time 24 h and subsequently it was used at the production of the composite material with the matrix.

The composite material with the biological reinforcement was cut by CNC cutting machine AWJ CT 0806 at the different velocity of the cutting head movement (traverse speed), i.e. 50, 250, 750 and 1000 mm/min (fig. 1 A). The working pressure was 380 MPa. A distance of the nozzle above the cut material was 3 mm. The diameter of the nozzle was 0.8 mm. An angle of the nozzle tilt to the composite material was 90°.

Two types of the cuts were performed on the test board from the composite material. The cut marked A was

oriented perpendicular to a longitudinal orientation of fibres at the composites reinforced with fibres (fig. 1 B). The cut B was performed parallel to the orientation of the fibres (fig. 1 B). The cut length was 60 mm.

The kerf measuring was performed inlet and outlet the water jet. The kerf width values were measured with a stereoscopic microscope Zeiss Stemi 508 with a cam AxioCam and evaluated by software (fig. 1 C). The measuring was performed 10 mm from water jet inlet to the composite material and it was finished 10 mm before the end of the cut. 30 values were measured. The measuring results were statistically tested according to ANOVA F-test.

The kerf taper angle of the composite material cut was calculated according to the equation 1. The tested material thickness t was constant for all three tested composite boards [11].

$$T = \arctan\left(\frac{\text{Kerf width}_{\text{Inlet}} - \text{Kerf width}_{\text{Outlet}}}{2.t}\right) \quad (1)$$

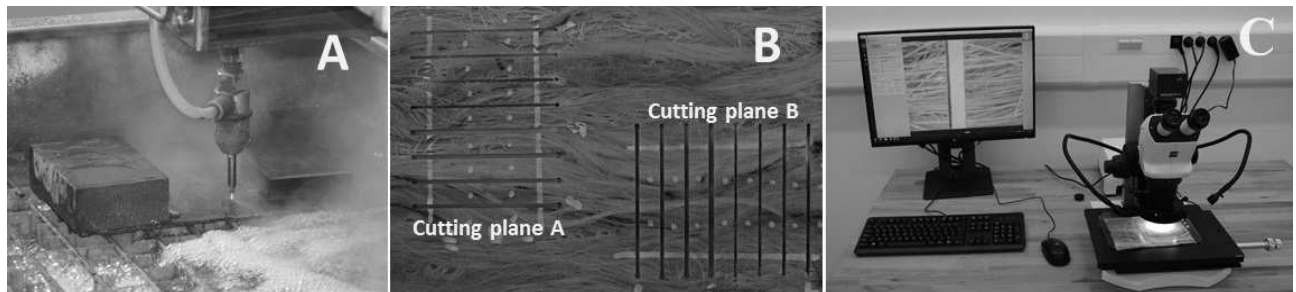


Fig. 1 Process of machining and evaluating of polymeric composite biological-reinforced materials: A: cutting of composite board by means of CNC AWJ CT 0806, B: tested material with created cuts in plane A and B by means of AWJ and WJ technology - inlet of water jet, C: evaluation of kerf width inlet and outlet by means of stereoscopic microscope Zeiss Stemi 508

3 Results and discussion

Results of the research on polymeric material machining, i.e. determining of the kerf width inlet and outlet the water jet are visible in fig. 2 for the composite with the reinforcing phase from false banana fibres (*Ensete ventricosum*), in fig. 3 for the composite with the reinforcing phase from *Jatropha Curcas* L. microparticles and in fig. 4 for the composite with reinforcing phase from technical hemp fibres.

It is obvious from the statistical comparison of the traverse speeds that the kerf widths inlet and outlet are statistically inhomogeneous groups ($p = 0.0000$ to 0.0007). So, there is the difference in the kerf width depending on the traverse speed, at both AWJ and WJ.

The optimum cut at the traverse speed 1000 mm/min at the technology AWJ in the plane A is visible in fig. 5 A, in the plane B in fig. 5 B. The difference between AWJ and WJ at the cut in the plane B at the same traverse speed is obvious from fig. 5 C. The presumption was also certified at the cutting of the composite materials with the biological reinforcement that the increase of the cutting effect is possible by adding the abrasive particles [16].

The experiment results proved that the kerf width is higher at AWJ technology (at the use of abrasive MESH

80) than at WJ, i.e. the water jet without the abrasive. This conclusion is valid for the cuts which were performed without a significant failure outlet the water jet from the composite material. A significant destruction in the bottom part of the cut occurred at the use of WJ technology and higher traverse speeds (namely 1000 mm/min) which is visible in fig. 6.

It is possible to agree with the results of Alberdi et al. who state that machining of different composite materials is very different so it is necessary to study them separately [11]. The results of measurements comparing AWJ and WJ technologies at three composite materials with different biological reinforcements (the same thickness of the cut material) certified these conclusions although the matrix was identical. This conclusion is very essential for the practical application and clearly shows a necessity of optimum cutting conditions testing at the change of the matrix, occasionally the fibres orientation.

Hejjaji et al. state in their research that the influence of machining parameters (jet traverse speed, jet pressure, scan step and stand-off distance) on the surface quality and damage is demonstrated [12]. The research results proved a quiddity of the traverse speed (the velocity of the cutting head movement) at both AWJ and WJ.

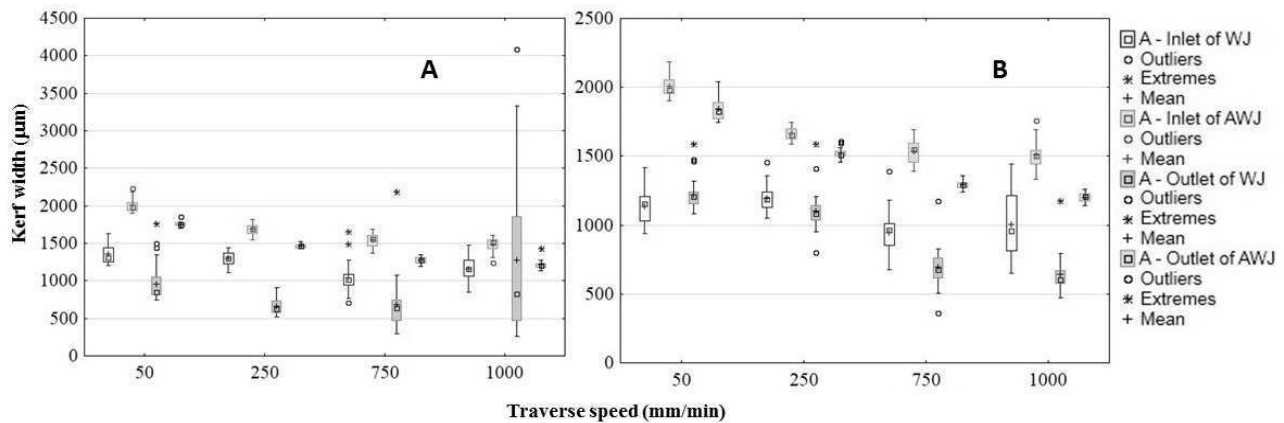


Fig. 2 Kerf width of cut by WJ and AWJ technology of polymeric composite material with reinforcing phase in form of natural false banana fibres (*Ensete ventricosum*): A: cut in plane A, B: cut in plane B

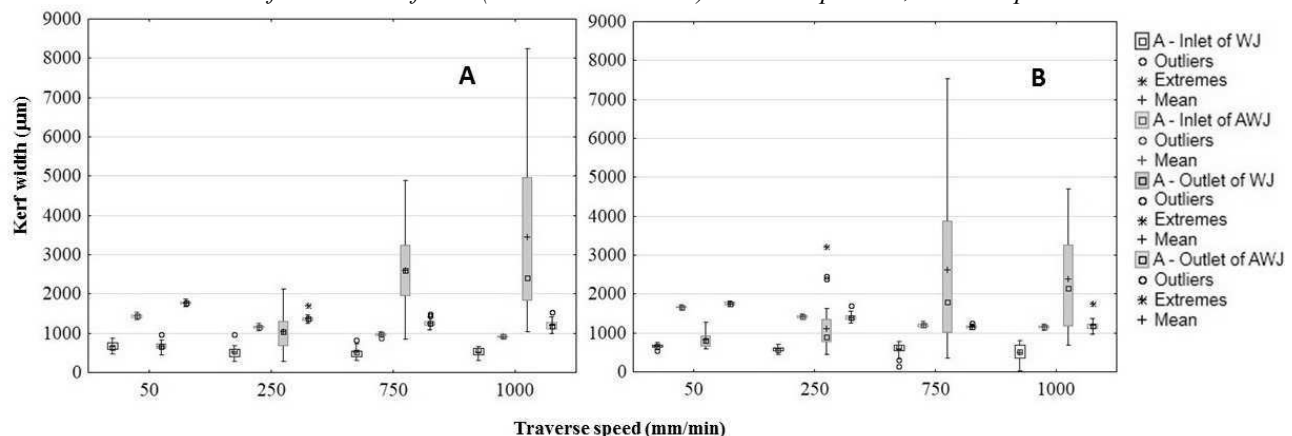


Fig. 3 Kerf width of cut by WJ and AWJ technology of polymeric composite material with reinforcing phase from *Jatropa Curcas L.* microparticles: A: cut in plane A, B: cut in plane B

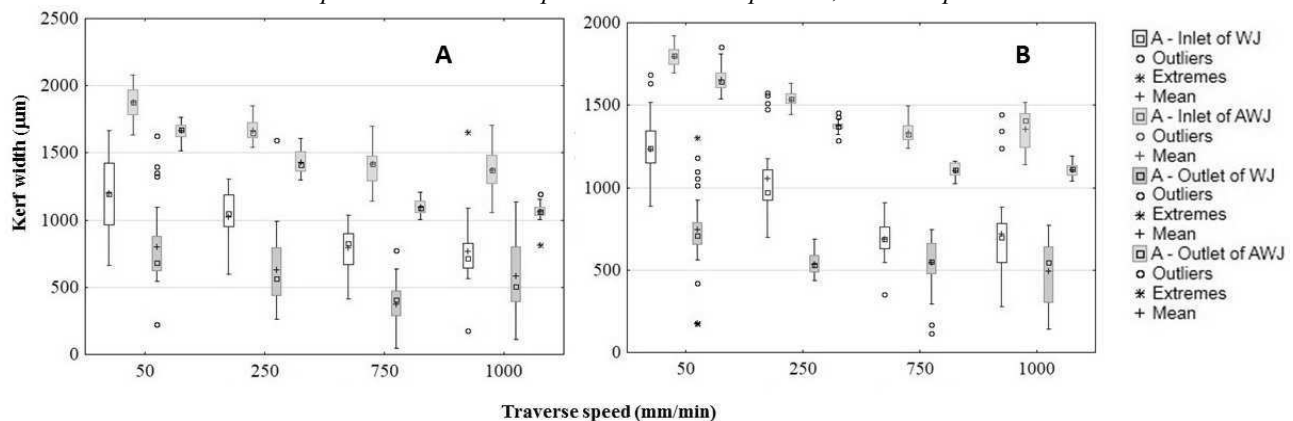


Fig. 4 Kerf width of cut by WJ and AWJ technology of polymeric composite material with reinforcing phase from natural fibres of technical hemp: A: cut in plane A, B: cut in plane B

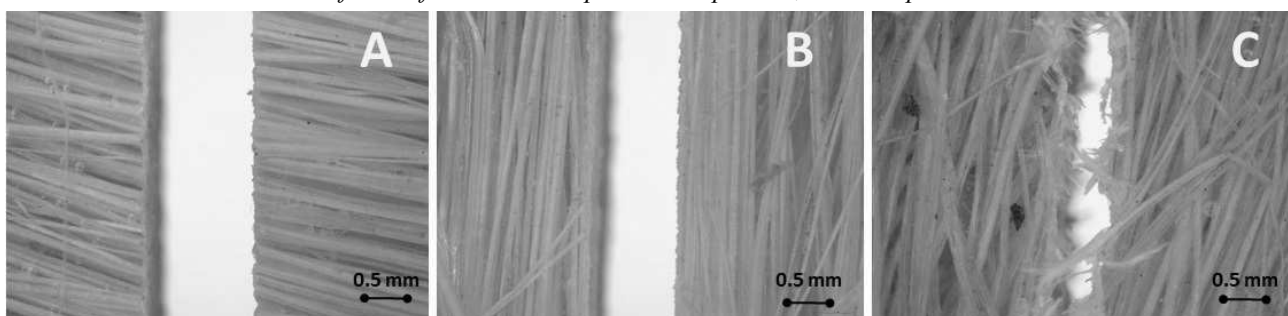


Fig. 5 Cut through composite material with reinforcing phase from natural false banana fibres (*Ensete ventricosum*) at traverse speed 1000 mm/min: A: cut in plane A with use of AWJ technology, B: cut in plane B with use of AWJ technology, C: cut in plane B with use of WJ technology

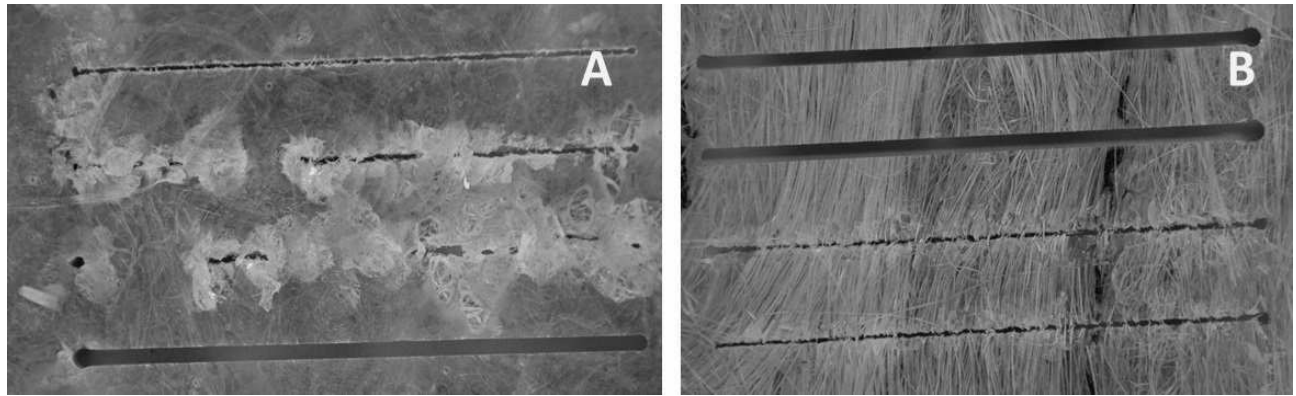


Fig. 6 Comparison of optimum cut and cut from significant deformation of composite material outlet water jet from material: A cut through composite material with reinforcing phase in form of technical hemp, B: cut through composite material with reinforcing phase in form of natural false banana fibres (*Ensete ventricosum*)

Results of the taper angle measuring are visible in tab. 1. Alberdi et al. proved that the taper angle depended on the thickness of cut material and the velocity of the cutting head movement [11]. The research results proved a quiddity of the influence of the reinforcing phase, e.g. the

kerf width is increasing outlet at cutting of the polymeric composite material reinforcing with *Jatropha Curcas* L. microparticles, i.e. the taper angle is negative. The taper angle is more uniform at various traverse speeds at the use of AWJ technology compared to WJ.

Tab. 1 Taper angle of cut through composite materials (PCFBF-EV – polymeric composite material reinforced with natural fibres of false banana (*Ensete ventricosum*), PCFTK – polymeric composite material reinforced with technical hemp fibres, PCFJCL – polymeric composite material reinforced with *Jatropha Curcas* L. microparticles)

| Traverse speed (mm/min) | | 50 | 250 | 750 | 1000 |
|-------------------------|---------------------------|-------|-------|--------|--------|
| AWJ | | | | | |
| PCFBF-EV | Plane A – taper angle (°) | 1.80 | 1.56 | 1.97 | 1.97 |
| | Plane B – taper angle (°) | 1.17 | 1.04 | 1.75 | 2.19 |
| PCFTK | Plane A – taper angle (°) | 1.51 | 1.67 | 2.31 | 2.22 |
| | Plane B – taper angle (°) | 1.02 | 1.16 | 1.63 | 1.80 |
| PCFJCL | Plane A – taper angle (°) | -2.41 | -1.59 | -2.04 | -2.07 |
| | Plane B – taper angle (°) | -0.65 | 0.13 | 0.29 | -0.30 |
| WJ | | | | | |
| PCFBF-EV | Plane A – taper angle (°) | 2.83 | 4.56 | 2.60 | -0.80 |
| | Plane B – taper angle (°) | -0.64 | 0.63 | 1.80 | 2.60 |
| PCFTK | Plane A – taper angle (°) | 2.90 | 2.81 | 2.93 | 1.32 |
| | Plane B – taper angle (°) | 3.49 | 3.68 | 1.02 | 1.61 |
| PCFJCL | Plane A – taper angle (°) | 0.02 | -3.56 | -14.59 | -20.10 |
| | Plane B – taper angle (°) | -1.17 | -3.82 | -14.22 | -13.38 |

The kerf width outlet is smaller than inlet. It is obvious that the jet loses its kinetic energy, i.e. it cannot additionally remove the material in the bottom part of the cut which leads to the narrow kerf outlet [8]. This is related to the resultant taper angle.

Wang states that the taper angle is slightly increasing with increasing traverse speed. The negative effect of the traverse speed on both sides of the kerf width is that smaller volume of abrasive acts at AWJ by faster motion [8].

The nearly stabilised kerf taper is the result of the comparable rate of decreasing for the top and bottom kerf widths [8]. It is possible to say that the cut is more uniform in the whole cross section at the minimum angle.

The research certified conclusions of Wang that the quality cuts of the polymeric composite materials can be effectively prepared by AWJ technology [17]. These conclusions at cutting various polymeric composites were proved not only at AWJ but also at WJ. However, it is

necessary to choose optimum traverse speed

4 Conclusions

The results present data ascertained by the experimental evaluation of machined polymeric composite materials by AWJ and WJ technologies. The experiment results proved that the machining of the composite materials with the polymeric matrix and different biological reinforcements by AWJ and WJ technologies is efficient method for processing of these composite materials.

The experiment results proved the quiddity of the combination of AWJ, WJ and the traverse speed. It was proved at the cutting of the polymeric composite materials that the traverse speed is of smaller influence on the kerf width inlet and outlet at AWJ technology. The significant destruction of the composite material occurred in the outlet side at higher traverse speeds (namely 750 and 1000 mm/in).

This is the undesirable factor for following application of these polymeric composite materials in the practice. They will be used as a design element which is applied on a basic material, e.g. chipboards in the furniture industry.

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