A REVIEW ON CURRENT RESEARCH TRENDS IN ABRASIVE WATER JET MACHINING

K.Siva Prasad[1], G.Chaitanya[2]

[1] Assistant Professor, Department of Mechanical Engineering, V. R. Siddhartha Engineering College, Andhra Pradesh, India
[2]Associate Professor Department of Mechanical Engineering R.V.R & J.C College of Engineering, Andhra Pradesh, India

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Abstract - *Abrasive water jet machining (AWJM) is one of the non conventional machining process for difficult to cut brittle, hard and thin materials. The process parameters which are mainly influence the quality of machining in AWJM are water pressure, stand-off distance, nozzle diameter, traverse speed, abrasive flow rate and abrasive size. This is an environment friendly and relatively inexpensive process with reasonably high material removal rate. The quality parameters considered in AWJM are kerf Characteristics, Surface Roughness (SR), Material Removal Rate (MRR), Nozzle wear and Depth of Cut. Various mathematical models and modern approaches are applied to optimize process parameters there by improve the performance characteristics. In the present paper an attempt is made to review the research work carried out so far in the area of AWJM.*

Key Words: AWJM, Process Parameters, Optimization

1. INTRODUCTION

Abrasive water jet machining (AWJM) is an unconventional machining method. In this method material removed by the impact of abrasive particles of the slurry on hard and brittle materials .This process is used to cut the material and make the holes or cavities and kerfs. In this machining process there is no change in physical and mechanical properties since this is a non-electrical and non-chemical and non thermal. Abrasive water jet machining contains abrasive particles like aluminium oxide silicon carbide to cut the hard materials like ceramics, glass, metals, advanced composite materials and soft metals. This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining.

A large amount of research has been carried out to understand the process and improve its performance. In this paper a review on various research activities carried out in the past decade on AWJM is provided. [44] In the early 1970's water jet cutting machine is started to cut plastic and wood materials. [45] AWJM was commercially available in 1980's in the area of unconventional machining process.

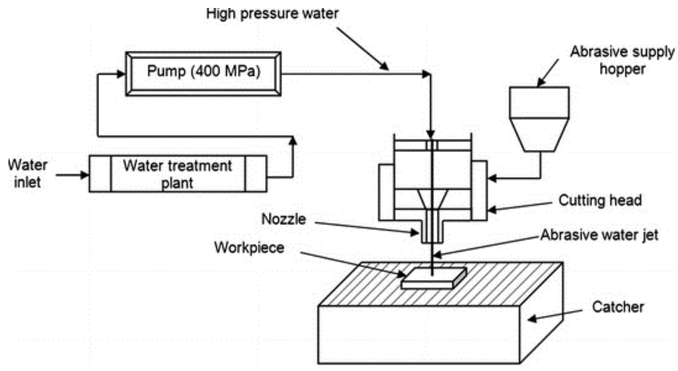

Fig.1 Schematic Diagram for abrasive water jet machine setup.

Above fig. shows how the abrasive water jet machine is working. It mainly consists of water pump, abrasive hopper, nozzle and mixing chamber. The pump sucks the water from the reservoir and supply to the intensifier there water pressure increases up to 4000 bar. This high pressurised water mixing with the abrasive particles in mixing chamber and forms abrasive slurry and that will be sending to nozzle through the tubing system. Abrasive slurry with high velocity strike the work surface, it erodes metal from the contact surface. Hence material removal has taken place.

2. ABRASIVE WATER JET MACHINING PROCESS FOR VARIOUS MATERIALS

A. Advanced Composite Materials

Advanced composite materials (ACMs) are also known as advanced polymer matrix composites. These materials are having high strength, dimensional stability, light weight with high stiffness, temperature and chemical resistance and easily process as compared with other materials. D.V.Srikanth et al [2] done investigation on the influence of different parameters like Pressure, SOD, Time, Abrasive grain size, nozzle diameter on the Metal removal of FRP (Fiber Reinforced Polymer) composite by Abrasive jet machining. Muller F et al [20] done investigation on machinibiltiy of SiC Particle Reinforced Metal Matrix Composites by non conventional machining process such as Electro Discharge Machining (EDM), laser cutting and Abrasive Water Jet (AWJ).

The surface integrity of the different machining processes are examined and compared. Hung,N.P el al[21] done research work on Electro discharge machining of metal matrix composites. Meaden,et al [22] done research on Laser cutting of titanium metal matrix composites.

B. Granite/Marbles

Granite is a common type of felsic intrusive igneous rock that is granular and phaneritic in texture. Granites can be predominantly white, pink, or gray in colour, depending on their mineralogy.[27] investigations on the behaviour of five artificial rocklike materials subjected to abrasive water jet cutting. [28]The effects of the AWJ operating variables on the kerf width were studied and the rock properties were correlated with the kerf widths. From the experimental results they observed that standoff distance and traverse speed are significant effect on the kerf widths. [30] Due to their unique characteristics such as excellent resistance to environmental effects and attractive decorative properties, granites has a special interest among natural stones. abrasive water jet (AWJ) cutting is being increasingly seen as a most promising machining method.

C. Advanced Ceramic Materials

Latest ceramic materials are silicon carbide, aluminum nitride, silicon nitride, zirconia, alumina, and titania-based materials, which are offering high performance characteristics as compared with unconventional materials. D. V. Srikanth et al,[4] Investigation conducted to assess the influence of Abrasive jet machining process parameters on MRR and Kerf of fibre glass. Lalchhuanvela, H.; Doloi, B.; Bhattacharyya, B. [23] Done research investigation on machining of Alumina ceramics by varying the Ultra sonic machining process parameters such as abrasive grit size, slurry concentration, power rating, tool feed rate and slurry flow rate. C.-H. Tsai H.-W. Chen,[24] done experiments by laser machining for shaping ceramic , defocused laser beam is applied throughout the length of the groove-cracks to generate a great thermal stress, which makes the two groove-cracks link together. The material removal is due to the linkage of the groove-cracks.from the experimental results they observed surface roughness and the inspection of crack defects.

D. Glass

Glass is a non-crystalline amorphous solid material. This is widely used in decorative usage for tableware, window panes and decorative usage. Silicate glass is the oldest glass. Axinte, E [26] Glass products have applications in design engineering, and they can solve many special problems. These materials can work in situations in which plastics and metals would fail and need to be part of designer's repertoire. N. Jagannatha, et al,[3] done investigation on drilling of soda lime glass by abrasive hot air jet machining to find the effect on MRR and Ra. J.M. Fan et al, [25] developed mathematical model for micro- hole drilling and micro-channel cutting on glass. They compared predictive models results with experimental investigation results and concluded that both are in good in agreement with experimental results.

E. Alloys

An alloy is a mixture of a metal and another element. Alloys are defined by a metallic bonding character. An alloy may be a solid solution of metal elements (a single phase) or a mixture of metallic phases (two or more solutions) Examples of alloys are brass, bronze, solder, steel, duralumin and bronze. Vasanth s et al [31], done investigation on machinibiltiy of titanium alloy. They find the influence of process parameters on surface roughness and topography for enhancing the process. From the experimental results it has been observed that the abrasive flow rate and standoff distance has the most significant role on determining surface quality. M. Uthayakumar et al [32] research work done on machinability of nickel-based super alloys. Selected process parameters are water jet pressure, traverse speed of jet nozzle, and standoff distance. By varying the selected process parameters they evaluated difference in kerf width, kerf wall inclination, and material removal rate (MRR).from the experimental results they observed that jet pressure is the most significant factor influencing the surface morphology and surface quality. K.S. Jai Aultrin et al [33] done research work on effect of process parameters on Material removal Rate and Surface roughness, while machining of copper iron alloys. They developed a predictive model for MRR and SR by regression analysis. From the experimental results they found that water pressure, abrasive flow rate, orifice diameter, nozzle diameter and standoff distance and along with their interactions have significant effect on the MRR and SR.

3. MAJOR AREAS OF AWJM RESEARCH

The author have done lot of research on different materials by varying various input process parameters such as nozzle diameter, standoff distance, abrasive flow rate, type of abrasive and pressure. By varying input parameters they evaluated output performance parameters like surface roughness, material removal rate, kerf geometry and depth of cut. By consider all the research on AWJM, authors identified two major areas. [47] There are AWJM process modelling and optimization and AWJM process monitoring and control.

3.1 AWJM Process Modeling and Optimization

AWJM process modelling is done in a scientific way to understand the system behaviour. Authors developing so many mathematical models to get good relationship between input and output parameters in terms of mathematical equations. Modelling and optimization is done as per the DOE such as Taguchi technique and response surface response methodology. Analysis and significant effect of each process parameters done by the ANOVA. Other optimization techniques such as artificial neural network (ANN), fuzzy logic (FL), genetic algorithm, grey relational analysis artificial bee colony (ABC) and simulated annealing are used by few researchers to optimize the process parameters. [34] Effect of process parameters on kerf width and surface geometry. Influence of process parameters considered such as traverse speed, abrasive flow rate, standoff distance and water pressure on depth of cut [35]. Influence of process parameters on surface roughness at upper region and lower region of cut surface.

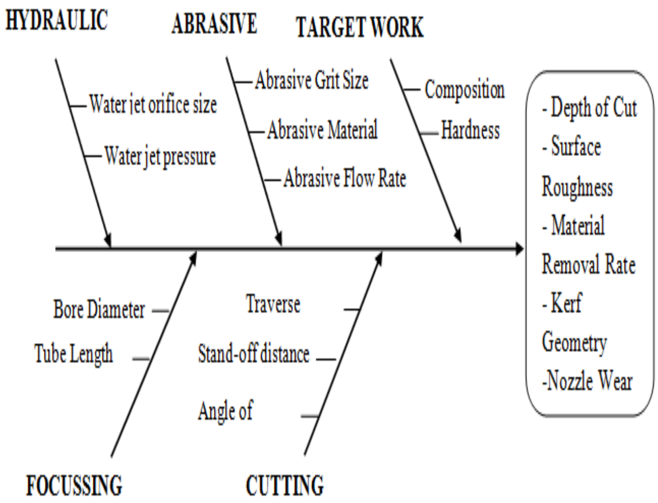

Fig. 2: Classification of Process parameters influencing the AWJM [48]

The selection of suitable machining conditions for the AWJM process is based on the analysis of various design parameters for different performance measures. The work carried out by researchers on effects of combination of different process parameters on various quality parameters are discussed below.

3.1.1 Effect of the process parameters on Depth of Cut

Sitarama Chakravarthy et al [13], done investigation on optimization of process parameters by using fuzzy logic and genetic algorithm on machining a granite to a predetermined depth of cut. From the experimental results multi response optimization procedure suggests best set of process parameters to increase the productivity and thereby reducing the cost. Devineni et al [14] had done experimental investigation on optimization of combined effect of process parameters on depth of cut and kerf width by using the abrasive water suspension jets. From the experimental results they observed that depth of cut influenced by the pressure and most significant factor affecting the kerf width is standoff distance.Lemma.E et al [15] done research work on abrasive water jet machining by nozzle oscillation technique. They had done some empirical model for predicting the depth of cut in both oscillation cutting and normal cutting process. From the experimental results they observed that oscillation cutting process more efficient than normal cutting process.Wang, J [16] did research work on prediction of depth of cut and minimization of delamination on polymer matrix composites. They developed empirical model for prediction of depth of cut and compared with experimental results.

D.S. Srinivasu and N. Ramesh Babu,[17] done investigation on a nero-gentic approach for selection of process parameters by varying the nozzle diameter. in this work they developed an artificial neural network model for prediction of depth of cut by varying the nozzle diameter and process parameters ,after that ANN combined with Genetic algorithm i.e nero-gentic approach. Which is compared with fuzzy genetic approach for effectiveness of the desired results. Farhad Kolahan et al [18] done research on effect of process parameters on depth of cut while machining 6036T-aluminium alloy by abrasive water jet machining. selected input process parameters are nozzle diameter, jet traverse rate, jet pressure and abrasive flow rate. By the taguchi method and regression model they developed relationship between input parameters and output parameters. From the experimental results they observed best set of process parameters for optimization.

3.1.2 Effects of the process parameter on Kerf Geometry

Shanmugam et al, [7] done investigation on alumina ceramic to minimize the kerf taper by the kerf-taper compensation technique. From the results they observed that angle has the highest effect on kerf taper. Karakurt et al, [8] done experiments on granites to find the kerf geometry by selecting the process parameters such as water pressure, abrasive flow rate standoff distance, traverse speed. Design of experiments done by the Taguchi method. They observed most influencing parameters on kerf geometry. Vishal Gupta et al, [9] done research work on effect of process parameters on kerf characteristics. Analysis done by the ANOVA to evaluate the significant effect of each process parameters on kerf geometry. From the analysis they observed affecting parameters. by the process parameters top kerf width, kerf taper angle are mostly effected. M.Ramulu et al,[10] done research on effect of process parameters on surface roughness and kerf taper of laminate specimens. Through ANOVA technique they find significant effect of process parameters on surface roughness and developed mathematical model to predict the surface roughness and kerf taper for cutting of 16mm thickness. J wang et al,[11] done experimental investigation on polymer matrix composites to study the effect of input process parameters on machinability of kerf characteristics by abrasive water jet machine. From the experimental results recommendations are made to optimize the process control and process optimization.

3.1.3 Effect of the process parameters on Material Removal Rate & Surface Roughness

Lingaraj.N and Gajendran.S [1] done research work on optimization of process parameters by using Taguchi multi response method (Weightage Method and Principal Component Analysis) and Response surface methodology. By the three methods compared the experimental results for MRR and Surface roughness. From the results they observed that Traverse rate and Abrasive flow rate are the most significant control factors on (Multi Response Performance Index) MRPI and standoff distance is the sub- significant parameter on MRPI. Traverse rate and Abrasive flow rate are the most significant control factors on TPCI and standoff distance is the sub- significant parameter on TPCI.

D.V. Srikanth, M. Sreenivasa Rao, done investigation on FRP composites by using Taguchi, under this they selected Abrasive grit (SIC) is thoroughly mixed with air and is flow through the Nozzle with constant flow rate throughout the completion of machining process. From the investigation they observed that to minimize the width of cut, nozzle should be placed close to the work surface. By increasing the jet pressure, cut slot width also increasing. The taper of cut gradually varies with standoff distance. Standoff distance and work feed rate influencing on surface roughness. By increasing jet pressure, the surface roughness decreases.

N. Jagannatha, et al,[3] done investigation on optimization of process parameters by abrasive hot air jet machining for glass using taguchi method and utility concept. To find the influence of abrasive hot air jet on Material removal rate (MRR) and surface roughness (Ra), drilling operation performed on soda lime glass. By Taguchi L9 orthogonal array they conducted experiments. Through ANOVA they observed that air temperature has the highest contribution of about 60.54% for MRR and 80.99% for Ra, the other parameters have less contributions. D. V. Srikanth et al, [4] conducted experiments on Ceramics to assess the influence of Abrasive jet machining process parameters on MRR and Kerf. The approach was based on Taguchi's method and analysis of variance to optimize the AJM process parameters for effective machining and to predict the optimal Values for each AJM parameter such as pressure, standoff distance, Abrasive flow rate and Nozzle diameter. From the experimental results they observed that by increase in Nozzle diameter the MRR increases, similarly decrease in Stand-off distance will reduce the divergence of the hole produced.

3.1.4. Effect of the process parameters on nozzle Wear

In abrasive water machining nozzle wear is affected by the mass flow rate, type of abrasive and pressure. Jegaraj et al [5] had done investigation on influence of orifice and focusing tube bore variation on the performance of abrasive water jets by cutting 6063-T6 aluminium alloy. Analysis has been done by the Taguchi method and analysis of variance (ANOVA). Fuzzy approach is used to generate the set of process parameters for the empirical equations. Nanduri et al. [6] had done research work on the phenomenon of nozzle wear by the abrasive water jet machining. The nozzle geometry such as inlet depth inlet angle, nozzle length, bore eccentricity and nozzle diameters on wear have been influenced. Hashish, M et al [12] conducted wear tests on soft (steel) tubes and harder (Tungsten carbide) tubes by using abrasive material(Aluminium oxide), a wide range of tool materials such as ceramics and carbides are tested by varying the machining parameters.

3.2 AWJM process monitoring and control

Pavol Hreha et al [38] describes the causes of arising vibration and acoustic emission, course of vibration and acoustic emission by analysing their frequency spectrum. Data were collected by touch sensors within controlled experiment, in which the AWJ technology for cutting alloy steel was used. Experimental data provide information about vibration and acoustic emission spectrum and enable us to find a dependency between the surface topography, and the emission spectrum.

[37] developed an analytical model for material removal in abrasive water jet machining (AWJM) of brittle material. The size of fracture that takes place on the backside of the work piece as the jet passes through the work piece is then predicted. Experimental results indicate that a strong correlation between the RMS AE signal and the characteristics of AWJM exists. [39Thermal energy distribution is analyzed, by using the technique of infrared 'thermography through isotherms and line-scans. Nozzle wear will be monitoring through the infrared thermography. Kovacevic et al [40] developed a fuzzy algorithm for the investigation of the wear state of the nozzle based upon a relationship between the inside diameter of the nozzle and the normal work piece force. Zohoor and Nourian [41] done experiments to determine the effect of process parameters such as traverse speed and nozzle diameter are significant effect on the kerf quality and geometry. They developed a control program algorithm to compensate the effect of nozzle diameter increase on cut surface quality and kerf width and the control program creates an offset with required amount in nozzle path. Rabani et al. [42] monitored the input jet energy that produces the part erosion using an acoustic emission sensor mounted on the target work piece surface while the jet feed velocity is acquired online from the machine axis encoders. With the pre-evaluation of TRE as specific response of the target material (i.e. Ti6Al4V) to the AWJ milling set of parameters, the area of abraded jet footprint can be calculated on line.

4. FUTURE SCOPE OF AWJM

A previous discussion shows major research in abrasive water jet machining. Investigators have contributed in different directions but still a lot of works are required to be done. The work presented above is an overview of the recent trends in development of AWJM.

AWJM replace the conventional machining of hard and difficult to cut materials, namely the Ultrasonic Machining, Laser Beam Machining and Electro Discharge Machining, which are slow machining process and also damage the surface integrity of the material. The AWJM process has sought the benefits of combining with other material removal methods to further expand its applications and improve the machining characteristics. Many researchers excluded influence of nozzle size and orifice diameter during the study of the performance characteristics. Many research scholars done investigation on influence of input process parameters on single quality characteristic as a objective during optimization of AWJM (like MRR, SR, Kerf characteristics, depth of cut).Very few literature is available on Multi objective optimization process. Now present scholars found it as the direction of future investigation work. No literature available so far for multi response optimization of process variables and more work is required to be done in this area. Also, various experimental tools used for optimization (such as Taguchi method and RSM) can be integrated together to incorporate the advantages of both simultaneously. very little research literature was available on nozzle wear. Research may be carried on the optimization for the power consumption, dimension accuracy and multi-objective optimization of AWJM process.

5. CONCLUSIONS

From the above discussions it can be concluded that:

1) AWJM is the most efficient process for difficult to cut materials, as compared with other conventional and non conventional machining process.
2) Most of the research carried on investigation on single quality characteristic optimization. Very little literature available on Multi-Objective Optimization, so in this area there is a scope for research. And also need research on process monitoring and control
3) Many of researchers considered standoff distance, traverse speed, water pressure and abrasive flow rate as process parameters for optimization of quality characteristics. Very little literature available on consideration of Nozzle size and orifice diameter. So in this area required more research.

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