Manufacturing Process II

Term paper

Abrasive Water Jet Machining

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ABSTRACT

This term paper focuses on various aspects of design methodologies for AWJM ,and a conclusion for computational models to reduce the operational and experimental cost, researchers have devised various models such as kerf prediction, and prediction of other parameters using interdisciplinary approach such as ANN(Artificial Neural Network). Also from literature review, there are experiments which were conducted to assess the influence of abrasive jet machining (AJM) process parameters on material removal rate and diameter of holes of glass plates using aluminum oxide type of abrasive particles. Taking into consideration data about various parameters of AWJM machining of Copper Iron Alloy, this paper tries to augur MRR by using regression and ANN models.

INTRODUCTION

Abrasive water jet cutting of material involves the effect of a high pressure velocity jet of water with induced abrasive particles on to materials to be cut. It is an extended version of water jet cutting in which the water jet contains abrasive particles such as Silicon carbide or Aluminium oxide in order to increase the material removal rate above that of water jet machining. The narrow cutting stream and computer controlled movement enables this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be cut by laser or thermal cut. Metallic, non-metallic and advanced composite materials of various thicknesses can be cut by this process.

This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining. In most cases, no secondary finishing is required, and no cutting burr is left. The typical surface finish is around 125-250 microns.

It is highly used in aerospace, automotive and electronics industries. In aerospace industries, parts such as titanium bodies for military aircrafts, engine components (Aluminium, Titanium, and heat resistant alloys), Aluminium body parts and interior cabin parts are made using abrasive water jet cutting.

LITERATURE REVIEW

There are many parameters that are associated with the AWJM process by which the efficiency, economy and quality can be determined and optimized. The process parameters can be divided into broadly four categories:

- Hydraulic parameters
  - Pump pressure (p)
  - Water-orifice diameter (do)
  - Water flow rate (mw)
- Mixing and acceleration parameters
  - Focus diameter (df)
  - Focus length (lf)
- Cutting parameters
  - Traverse rate (v)
  - Number of passes (np)
  - Standoff distance (x)
  - Impact angle (ϕ)
- Abrasive parameters
  - Abrasive mass flow-rate (ma)
  - Abrasive particle diameter (dp)
  - Abrasive particle size distribution (f (dp))
  - Abrasive particle shape
  - Abrasive particle hardness (Hp)

However, the output parameters can be identified as:

Kerf Taper Angle, Surface Roughness, Depth of Cut and Material Removal Rate.

Moreover we will tend to focus only on some parameters and brief about a generalized trend observed. Note: The trend summarized considers all the input parameters in an increasing trend.

		Output Parameters		
		Kerf Taper Angle	**Depth of Cut**	**Surface Roughness**
Input Parameters	**Hydraulic Pressure**	Decreases	Increases	Decreases
	Traverse Speed	Increases	Decreases	Increases
	Standoff Distance	Increases	Decreases	Increases
	AbrasiveFlow Rate	Decreases	Increases	Increases(upto a limit and then Decreases)
	Type of Abrasive	Higher hardness particles give less taper angle.	-	Higher hardness particles give smoother finish.

Now, Focusing more on MRR as the output parameters many researchers have predicted its behaviour as follows: -

- The effects of stand –off- distance on MRR and penetration rates have been reported by some researchers. These investigations indicate that after a threshold pressure, the MRR and penetration rates increase with nozzle pressure.
- For brittle materials, normal impingement results in maximum MRR and for ductile materials, an impingement angle of 15-20 degrees results in maximum MRR.
- As the abrasive grit size and mixing ratio increase, the MRR and penetration rate increase but the surfaces finish value which is measured in Ra decreases.
- Domiaty and Hafez reported that cutting time decreases with increase in standoff distance. The increase of the nozzle diameter increases the MRR due to the increase of the flow rate of the abrasive particles.

After studying relations between various parameters, the focus shifts to reduce experimentation efforts by devising certain mathematical models to reduce overall cost and come to an analytical conclusion. Adherence to this thought process, D.A. Axinte, D.S. Srinivasu, J. Billingham, and M. Cooper had published a paper that predicted the kerf on the target material, under certain conditions.

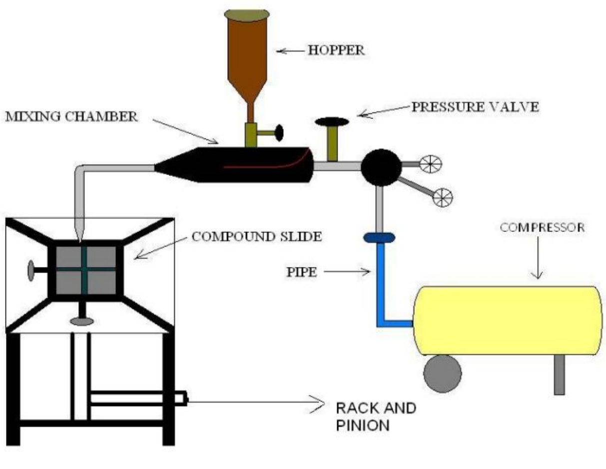
Geometrical modelling of abrasive waterjet footprints, A study for 90(deg) jet impact angle was done and the experimental and analytical results are nearly identical. That was a great breakthrough, as for certain working conditions the model was accurate enough to get deployed into manufacturing computations.

Proceeding further, all the traditional AWJM models use some form of approximation and always consider only some of the parameters while modelling the process. This means some of the factors are ignored while modelling, which can cause a severe impact on the process under certain conditions.There doesn't exist a computational model which includes all the input parameters. However, empirical and numerical models work only for limited conditions.So researchers have attempted to use Neural networks to overcome this shortcoming. They have tried to train their neural network on experimental data , and predict some other parameters.

METHODOLOGY/MODELLING

To analyse the influence of abrasive jet machining (AJM) process parameters (Nozzle tip distance and Pressure) on material removal rate and diameter of holes made in glass plates using aluminum oxide type of abrasive particles, the following experimental modelling was required: -

- The experimental work was carried on a test rig.
- The abrasive grits (alumina) were mixed with air stream ahead of nozzle and the abrasive flow rate was kept constant throughout the machining process.
- The jet nozzle was made of tool steel to carry high wear resistance.
- Drilling of glass sheets was conducted on the parameters listed in Table below.
- Glass was used as a workpiece material because of its homogeneous properties.



The results obtained from above modelling were conclusive and prognostic that: - With the increase in nozzle tip distance (NTD), the top surface diameter and bottom surface diameter of hole increases as it is in general observation of abrasive jet machining processes.

As the pressure increases, the material removal rate (MRR) is also increased.

S.No	AJM Parameter	Condition
1	Type of abrasive	alumina
2	Abrasive size	0.15-1.25 mm
3	Jet pressure	5.5-7.5 k g/cm^2
4	Nozzle tip distance	6-18 mm

Proceeding further, construction of the computational model for a specific set of working conditions, to get a better hold of the basics and predicting the working parameters. Using constant parameters as: mf = 0.7 kg/min; P = 345 MPa; D0 = 3 mm; Ønozzle = 1 mm, for AWJM setup. The mathematical formulation uses the condensation of differential equations for high feed rates. These models were simulated using Matlab and experimental data was collected using a 3D scanner(Talysurf CLI 1000).

MODEL 1: Considering feed rate to be the only working parameter keeping other parameters to be fixed. The results for this model were good but the result deviates from 3D Scanning of the kerf profile using Talysurf CLI 1000. By backtracking and trying to find the actual cause for this deviation researchers added Nozzle tip distance(NTD) or Stand-off distance as a working parameter.

MODEL 2: After including NTD as a working parameter with feed rate Utilising the same calibration method as before and the corrected jet footprint model, the comparison between the predicted (modelled) kerf profiles and the experimental data is done. Error involved in this model was <5% which is a great breakthrough.

Using some new theories/concepts such as Neural networks, two neural networks BPN and RBFN have been trained on the experimental data available. Some parameters were given as input to find corresponding parameters and the error was determined. These results were also compared with linear and second order regression models, which showed that the relationship between the given input output parameters was not linear.

RESEARCH GAP/PROBLEM FORMULATION

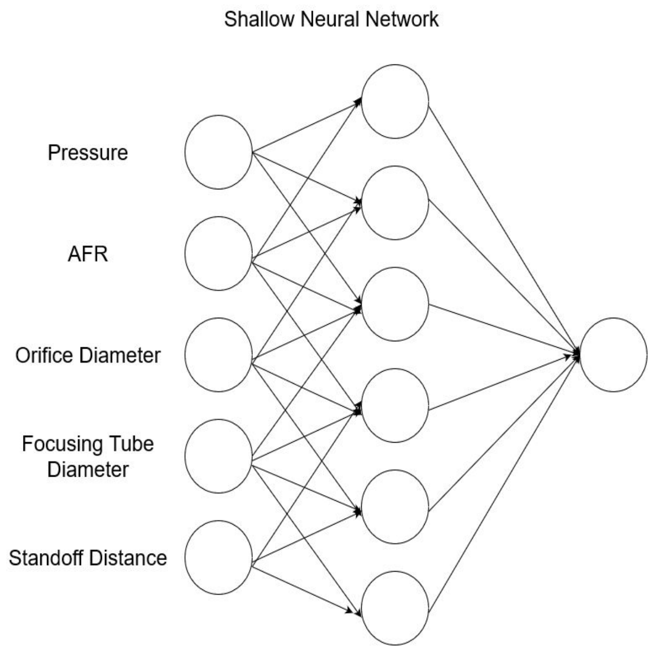
- The effect of various input parameters on the shape of the abrasive jet machined surface and on abrasive jet deburred edges are not widely investigated and published. Some researchers have reported that the abrasive jet machined surface is reverse bell mouthed in shape but no explanations have been given by them.
- Computational Study that we had discussed revolves around a 90deg impact angle on the work material, that creates a bias for certain working parameters, on the other hand while constructing the mathematical model for this setup, conversion of nonlinear partial differential equations for high feed rate into a simpler relation, where terms can be linearized tend to deviate the results from experimental results.
- As observed, many parameters control the output in AWJM, therefore a good analytic model taking into consideration major parameters to predict the output for different materials is always a good step. Therefore, this term paper will focus on two models built by us to predict an output parameter for AWJM.

IMPLEMENTATION

Table 1: Experimental Data of Cutting (AWJM) of Copper Iron Alloy.

Exp. No.	Pressure (Bar)	Abrasive flow rate (kg/min)	Orifice diameter (mm)	Focusing tube diameter (mm)	Standoff distance (mm)	MRR (mm^3/min)
1	3400	0.55	0.33	0.99	3	897.8
2	3600	0.55	0.33	0.99	1	1000.03
3	3600	0.55	0.3	1.05	2	961.93
4	3600	0.55	0.33	0.9	3	918.21
5	3800	0.55	0.33	0.9	2	1043.96
6	3600	0.55	0.33	0.99	2	928.76
7	3400	0.4	0.33	0.99	2	762.29
8	3600	0.7	0.35	0.99	2	985.39
9	3800	0.55	0.33	0.99	3	987.8
10	3800	0.55	0.3	0.99	2	1025.41
11	3600	0.55	0.33	0.99	3	907.89
12	3400	0.55	0.33	1.05	2	800.02
13	3600	0.4	0.33	0.99	1	920.3
14	3600	0.55	0.33	0.99	2	922.4
15	3600	0.55	0.35	0.9	2	948.38
16	3600	0.55	0.3	0.9	2	950.62
17	3400	0.55	0.33	0.9	2	817.84
18	3600	0.55	0.33	0.99	2	897.8
19	3600	0.4	0.3	0.99	2	827.89
20	3400	0.55	0.35	0.99	2	814.54
21	3800	0.4	0.33	0.99	2	961.93
22	3600	0.7	0.33	0.99	3	997.56
23	3600	0.7	0.33	0.99	1	987.8
24	3600	0.4	0.35	0.99	2	846.98
25	3600	0.4	0.33	0.9	2	863.27
26	3600	0.55	0.35	0.99	3	928.76

We selected some input parameters for Copper Iron Alloy AWJM such as Pressure, AFR, Orifice, Focusing tube diameter, Standoff Distance(STD) and made a regression and ANN model to estimate the Material Removal Rate(MRR).

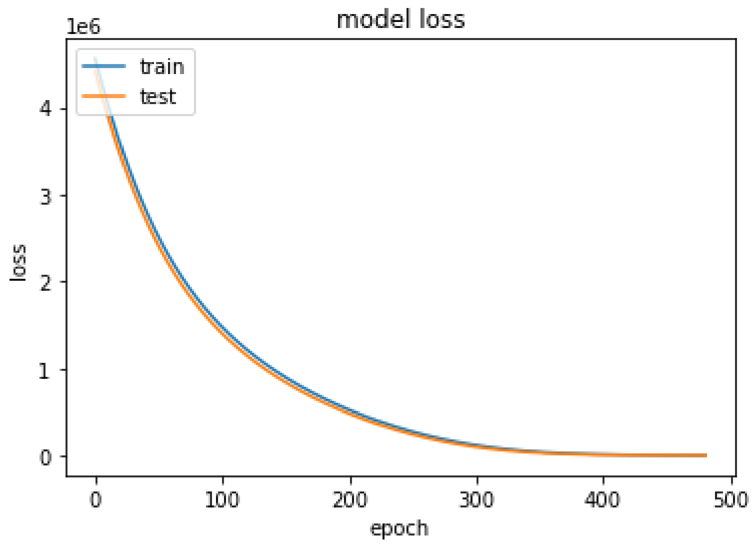


While constructing the **regression model** we had performed several iterations to select the correct degree for the polynomial regression fit. As a result we had selected the **2nd degree multivariate polynomial** for this model.

For **ANN**, as shown in the illustration we have constructed a shallow Neural network, consisting of 5 neurons in the first layer followed by 6 neurons in the middle layer and finally a single output neuron i.e MRR(Material Removal Rate.

CONCLUSION & FUTURE PROSPECTS

Further improvement in the regression model and ANN can be done by analyzing the appropriate data and deploying techniques like Hyper-Parameter Tuning to obtain better results and less error. This model considers shallow neural networks but we could have devised a Deep Neural Network(using more hidden layers) to get better insights to experimental results. Further, different frameworks can be used without loss of generality.



Bibliography

Bhaskar Chandra, J. S. (2011). A Study of effect of Process Parameters of Abrasive jet machining. *Bhaskar Chandra et al. / International Journal of Engineering Science and Technology (IJEST)* , 504-513.

D.A. Axinte, D. S. (2010). Geometrical modelling of abrasive waterjet footprints: A study for 908. *CIRP Annals - Manufacturing Technology* , 341–346.

El Mabrouk, O. &. (2017). An Implementation of Fuzzy Logic Technique to Predict the Material Removal Rate in Abrasive Water Jet Machining Process. *Libyan Journal for Engineering Research (LyJER)* .

Jignesh K Patel, A. A. (2015). THE INFLUENCE OF ABRASIVE WATER JET MACHINING PARAMETERS ON VARIOUS RESPONSES—A REVIEW. *Int. J. Mech. Eng. & Rob. Res. 2015* , 383-364.

Kovacevic, A. W. (1998). *Principles of Abrasive Water Jet Machining.* London: Springer-Verlag London Limited.

Pratik J. Parikh, S. S. (2008). Parameter estimation for abrasive water jet machining process using neural networks. *Int J Adv Manuf Technol* , 497-502.

Computational Model