A Review on Abrasive Water Jet Machining Process and its process parameters

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Abstract— **Abrasive water jet machining (AWJM) is one of the recent non-traditional methods that have been used widely in industry for machining of different materials in a variety of applications. Material removal in this process is due to erosion of a small volume with each particle striking the surface at high velocity. The numbers of particles striking the surface are in the order of tens of thousands per second. It is highly suitable for ceramics and composite materials. Composite materials are being increasingly used in various applications like space, aircraft, marine, architectural and automobile sector because of their superior physical and mechanical properties even though they are a little bit costly. Machining of composite materials is of great interest because of variety of reinforcement from high strength fibers to natural fibers. There are so many process parameter affect quality of machined surface cut by AWJM. Important process parameters which mainly affect the quality of cutting are traverse speed, hydraulic pressure, stand of distance, abrasive flow rate and types of abrasive. Abrasive water jet machining provides some advantages over conventional and non-conventional machining process for cutting the composite materials like no thermal effect, high machining versatility and small cutting forces.**

Index Terms—**Surface Roughness, Kerf Characteristics, Abrasive Water Jet Machining, Traverse Speed.**

1. INTRODUCTION

AWJM is a well-established non-traditional machining process. Abrasive water jet machining makes use of the principles of both abrasive jet machining and water jet machining. AWJM is a non-conventional machining process where material is removed by impact erosion of high pressure high velocity of water and entrained high velocity of grit abrasives on a work piece [5]. In the early 60's O. Imanaka, University of Tokyo applied pure water for industrial machining. In the late 60's R. Franz of University of Michigan, examine the cutting of wood with high velocity jets. The first industrial application manufactured by McCartney Manufacturing Company and installed in Alto Boxboard in 1972. The invention of the abrasive water jet in 1980 and in 1983 the first commercial system with abrasive entrainment in the jet became available. The added abrasives increased the range of materials, which can be cut with a Watergate drastically. [2] This technology is most widely used compare to other non-conventional technology because of its distinct advantages. It is used for cutting a wide variety of materials ranging from soft to hard materials. This technique is especially suitable for very soft, brittle and fibrous materials. This technology is less sensitive to material properties as it does not cause chatter. This process is without much heat generation so machined surface is free from heat affected zone and residual stresses.
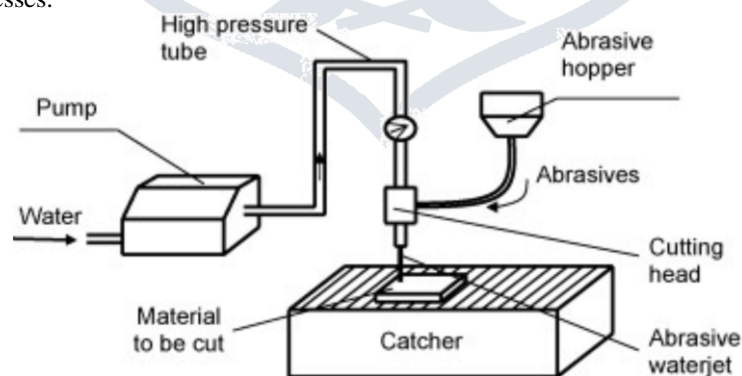
Schematic view of the Abrasive Water Jet Machining process

AWJM has high machining versatility and high flexibility. The major drawback of this process is, it generate loud noise and a messy working environment [5]. AWJM have certain advantageous characteristics, which helped to achieve significant penetration into manufacturing industries. [3]
- Extremely fast set-up and programming
- Very little fixturing for most parts
- Machine virtually any 2D shape on any material
- Very low side forces during the machining
- Almost no heat generated on the part

• Machine thick plates

AWJM is normally used for Paint removal, Cutting soft materials, Cutting frozen meat, Mass Immunization, Surgery, Cutting, Nuclear Plant Dismantling, Pocket Milling, Drilling, Turning, Textile, Leather industry. Materials which are cut by AWJM are Steels, Non-ferrous alloys, Ti alloys, Ni- alloys, Polymers, Honeycombs, Metal Matrix Composite, Ceramic Matrix Composite, Concrete, Stone – Granite, Wood, Reinforced plastics, Metal Polymer Laminates, Glass Fiber Metal Laminates.

 The advantages that have been reported for the process are: no thermal distortion on the work piece, high machining versatility to cut virtually any materials, high flexibility to cut in any direction, small cutting forces. AWJ for non-through cutting, where the depth of cut (DOC) is controlled has been less reported. AWJ milling presents an opportunity to minimize machining costs and increase process flexibility. Various researchers have investigated AWJ milling of non-open areas such as pockets by using a mask to cover the jet of water from surfaces around the machining area. However, these are the system's Critical Quality Attributes (CQAs). In order to investigate the effect of CPPs (Critical Process Parameters) on system Critical Quality Attributes (CQAs), a Design of Experiments (DoE) approach was used. DoE is a useful statistical technique to identify important CPPs and their impact on the CQAs by generating mathematical models and evaluating whether or not CPPs are statistically significant in the process. The models can be used to analyze the behavior of the system and make predictions of CQAs. After characterization of the parameters, system optimization process and robustness testing is usually followed for the better design of set of parameters for the process.

The CPPs involved in AWJ have been classified as;
 •Cutting Factors: Stand-off distance, traverse speed, traverse direction, traverse rate, impact angle, and number of passes;
 •Hydraulic Factors: Water pressure, orifice diameter, water jet velocity and direction;
 •Abrasive Factors: Abrasive feed rate, abrasive material, particle diameter, abrasive mass flow rate, abrasive size distribution, abrasive particles shape, abrasive hardness;
• Mixing Factors: Focus diameter, focus length, abrasive feeding direction, and the material of focusing tube, nozzle parameters etc.

The drawbacks of this process are messy working conditions due to abrasive and water mix which needs to be recycled in case of costly abrasive and in case of once use abrasives like sand the process becomes more noisy and messy due to water and sand mix which forms the mud at the bottom of the work table.

2. LITERATURE SURVEY

H. Hocheng and K.R. Chang [4] has carried out work on the kerf formation of a ceramic plate cut by an abrasive water jet. There is a critical combination of hydraulic pressure, abrasive flow rate and traverse speed for through- out cut below which it cannot be achieved for certain thickness. A sufficient supply of hydraulic energy, fine mesh abrasives at moderate speed gives smooth kerf surface. By experiment they find kerf width increases with pressure increase, traverse speed increase, abrasive flow rate increase and abrasive size increase. Taper ratio increases with traverse speed increases and decreases with pressure increases and abrasive size increases. Taper ratio has no effect with increase in abrasive flow rate.

Cutting results	Cutting parameters			
	Pressure ↑	Traverse speed ↑	Abrasive flow rate ↑	Abrasive size ↑
Kerf width	↑	↓	↑	↑
Taper ratio	↓	↑	×	↓
Surface roughness	×	↑	↓	↑
Material removal rate	↑	↑	↑	↑
Through-cut capability	↑	↓	↑	↑

(↑) Increase; (↓) decrease; (×) not obvious.

J. John Rozario Jegaraj, N. Ramesh Babu [8] had worked on strategy for efficient and quality cutting of materials with abrasive water jets considering the variation in orifice and focusing nozzle diameter in cutting 6063-T6 aluminium alloy. They found the effect of orifice size and focusing nozzle diameter on depth of cut, material removal rate, cutting efficiency, kerf geometry and surface roughness. The ratio of 3:1 between focusing nozzle diameter to orifice size was suggested as the best suited combination out of several combinations of focusing nozzle to orifice size in order to achieve the maximum depth of cut in cutting they suggest the ratio of 5:1 and beyond cause ineffective entrainment of abrasives in cutting head. It is noticed that with an increase in hydraulic pressure for different combinations of orifice and focusing nozzle size the depth of cut increased. The material removed increased with an increase in the size of focusing nozzle up to 1.2 mm diameter but with further increase it is reduced. The abrasive flow rate is found to be less significant on kerf width. This study suggests maintaining the orifice size and focusing nozzle size within certain limits say 0.25–0.3 mm and 1.2 mm, respectively, for maintaining less taper on kerf.

Any increase in the size of orifice and focusing nozzle is not much effect the surface quality but larger size of orifice produce a better surface finish on cut surface

Ahmet Hascalik et al [2] have studied the process for the titanium grade 5 material and their study revealed some important results and discussions which are as below.
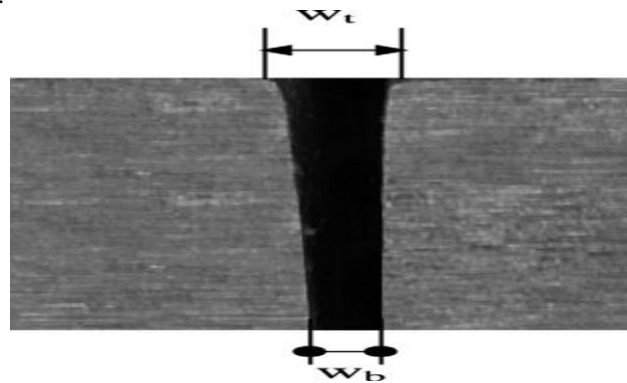

They have measured the kerf characteristics of the cut by means of measurement of top width and bottom width of the cut and then relating it with the below equation they have found the kerf characteristics for that material. The results are in form of kerf taper angle.

$$ T = \arctan\left(\frac{W_{top} - W_{bottom}}{2 \cdot t}\right) $$

This is the equation they have used for the taper measurements. They have suggested that the process shows smooth cutting region as well as the rough cutting region as the depth of cut increases.
At the beginning of the cutting the top most part receives higher pressure water jet and thus gives out clean cut or in other words smooth cutting region and as the depth of cut increases the rough cut region shows up due to the reason that the water pressure decreases and the striation of water at the depth on the sides of the material. The depth of the cut and the smooth cutting region are two major characteristics in AWJM process. While the depth of the cut represents the capacity of the jet to penetrate into the material, the depth of SCR ideally equal to the total cutting surface area is always desirable. Generally, the smooth cutting region is taken as the average surface quality.

Kamlesh H.Thakkar et al [7] has used taguchi and ANOVA for the analysis of the process and they have found mean and signal to noise ratio and plotted the graphs for that. The graphs for the SN ratio and mean are as shown below.
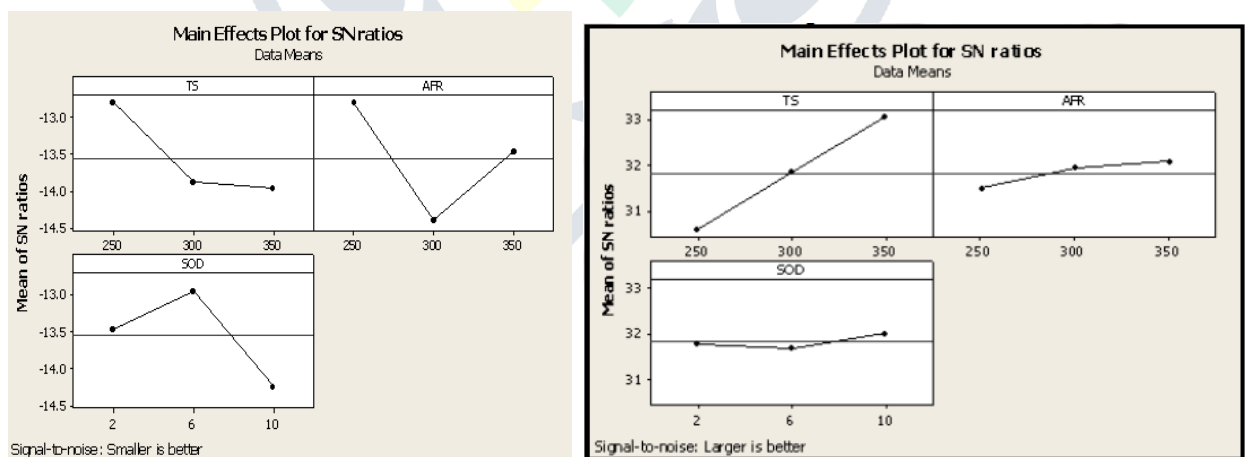

D.V. Srikanth et al [9] has shown the effect of different process parameters on the metal removal rate and surface finish. The MRR and surface finish depends upon many parameters but some of them are more significant and those are stand-off-distance (SOD) which is distance of nozzle tip from the work piece. They have also shown that the experimental work carried out by selecting three or four significant parameters will show different results for the same set of three parameters of four parameters with the same level of values due to the reason that is there are many other parameters also there which will affect the output or the objective and thus the objective function. For that they have taken the average value of those experiments with the same set of parameters and thus reducing L27 orthogonal array experiments in to set of 9 values for the output objective function. hence they have shown that apart from the significant parameters that have major effect on the outcome there are other parameters also which have also been affecting the output of the process which are like nozzle orifice diameter, nozzle angle and also the angle of strike of water jet at the work

piece and many more parameters are there. So all those parameters are also affecting the process but are affecting less compared to pressure, stand-off distance of nozzle, abrasive flow rate and traverse speed of the jet.

They also carried out effect of process parameters during practical are compared with theoretical results. Stephen Wan et al. (2010) presented simple deterministic process models for the prediction of the evolution of the cross-sectional profile of glass channels generated by erosive wear in micro air abrasive jet machining using a round nozzle. Apart from the Experimental works detailed theoretical studies are also performed on Abrasive Jet Machining Process by using some theoretical approach to optimize the parameters.

Vishal Gupta et al. [10] Design of Experiments (DOE) Experimental design is a useful complement to multivariate data analysis because it generates "structured" data tables, i.e. data tables that contain an important amount of structured variation. This under lying Structure will then be used as a basis for multivariate modeling, which will guarantee stable and robust models. The DOE Technique helps to study many factors simultaneously and most economically. By studying the effects of individual Factors on the results, the best factor combination can be determined.
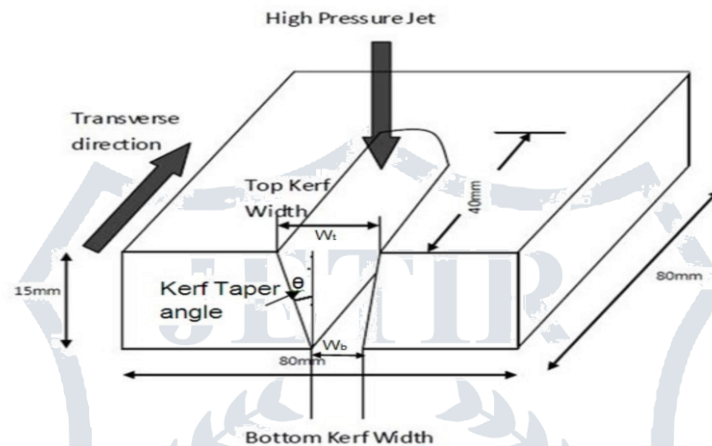
Optimization based on TAGUCHI approach is used to achieve more efficient cutting parameters. Parameter design is the key step in the Taguchi approach to achieve high quality without increasing cost. To solve this problem Taguchi approach uses a special design of orthogonal arrays where the experimental results are transformed into the S/N ratio as the measure of the quality characteristic deviating from the desired value. Analysis of Variance (ANOVA) is the method used to find out the optimum values of parameters by using signal to noise ratio. In ANOVA the parameters are compared by using variance and mean deviation using statistical processes.

They have conducted the experiments with different settings of input parameters which are water pressure, nozzle transverse speed and abrasive flow rate, and the values of output parameter such as top kerf width, kerf taper angle are recorded and these are plotted as per Taguchi's design of experiments methodology. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. The analysis of response data is done by software "MINITAB 16" specifically used for the design of experiment applications. The detailed description of the analysis is given as under in this section.

3. SUMMARY

So many investigations are carried out on AWJM process. Material Removal Rate or production is improved by improving the traverse speed but major problem faced with increasing traverse speed is that surface roughness and kerf quality are decreased. Types of abrasive and abrasive flow rate are also affecting the MRR. By increasing abrasive flow rate MRR is increased but it decrease the surface roughness characteristics. The researchers also studied the effect of pressure and traverse speed on surface roughness and kerf characteristics with the objective being either one of them and thus they have performed single objective function optimization and study.

The significant factors are more in number and some researchers are interested in selecting more number of those significant parameters for the study and thus carrying out multiple functions of those parameters and may create multi objective function for the study. Thus allowing further future scope of multi objective function for the abrasive water jet machining process

4. CONCLUSION

Quality of cutting surface in AWJM is depending on so many process parameters. Process parameter which affect less or more on quality of cutting in AWJM are hydraulic pressure, Stand-off distance, types of abrasive, size of abrasives, abrasive flow rate, nozzle diameter, orifice size, and traverse speed. Quality of cutting surface is measured by material removal rate, surface roughness, kerf width, kerf taper ratio. From the literature review compare to above all mentioned parameter traverse speed is most effective parameter for MRR. Abrasive flow rate is also an important parameter for increasing MRR. But beyond some limit with increase in abrasive flow rate and traverse speed the surface roughness decreases. Increasing traverse speed also increase the kerf geometry. So it is required to find optimum condition for process parameter to give better quality of cutting surface. Traverse speed is directly proportional to productivity and should be selected as high as possible without compromising kerf quality and surface roughness.

5. FUTURE SCOPE

The future scope of the work for this process has scope in nozzle parameters as well as combination of more than two output functions in to one function that is formation of multitask or multi-objective function by taking more than two output functions simultaneously for the study and then optimization of parameters for that objective function.

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