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Review on Optimization of Abrasive Waterjet Nozzle Design using CFD Modeling

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***Abstract*—*Abrasive Water Jet Machining (AWJM) is the non-traditional material removal 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. 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. Important quality parameters in AWJM are Material Removal Rate (MRR), kerf width, tapering of nozzle. This paper reviews the research work carried out so far in the area AWJM and also to analyze the effect of inlet pressure on wall shear and exit kinetic energy.**

***Index Terms*— AWJM, CFD, MRR, SOD.**

I. INTRODUCTION

Abrasive water jet machining (AWJM) is a mechanical material removal process used to erode holes and cavities by the impact of abrasive particles of the slurry on hard and brittle materials. Since the process is non- thermal, non-chemical and non-electrical it creates no change in the metallurgical and physical properties of the work piece.

A. Basic Principle

In abrasive jet machining process, a focused steam of abrasive particles (of size 10 to 40 microns) carried by high pressure gas or air at a velocity of about 150 to 300 m/sec is made to impinge on the work surface through a nozzle, and the work material is removed by erosion by the high velocity abrasive particles. The inside diameter (ID) of the nozzle through which abrasive particles flow is about 0.18 to 0.80 mm and the stand-off distance (i.e. distance between nozzle tip and workpiece) is kept about 0.3 to 20.0 mm. The process can be easily controlled to vary the metal removal rate which depends on flow rate and size of abrasive particles. This process is best suited for machining super alloys and refractory type of materials, and also machining thin sections of hard materials and making intricate hard holes. The cutting action is cool because the carrier gas serves as coolant.When an abrasive particle (like Al_2O_3 or SiC) having sharp edges hits a brittle and fragile material with a high speed, it makes dent into the material and lodges a small particle from it by a tiny brittle fracture. The lodged out or wear particle is carried away by the air or gas. The operating elements in AJM are abrasive, carrier gas and the nozzle as schematically shown in the following Figure.
The distance between the nozzle tip and the work surface has great influence on the diameter of cut, its shape and size and also rate of material removal. The following Figure shows the variation in the diameter of cut

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with change in the stand off distance (SOD). It is evident that the SOD changes the abrasive particles spreads (i.e. covers wider area) on the work surface and consequently increases the diameter of the cut.

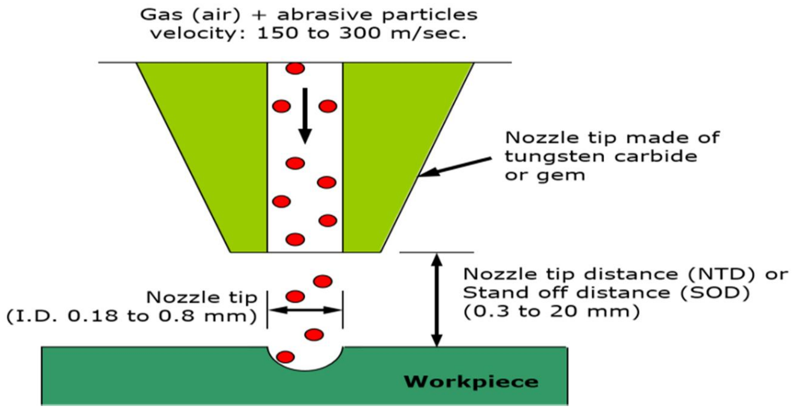

Figure 1 Principle of Abrasive Jet Machining

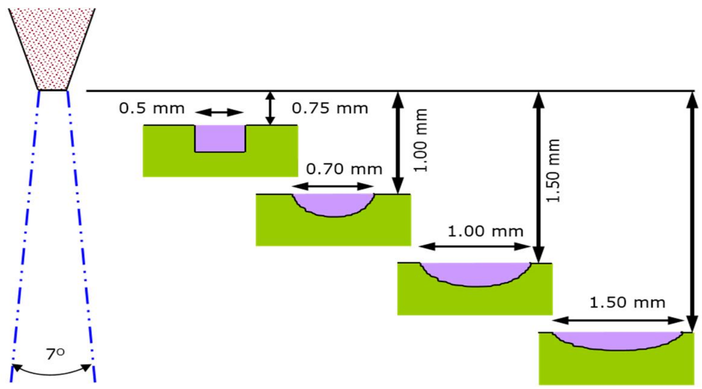

Figure 2.Variation in the diameter of cut with change in the stand off distance (SOD)

B. The basic unit of AJM

The basic unit is schematically shown in following Figure. It consists of gas supply system (compressor), filter, pressure regulator, mixing chamber, nozzle assembly and the work holding device. In the mixing chamber, the abrasive is allowed to flow into the gas stream. The mixing ratio is generally controlled by a vibrator. The particle and gas mixture comes out of the nozzle inside the machining chamber of the machine tool unit. The feed motion can be given either to the work holding device or to the nozzle.

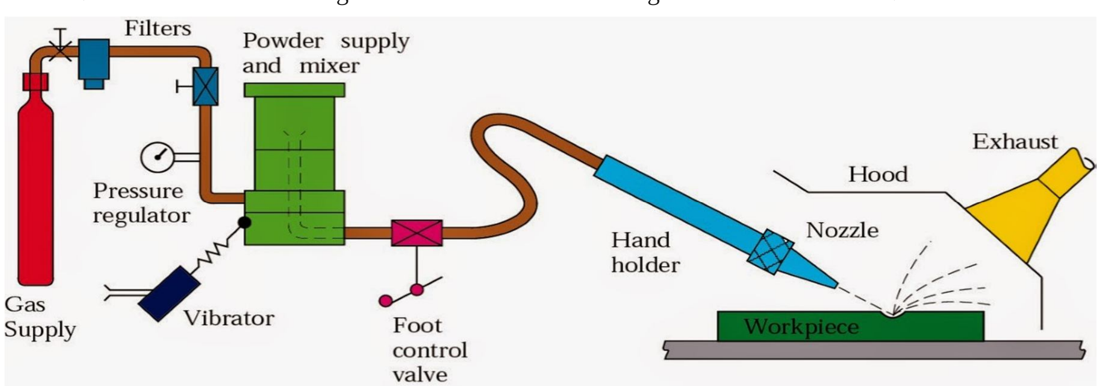

Figure 3. Diagram of Abrasive Jet Machining

II. LITERATURE REVIEW

C. Narayanan et al[1] had worked on Computational Fluid Dynamic Simulation of Flow in Abrasive Water Jet Machining and they found In this machining, the abrasives are mixed with suspended liquid to form semi liquid mixture. The aim of their project was to analyze the effect of inlet pressure on wall shear and exit kinetic energy. The analysis could be carried out by changing the taper angle of the nozzle, so as to obtain optimized process parameters for minimum nozzle wear. The two phase flow analysis would be carried by using computational fluid dynamics tool CFX.They modeled the nozzle head of varying taper angles AWJM by using pro/E software and it is saved.Then it is imported in ICEM meshing software for meshing the model. Tetrahedron is used for fine meshing. Then it is imported in CFX Pre for giving input parameters and properties of water and abrasive and flow is considered as two phase flow mixture in which water is liquid phase and abrasives is solid phase.

The general specifications of their model

Focus tube (Mixing tube) Diameter : 0.76 mm
Focus tube length : 76 mm
Taper angle of nozzle : 45 deg
Mixing chamber diameter: 6 mm
Mixing chamber length: 12 mm
Orifice diameter : 0.2 mm
Water inlet diameter : 2.5 mm
Abrasive inlet diameter : 3 mm
The pressure of water is taken as 400 bar and Density of water 1000 kg/m3
The velocity and mass flow rate of water and abrasive will be calculated by using the standard dimensions.

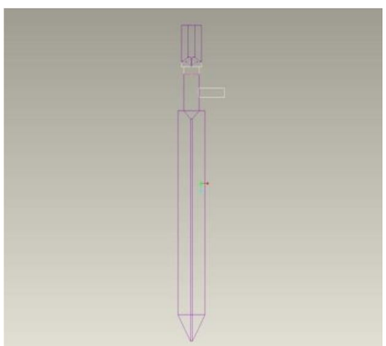

Figure 4. Pro/E model of nozzle head

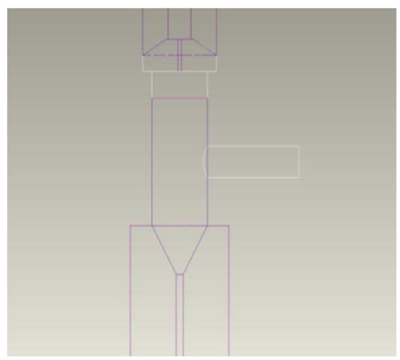

Figure 5.15 deg. Taper Angle

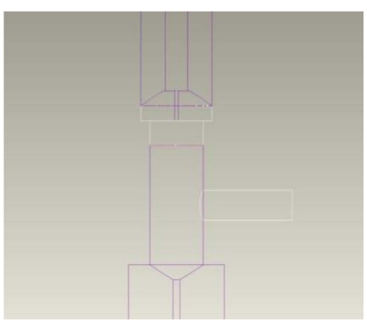

Figure 6.30 deg. Taper Angle

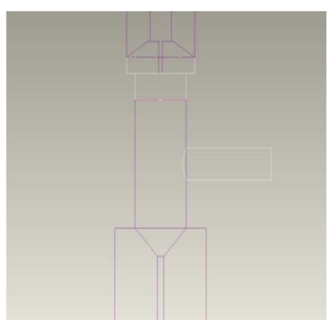

Figure 7.45 deg. Taper Angle

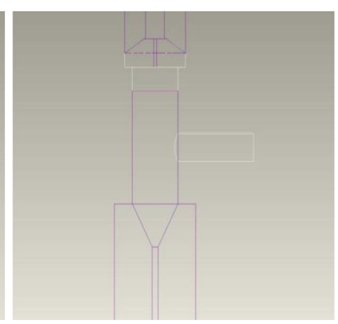

Figure 8.60 deg. Taper Angle

After modeling and simulation they observed Loss in kinetic energy when the flow is along the focus tube.This may be due to some of the abrasive particles do collide with the focusing tube wall. The kinetic energy loss is relatively less for 45° taper angle.

• The magnitude of wall shear stress increases when the taper angle increases. The wall shear in the mixing chamber increases sharply after the mixing region.

• The energy dissipation due to wall shear is relatively low for 30° taper angle.

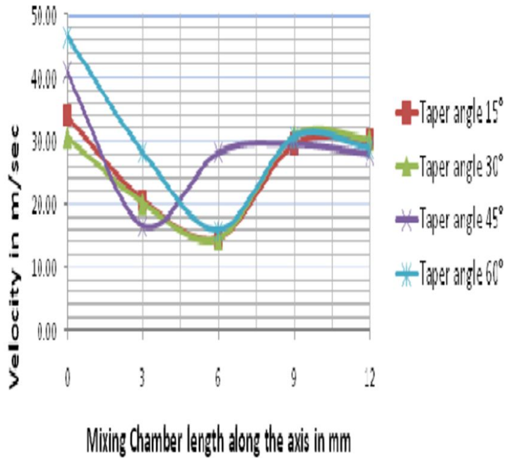

Figure 9.a. Mixing Chamber

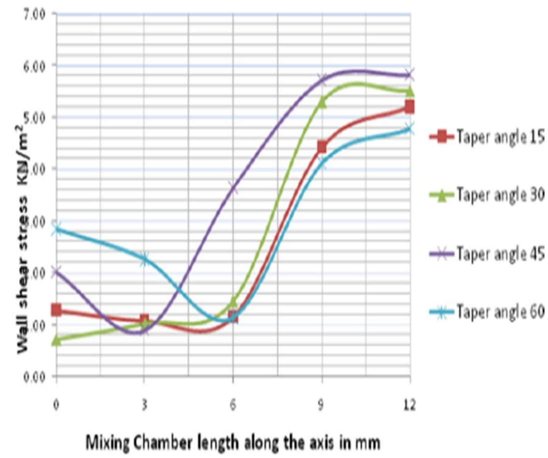

Figure 9.b Mixing Chamber

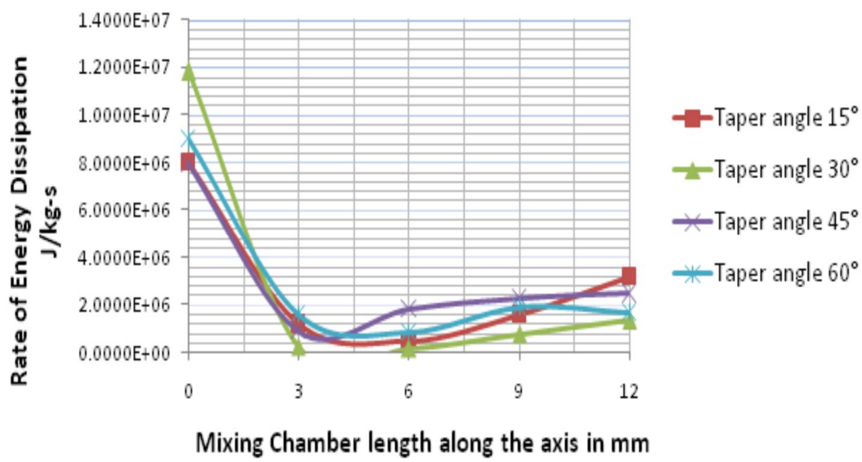

Figure 9.c Mixing Chamber

Kovacevic et al.[2] One of the most associated problems with AWJ is the erosion in the wall of the nozzle.The nozzle needs to be replaced since the water travels at high velocity and contains abrasive particles which may damage nozzle wall. Nozzles made of tungsten carbide have an average life of 12 to 30 hours while nozzles of sapphire last for about 300 hour of operation when used with 27 µm abrasive powder.Kovacevic has stated that under selected conditions, the optimal nozzle diameter is 2.2 mm which is 83% from the original diameter of 1.2 mm. Further increase will cause a significant decrease in the depth of AWJ penetration and decreases the surface quality of the machined sample.

A.A. Khan, M.M. Hague [3] analyse the performance of different abrasive materials during abrasive water jet machining of glass. They make comparative analysis of the performance of garnet, aluminium oxide and silicon carbide abrasive in abrasive water-jet machining of glass. Their hardness of the abrasives was 1350, 2100 and 2500 knoops, respectively. Hardness is an important character of the abrasives that affect the cut geometry. The depth of penetration of the jet increases with the increase in hardness of the abrasives. They compare the effect of different of abrasive on taper of cut by varying cutting parameter standoff distance, work feed rate, pressure. It is found that the garnet abrasives produced the largest taper of cut followed by aluminium oxide and silicon carbide abrasives. For all kinds of abrasives, the taper of cut increases with

SOD. For all the types of abrasives used taper of cut decreases with increase in jet pressure. Taper of cut is smaller for silicon carbide abrasives followed by aluminium oxide and garnet.
P K Ray and Dr A K Paul [4] had investigated that the MRR increases with increase of air pressure, grain size and with increase in nozzle diameter. MRR increases with increase in stand off distance (SOD) at a particular pressure. They found after work that initially MRR increases and then it is almost constant for small range and after that MRR decreased as SOD increases. They introduced a material removal factor (MRF). MRF is a non-dimensional parameter and it gives the weight of material removed per gram of abrasive particles. MRF decreases with increase in pressure that means the quantity of material removed per gram of abrasives at a lower pressure is higher than the quantity of material removed per gram of abrasives at a higher pressure. This is happened because at higher air pressure more number of abrasive particles are carried through the nozzle so more number of inter particle collisions and hence more loss of energy.

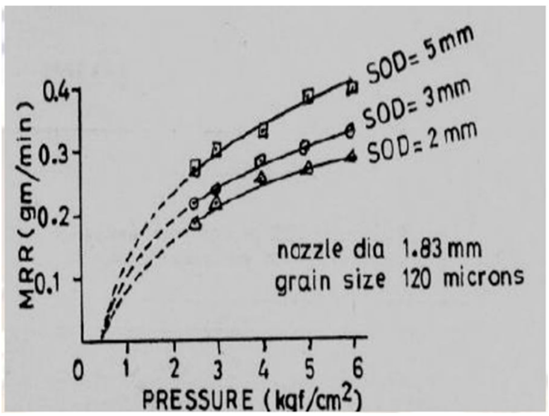

Figure 10.a MRR vs PRESSURE

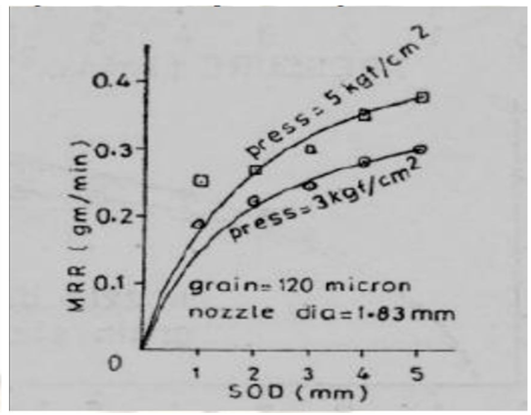

Figure 10.b. MRR vs SOD

III. Conclusions

From above literature review we found that depth of Cavity depend on NTD,abrasive particle size,velocity of Jet etc.MMR depends on abrasive flow rate.The Exit velocity through the nozzle depend on abrasive particle size and the kinetic energy lost is high in the cases of taper angle 30° and 60° than in the case of 45° taper angle.MRR increases with increase of air pressure, grain size and with increase in nozzle diameter.

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