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THE APPLICATION OF THE FINITE ELEMENT METHOD TO SILMULATION OF THE ABRASIVE WATERJET MACHINING

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ABSTRACT
The article presents the abrasive waterjet machining model, which permits to prognosis the erosion depth of workpiece using the finite element method. The main goal of the research showed in that article was building a FE model, which simulate AWJ process with the observation of complex erosion process. It would permit effective increasing of the AWJ process by faster setting of cutting parameters without experimental research. During analysis using the finite element method also permits to trace a damage of workpiece in the cutting zone. The FE model enriches the mathematical model, which permits to prognosis the cutting depth. The mathematical model decreases significantly time of experimental research. On the basis only few experimental tests of the complex material cutting by using the AWJM can determine the depth of cutting for wider range parameters i.e. abrasive flow rate, feed rate and pressure.
Keywords: AWJM, FE analysis, polymeric composite cutting

1. INTRODUCTION
The abrasive waterjet machining has got the application during the shaping of workpiece by the jet-erosion method. Next to the abrasive waterjet exist the wide gamut of non-convencional erosion method, for example laser, plasma. However due to the technology and quality problems very often first place aware the abrasive waterjet machining technology. The impacting force of cutting jet with abrasive admixture next to super-hard materials machining, excellent cutting materials for the great depth until 300 mm. Additionally, thanks to extra-technologies of cutterhead applies during the cutting in modern AWJ machine for example dynamic waterjet, 3D machining can achieve high quality of surface along of kerf depth.
At present, thanks to development computer matrix mechanics, are conducted modeling research of complicated machining process. The main of goal of this research is model building, which can simulate the entire machining process. Computer simulation permits to observe complex erosion phenomena, which can not observe during the cutting process. It could permit to adapt machining parameters with simultaneous diagnosis of damage workpiece and prognosis of cutting depth. Today it is very difficult to determine quality of machined surface before the cutting process. It is more difficult when it is necessary to determine quality of machined surface for more complex materials, for example inhomogeneous material or composite reinforced by fibres. First of all it concerning cracking and delamination, which is invisible afterwards machining and can be very dangerous in while them working i.e. propeller, fuselage of an airplane, spaceship. Because of that the modeling research is made to evaluate quality of product as early as the preparation of technology process.
This article shows the example of application the computer simulation of cutting machining to determine depth of cutting using AWJM method. In first part of research was showed the way of determination the failure material, erosion phenomena and delamination of composite reinforced fibres - workpiece. The next step of modeling research was define flow abrasive, which impact to

surface of workpiece. After that the analysis of the AWJM using the finite element method was carried out. Additionally, the mathematical model was made to full simulation of the impacting waterjet on surface workpiece. That AWJM model permitted to forecast the depth of cutting be the waterjet.

In the final effect were obtained concurrent results with experimental for determined range machining parameters during he abrasive waterjet machining.

2. FE ANALYSIS AND RESULTS

The model of impacting the flow abrasive on surface workpiece consists of two approach. In the first approach was modeled one abrasive particle, which impact on surface workpiece and in the next approach was built the mathematical model.

The conditions of cutting are dependent on AWJM parameters i.e. jet velocity, mass flow abrasive, tube diameter and shape of tube. Additionally to the FE model is dependent on abrasive mixing coefficient which decide about initial conditions of the AWJM model. It can be noticed that all mentioned parameters influence on abrasive mixing coefficient. Values of abrasive mixing coefficient is dependent on mentioned above parameters.

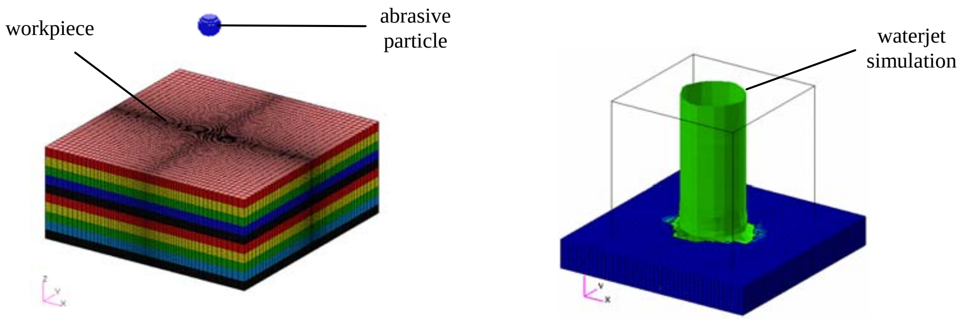


Figure 1. FE impacting of single abrasive particle model and FE simulation of waterjet cutting.

The FE analyses were carried out for various pressure of waterjet at constant abrasives mixing coefficient i.e. 0.65, 0.71, 0.78, 0.85. That approach allow to take into account a feature of the AWJM, which is increasing of mixing efficiency with the increasing of pressure. It must be noticed that the abrasive mixing coefficient is dependent on shape of mixing tube as well.

Below is showed the relationship of abrasive mixing coefficient according to Himmelreich and Hashish presented in article [1].

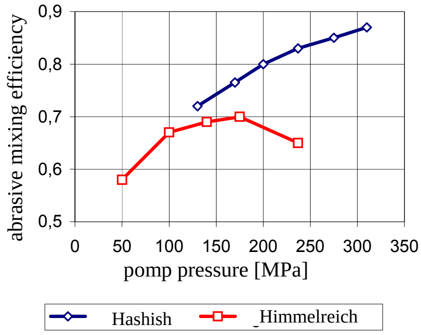


Figure 2. The relationship between pressure and abrasive mixing efficiency.

The according to suggestion of authors was assumed that the abrasive mixing coefficient is equal to between 0.65 ÷ 0.85. The additionally was assumed that for the pressure between 90 and 150 MPa, the abrasive mixing coefficient is equal to 0.65 ÷ 0.75 and for the pressure above 150 MPa, the abrasive mixing coefficient is equal to 0.75 ÷ 0.85.

The model AWJM was developed by using the mathematical model, which significantly extents the application of model. The mathematical model permits to including features of AWJM, which can not include to analysis using the finite element method.
The total erosion depth of workpiece was described using the mathematical equation. That equation takes into account the depth value of single abrasive particle h_{FEA}, which was calculated using the finite element method. That value was multiplied by number of all abrasive particles, which impacts on workpiece surface during the cutting process. Number of all abrasive particles are depended on flow abrasive value and time of impacting on surface of workpiece. That time of interaction is depended on feed rate of cutting.
The most important element of mathematical model is a coefficient, which works as a feedback. Work of coefficient relies on comparison two depth: penetration depth of single abrasive particle multiplied by all abrasive particles and real depth of penetration during the cutting process

$$e = n \cdot \frac{h_{mes}}{h} \qquad 1)$$

That coefficient is obtained by conducted only some cutting tests and depth of penetration measurements. The next step on the basis of some tests, the coefficient is approximated as exponential function.
Below are showed coefficient values for various feed rates i.e. 1000 mm/min, 2000 mm/min, 5000 mm/min, 8000 mm/min:

1. TSE material, pressure 160 MPa
   e_1 = 964.570; e_2 = 877.7586; e_3 = 585.1725; e_4 = 731.466
2. TSM material, pressure 160 MPa
   e_1 = 1925.173; e_2 = 1718.905; e_3 = 1604.311; e_4 = 1880.052

It must be noticed that on the basis of only some test, the mathematical model can prognoses a penetration depth for wider range feed rates with out realization experimental research.

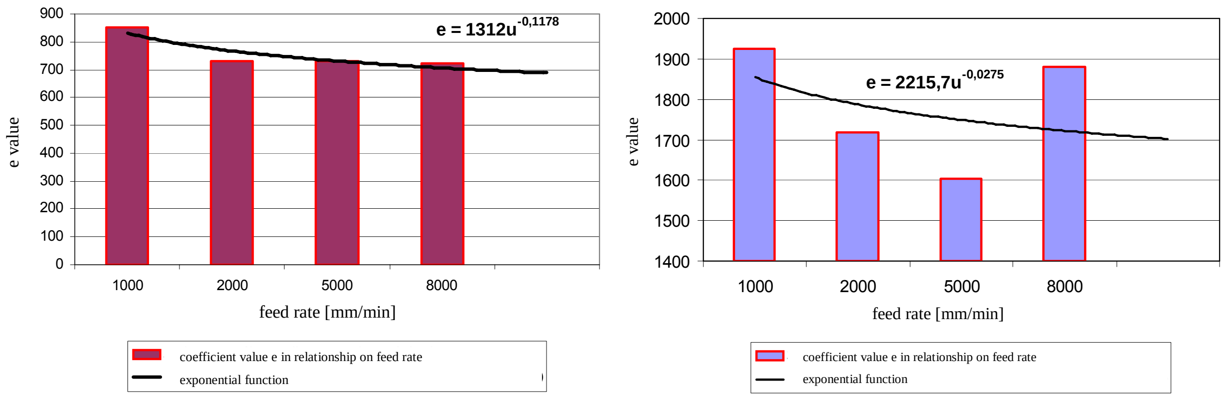
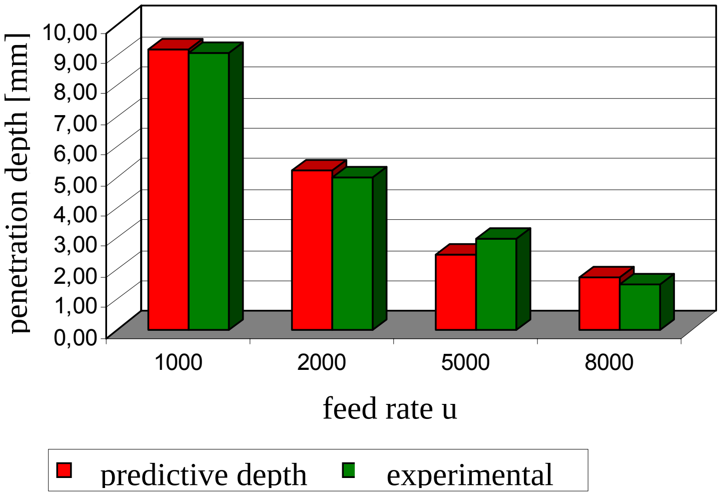


Figure 3. Determination of exponential function.

The predictive depth of abrasive waterjet penetration model is showed as a number of abrasive particles function:

$$h = \frac{1}{e} h_{mes}(n) \qquad 2)$$

Example of results on the basis FE analysis and mathematical model for TSE material are showed below.



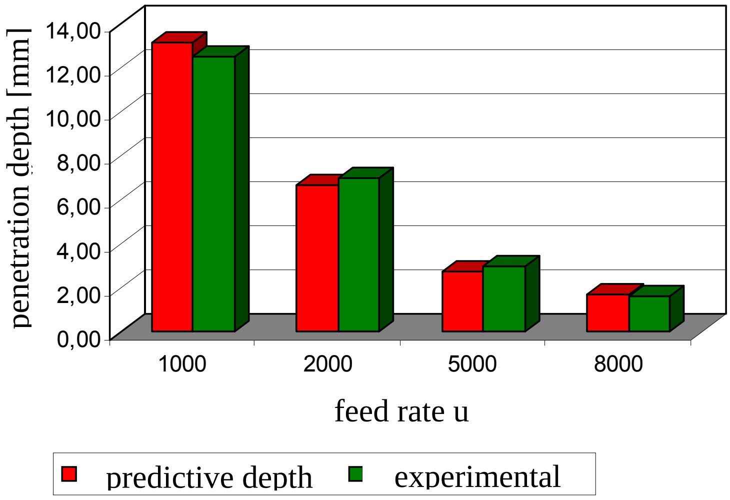


Figure 4. Comparision between predictive depth and experimental depth.

3. CONCLUSION

The predictive depth model does not take into account the friction between abrasive particles and the micro-cutting process. Mentioned interaction is dominant element at cutting process of workpiece, when impacting abrasive particles have got abrading properties on lateral surface of kerf.. Presented the FE model analyses only ballistic properties.

The cracking mechanism of workpiece in local of interaction abrasive waterjet and workpiece is resulted some phenomena. A pressure above 50 MPa at the interaction of abrasive waterjet should be considered as percussion pressure (effect of interaction percussion loading is deformation for the initial loading velocity is more than 0.416 m/s). Exerted percussion pressure by the abrasive particle causes propagation of impacting waves with acoustic velocity, which produces large stresses at micro-local and next it causes internal damage structure of machined material. Because of those type of external loadings, the stresses in workpiece very fast achieve critical values, which cause brittle cracking.

4. REFERENCES

[1] Momber A.W., Kovacevic R.: Principles of Abrasive Water Jet Machining. Springer=Verlag London Limited 1998.