ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

CORRELATION OF CUTTING DATA BY ABRASIVE WATER JET

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Abstract: New, difficult-to-machine materials and increased part complexity have resulted in the creation of new manufacturing processes, known as nontraditional manufacturing processes. Water jet cutting is one of the newest technique in non-traditional machining processes. This paper presents concrete use and advantages of the multiple factor experiment by modeling of cutting speed in abrasive water jet machining.

Keywords: nontraditional manufacturing processes, abrasive water jet cutting, mathematical modeling

1. INTRODUCTION

Abrasive water jet machining is unique process that is able to cut almost all materials cost effectively and is quickly becoming a new "standard tool" in machine shops around the world. The basic technology is both simple and extremely complex.

The use of the abrasive water jet for machining or finishing purposes is based on the principle of erosion of the material upon which the jet hits. Each of two components of the jet, i.e. the water and the abrasive material has both a separate purpose and a supportive purpose. It is the primary purpose of the abrasive material within the jet stream to provide the erosive forces. It is the primary purpose of the jet to deliver the abrasive material to the workpiece for the purpose of erosion. However the jet also accelerates the abrasive material to a speed such, that the impact and change in momentum of the abrasive material can perform its function. In addition it is an additional purpose of the water to carry both the abrasive material and the eroded material clear of the work area so that additional processing can be performed. In one way or another in any machining process the spent material must be gotten our of the way and the water jet provides that mechanism [1], [3].

2. ABRASIVE WATER JET CUTTING PROCESS

Abrasive water jet machining is appropriate and cost effect for a number of procedures and materials and are applied in nearly all areas of modern industry, such as automotive industry, aerospace industry, construction engineering, environmental technology, chemical process engineering, and industrial maintenance.

In the area of manufacturing, the water jet-technique is used for: material cutting, deburring by plain water jets, surface peening by plain water jets, conventional machining with water-jet assistance, cutting of difficult-to-machine materials by abrasive water jets, milling and 3-D-shaping by abrasive water jets, turning by abrasive water jets, piercing and drilling by abrasive water jets, polishing by abrasive water jets etc.

At its basic, water flows from a pump, through plumbing, and out of a cutting head. The energy required for cutting materials is obtained by pressurizing water to high pressures and then forming a high-intensity cutting stream by focusing this water through a small orifice.

The abrasive water jet differs from the pure water jet in just a few ways. In pure water jet, the supersonic stream erodes the material. In the abrasive water jet, the water jet stream accelerates abrasive particles and those particles, not the water, erode the material. The abrasive water jet is hundreds, if not thousands of times more powerful than a pure water jet. Both the water jet and the abrasive water jet have their place. Where the pure water jet cuts soft materials, the abrasive water jet cuts hard materials, such as metals, stone, composites and ceramics.

An abrasive water jet is a jet of water which contains abrasive material. Solid particles – the "abrasive" – join the water jet in mixing chamber (Fig. 1) and are focused by the abrasive nozzle. High pressure water enters the upper portion of the nozzle assembly and passes through a small-diameter orifice to form a narrow jet. The water jet then passes through a small chamber where a Venturi effect creates a slight vacuum that pulls abrasive material and air into this area through a feed tube. The abrasive particles are accelerated by the moving stream of water, and together they pass into a long, hollow cylindrical nozzle. The nozzle acts like a rifle barrel to accelerate the abrasive particles. The abrasive and water mixture exits the nozzle as a coherent stream and cuts the material. It's critical that the orifice and the nozzle be precisely aligned to ensure that the water jet passes directly down the center of the nozzle. Otherwise the quality of the abrasive water jet will be diffused, the quality of the cuts it produces will be poor, and the life of the nozzle will be short. In the past, most cutting head designs required the operator to adjust the alignment of the jewel and nozzle during operation. Modern cutting head designs rely on precisely machined components to align the orifice and nozzle during assembly, thereby eliminating the need for operator adjustments.

Nozzles are approximately 70 mm long, with inside diameters that can vary from about 0.8 mm to 1.2 mm. The normal standoff distance between the nozzle and the workpiece is usually between 0.25 mm and 2.5 mm.

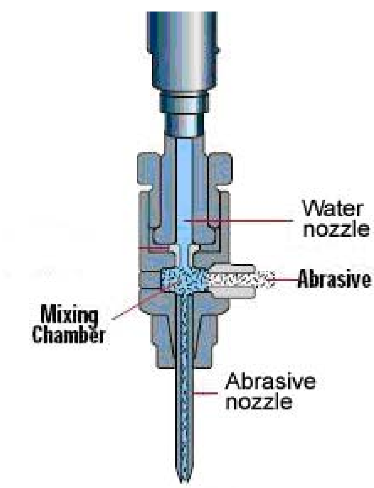

Figure 1. Abrasive water jet cutting head

3. INFLUENCING PARAMETERS OF ABRASIVE WATER JET CUTTING SPEED

Abrasive water jet cutting process depends on a large number of process parameters such as water pressure, orifice diameter, standoff distance, abrasive rate, cutting speed etc.

The key parameter that controls cutting speed is the water nozzle diameter. The other two parameters that greatly influence the cutting speed are the water pressure and the abrasive rate. Water pressure has a great influence on the cutting speed. Most in abrasive water jet cutting circles follow a simple rule: the higher the pressure, the higher the cutting speed, the lower the costs. Higher pressures result in faster cutting. To cut as fast as possible, the system should be operated using the maximum pump power available. The pump power is the determining factor in the water jet cutting. The most common pump size is the 37 kW pump powering one head. The order of popularity follows 75 kW, 18 kW, and 112 kW. Over 60% of all pumps produced today are of 37 kW or 75 kW.

The power in the abrasive jet at the exit of the nozzle is a function of pressure, flow and nozzle size. Power output is more sensitive to changes in nozzle diameter than pressure: doubling the nozzle diameter increases the jet power by a factor of 4, whereas doubling the pressure increases the power by a factor 2.8. In abrasive water jet cutting it is often thought that to reduce the abrasive rate saves money. There is a peak performance point that abrasive water jets operate. As abrasive rate is increased cut speed goes up and cost per meter goes down. Cut speed and cost per meter are both at their optimum. This fact is independent of the material of workpiece, or the power of the system. But, too much abrasive will clog in the mixing chamber. However, the optimum values of these parameters are not totally independent. The optimum abrasive rate can be related to the water rate. Orifice/nozzle size combination has an influence on cutting speed. The orifice size dictates the volume of water output by the cutting head. Larger orifices will typically produce a faster cut but will require more pump power. Generally a focusing tube which is about three times larger than the orifice provides optimal cutting efficiency, balancing cost and cutting speed. Typical orifice/nozzle combinations are: 6/21 (0.15/0.54 mm), 9/30 (0.23/0.76 mm), 13/43 (0.33/1.10 mm), 18/63 (0.45/1.60 mm) for water pressure of 400 MPa.

The abrasive used in abrasive water jet cutting is hard sand that is specially screened and sized. The most common abrasive is garnet. Different mesh sizes are used for different jobs: 120 mesh - produces smooth surface, 80 mesh - most common, general purpose, 50 mesh – cuts a little faster than 80, with slightly rougher surface. Cutting speed depends and on the material, the thickness, the quality of the edge finish and tolerance. Cutting speed varies and as a function of the geometry of the part ([2],[5], [6],[7]).

4. METHODOLOGY OF MODELING

In the present study, the influence of orifice size and abrasive nozzle, material thickness, water jet pressure and abrasive flow rate on the performance of abrasive water jet cutting. Mathematical design approach is employed for conducting the data considering the water jet pressure, abrasive flow rate and material thickness at different levels. To identify the process parameters that are statistically significant in the process, analysis of variance is performed. By considering these significant parameters, the orthogonal polynomial models are developed in order to predict the cutting performance in terms of cutting speed. These empirical relations are used to develop the response surfaces, which are used to generate model available in MATLAB software package.

With today's ever-increasing complexity of models, design of experiment has become an essential part of the modeling process. Design of experiment (DOE) is the process of planning the experiments considering the process parameters at different levels so as to acqure necessary information for building statistical models, which can aid in predicting the process performance.

The design editor within the MBC Toolbox - a part of MATLAB software package is used as a help in mathematical design. Central composite design provides a simple, efficient and systematic approach for optimal design of experiments to asses the performance, quality and cost. In order to detect curvature in the ralationshop between an input factor (independent) and an outcome (dependent) variable, we need at least 3 levels for the respecive factor (three design points). One of designs for three factors is faced (CCF) designs, that have the star points on the faces of the cube.

For analytical model and analysis of cutting data it is used Model-based calibration toolbox, design of experiments and statistical modeling, version 1.1 of software package MATLAB, version 6.5, release 13.

The model was planned by adopting full factorial experimentation procedure. In this model, the water jet pressure, abrasive flow rate and material thickness were varied at different levels and the orifice size and abrasive nozzle was kept constant.

The process parameters, such as water jet pressure, abrasive flow rate and material thickness are varied at three levels. In Table 1, the range of different process parameters and factor levels used for this study are shown.

Table 1. Process parameters and their levels

Symbol	Parameters	Units	Level 1	Level 2	Level 3
s	Material thickness	mm	3	5	7
p	Water pressure	MPa	360	380	400
q	Abrasive flow rate	g/min	300	350	400

Other influencing parameters, such: orifice size, abrasive nozzle diameter and abrasive size kept constant. All the cutting data are for standoff distance of 3 mm, jet impact angle of 90^o, garnet abrasives of 80-mesh, orifice/focusing tube size of 0,33/1,10 mm.

Cutting data (Table 2) is given from manufacturer "KMT Waterjet Systems Inc." for material carbon stool and medium edge quality.

Table 2. Cutting data

Exp. num	Code			Input factors			Output factor
	X_1	X_2	X_3	q (g/min)	s (mm)	p (MPa)	v (mm/min)
1	+1	+1	+1	400	7	400	190
2	-1	+1	+1	300	7	400	170
3	+1	-1	+1	400	3	400	520
4	-1	-1	+1	300	3	400	465
5	+1	+1	-1	400	7	360	150
6	-1	+1	-1	300	7	360	135
7	+1	-1	-1	400	3	360	430
8	-1	-1	-1	300	3	360	380
9	+1	0	0	400	5	380	255
10	-1	0	0	300	5	380	230
11	0	+1	0	350	7	380	160
12	0	-1	0	350	3	380	450
13	0	0	+1	350	5	400	270
14	0	0	-1	350	5	360	220
15	0	0	0	350	5	380	240

5. MATHEMATICAL MODELING OF CUTTING SPEED

For mathematical modelling of cutting speed is chosen power function:

$$v = Cs^{p_1} p^{p_2} q^{p_3} \qquad (1)$$

where v – cutting speed, s – material thickness, p – water pressure, q – abrasive flow rate, C, p_i – constants.

This analytical model, in form of power function, can make linear by logarithm [8].

$$\ln v = \ln C + p_1 \ln s + p_2 \ln p + p_3 \ln q \qquad (2)$$

Put in y=lnv, p_0=lnC, x_1=lns, x_2=lnp and x_3=lnq we have:

$$y = p_0 + p_1 x_1 + p_2 x_2 + p_3 x_3 \qquad (3)$$

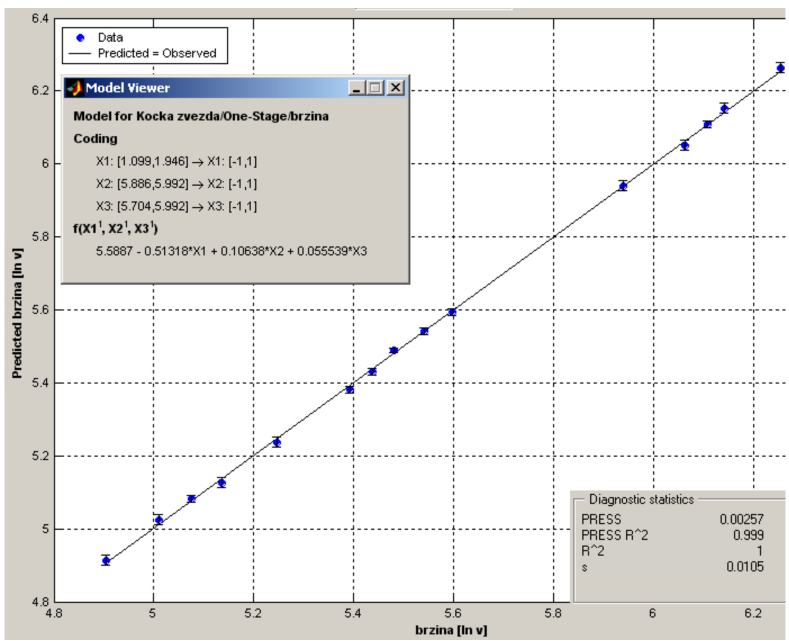

Figure 2. Response model

In setup it is given test plan of experimental model with three input variables (material thickness, water pressure and abrasive flow rate) and one output variable (cutting speed). Experimental data can be loaded in test plan from files, from the MATLAB workspace, and from tailor-made Excel sheets. Next step is creating of test plan, which compose of data inputs and a model. The type of the model is the shape of curve used to fit the test data, for example, quadratic, cubic, or polyspline curves.

After program run the response feature pane appears, showing the fit of the model to the input data. Response model with diagnostic statistics are shown in Figure 2.

Model viewer (Fig. 2) gives correlation coefficients. Regression equation now is:

$$y = 5.5887 - 0.51318 \cdot x_1 + 0.10638 \cdot x_2 + 0.055539 \cdot x_3 \qquad (4)$$

Coding values in equation (4) are:

$$x_1 = 1 + 2\frac{\ln q - \ln q_{max}}{\ln q_{max} - \ln q_{min}} = 1 + 2\frac{\ln q - \ln 400}{\ln 400 - \ln 300} = -40.651 + 6.952 \cdot \ln q$$

$$x_2 = 1 + 2\frac{\ln s - \ln s_{max}}{\ln s_{max} - \ln s_{min}} = 1 + 2\frac{\ln s - \ln 7}{\ln 7 - \ln 3} = -3.5932 + 2.3604 \cdot \ln s \qquad (5)$$

$$x_3 = 1 + 2\frac{\ln p - \ln p_{max}}{\ln p_{max} - \ln p_{min}} = 1 + 2\frac{\ln p - \ln 400}{\ln 400 - \ln 360} = -112.6907 + 18.9753 \cdot \ln p$$

Substitute of coding values we obtain regression equation for cutting speed in form:

$$v = \frac{1}{910} \cdot \frac{p^{2.019} q^{0.386}}{s^{1.211}} \qquad (6)$$

where v (mm/min) – cutting speed, p (MPa) – water pressure, q (g/min) – abrasive rate, s (mm) – material thickness.

According to regression equation, experimental data and predicted cutting speed are given in table 3.

6. CONCLUSION

Abrasive water jet is the fastest growing major machine tool process in the world. As complex process water jet cutting depends on a large number of process parameters, which determine machined part quality. Whereby "quality" describes the combination of surface finish, tolerance and other properties of the cut.

In this work, investigations were carried out to study the influence of some process influencing parameters (such as water pressure, abrasive flow rate) on the cutting performance, such as cutting speed using full factorial experimentation procedure.

The cutting speed is one of the most important parameter of this technology, because with the quality of the machined surface and the costs of the technology can be controlled.

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