A REVIEW ON EFFECT OF INPUT PROCESS PARAMETER ON OUTPUT PARAMETER ON ABRASIVE WATER JET MACHINING

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ABSTRACT
Abrasive Water jet machining (AWJM) is a non-traditional manufacturing process, is an emerging machining technology option for hard material parts that are extremely difficult-to-machine by conventional machining processes. A fine stream of high velocity water mixed with abrasive particles gives relatively in less cost and environment friendly manufacturing with reasonably high material removal rate. There are so many process parameters which affect the quality of machined surface cut by AWJM. But, the traverse speed, hydraulic pressure, stand-off distance, Abrasive flow rate and type of abrasive are important. However, the important performance measures in AWJM are Material Removal Rate (MRR), Surface Roughness (SR), Kerf width, Depth of cut. This paper reviews the research work carried on the AWJM research relating to performance measure input parameter to its output parameter.

Keywords: AWJM, Process parameter, Process optimization, Surface roughness, Depth of cut, Kerf width, MRR, RSM

1. INTRODUCTION

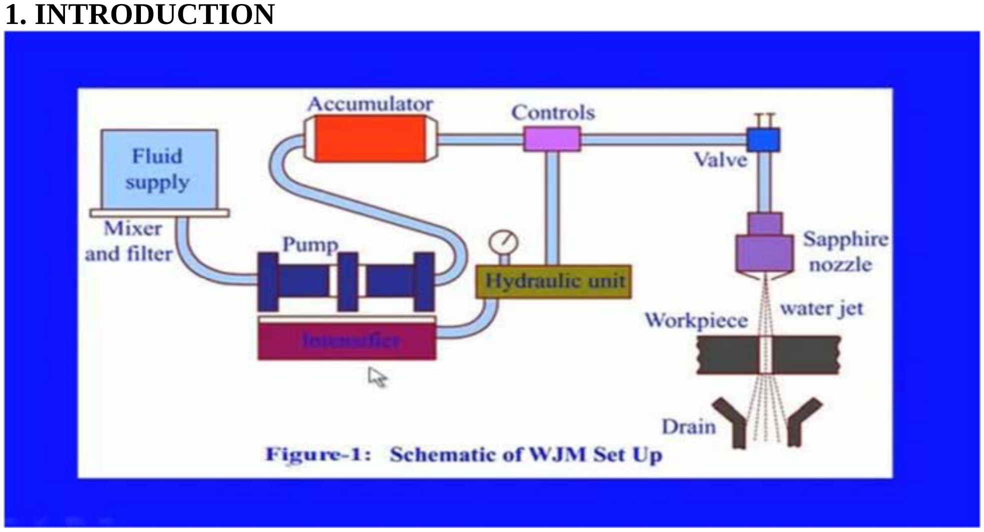

Fig 1: Line Diagram of Abrasive Water Jet Machining Process

Water jet cutting machines started to operate in the early 1970s for cutting wood and plastics material [1] and cutting by abrasive water jet was first commercialized in the late 1980s as a pioneering breakthrough in the area of unconventional processing technologies [2]. In AWJ machining process, the work piece material is removed by the action of a high-velocity jet of water mixed with abrasive particles based on the principle of erosion of the material upon which the water jet hits [3]. AWJ has few advantages such as high machining versatility, small cutting forces, high flexibility and no thermal distortion [4]. Comparing with other complementary machining processes, no heat affected zone (HAZ) on the work piece is produced [5]. AWJM is widely used in the processing of materials such as titanium, steel, brass, aluminium, stone, Inconel and any kind of glass and composites [6]. AWJM is normally used for applications like Paint removal, Cutting frozen meat, Surgery, Cutting, Pocket Milling, Turning, Drilling, Textile, Leather industry. Materials which are cut by AWJM are Steels, Non-ferrous alloys, Super alloys, Exotic materials, Ti alloys, Ni-alloys, Polymers, Metal Matrix Composite, Ceramic Matrix Composite ,high tech ceramics, Concrete, Wood, Plastics, Metal Polymer Laminates, glass etc.

2. Input and Output Process Parameter used in AWJM

There are several parameters that affect the cutting performance of the abrasive water jet

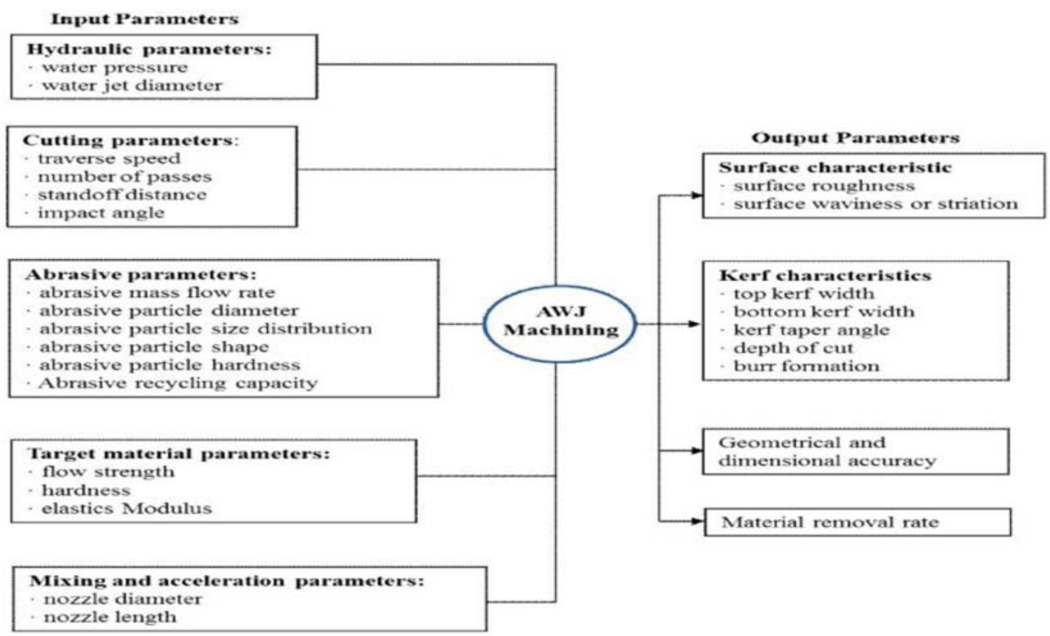

Figure 2: Process Parameters Influencing the AWJ Machining

1. Hydraulic parameters: water orifice size, water jet pressure, water quality.

2. Abrasive parameters: abrasive material, abrasive size and abrasive flow rate.

3. Target work material parameters: composition and hardness.

4. Cutting parameters: traverse rate (nozzle feed rate), standoff distance, impingement angle and depth of cut and material to be cut.

5. Focusing Tube: bore diameter, tube length. . With the help of different literature review different input process parameters which influences AWJ cutting were observed on output process parameter 1) Surfaces roughness 2) Kerf geometry 3) Depth of cut 4) Material removal rate.

3. REVIEW OF LITERATURE

Selvan et al, (2012) has carried out experiment on cutting of Aluminium by AWJM using process parameter Taguchi’s measure the performance surface roughness he was found Increase in water Pressure is associated with a decrease in surface roughness. Surface roughness constantly decreases as mass flow rate increases surface Smoothness increase as standoff distance decreases.

Azmir et al, (2009) has done work of investigation on abrasive water jet machining of cutting composite Kevlar 129. His was to assess Pump pressure most significant factor

Babu and Muthukrishnan (2014) has carried out experiment experiments on cutting of Brass-360by used Taguchi, DOE, Anova Scanning Electron Microscope measure the performance on surface roughness It was found that the Pump pressure was the most significant parameter Affecting the surface roughness.

Aydin et al, (2013) cutting of Granite by AWJM using process parameter used Taguchi, DOE, Anova measure the performance on surface roughness It was found that Water pressure & the abrasive flow rate are the most significant factors influencing the surface roughness of granites.

Valıcek et al. (2007) has done work cutting Steel samples of size 20x20x8mm plates. His aim was to assess the (AWJM) process parameters traverse speed on surface roughness using CCD camera he observed Proper traverse speed can be chosen depending upon the required quality of the cut wall

Pal and Choudhury (2014)has carried out experiment experiments on cutting blind pockets Titanium alloy25x25x1 mm by AWJM using process parameter abrasive CMM machine used observed deeper pocket at higher water pressure

Begic et al, (2015) studied the effects of material thickness 15mm, 30mm cutting Aluminium influence of process parameter Surf-Test Mitutoyo stylus instrument they analysed that traverse speed has great effect on the surface roughness at the bottom of the cut

Akkurt et al, (2004) abrasive water jet cutting effects of feed rate and thickness of pure aluminium, Al-6061 aluminium alloy, brass-353, AISI 1030 and AISI 304 steel materials are cut 5mm& 20mm with AWJ at different feed rates. The pressure of the AWJ negatively affects the surface roughness

Selvan et al,(2012) has carried out experiment experiments on cutting of Grey cast iron.by AWJM using process parameter Taguchi's Method and Analysis of Variance .measure the performance surface roughness he was found High water pressure is preferred to obtain good surface finish. Surface roughness constantly decreases as mass flow rate increases. Nozzle traverse speed increase, Surface roughness increases.

Abdullah et al, (2016) cutting Marble work pieces Carrera white and Indian green Cutting .by AWJM using process parameter (CMM), Analysis of Variance .measure the performance surface roughness he was found TS and material type were the most significant factors that affected surface roughness And Kerf taper ratio. Also, although AFR was found to have significant effect on surface waviness.

Akkurt (2015) has carried out experiment experiments on cutting Al 6061 aluminium alloy cutting dimensions 20mm thickness. Abrasive water jet abrasive garnet 80 mesh. Measure the performance surface microstructure and hardness he was found Abrasive water jet method can be effectively used in industrial applications

Wang et al, (2003) has done work of investigation on abrasive water jet machining12.7mm thick slab cutting of Alumina ceramics. His aim was to assess the influence of Abrasive Water Jet Machining (AWJM) process parameters Nozzle traverse speed on Kerf analysis using Multipass cutting he was observed Multipass AWJ cutting has reduces the kerf taper

Gupta et al,(2014) Minimization of kerf taper angle and kerf width using Taguchi's method marble to investigate kerf characteristics Three different process parameters the results revealed that the nozzle transverse speed was the most significant factor affecting the top kerf width, the kerf taper angle.

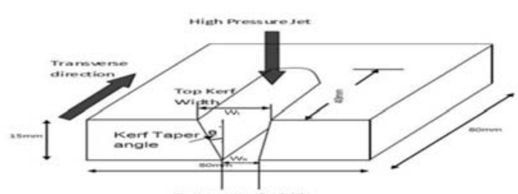

Fig3. Kerf geometry of an AWJ cut

For top kerf width, nozzle transverse speed has emerged as most significant parameter

Khan and Haque (2007) had study on Performance of different abrasive materials during abrasive water jet machining of glass. Different types of abrasives are used present work gives a comparative analysis of the performance of garnet, aluminium oxide and silicon oxide& Carbide as nozzle material

Kara Kurt et al, (2013) cutting Granitic rocks by AWJM using process parameter performance measure on kerf width. Taguchi orthogonal arrays used It is observed that standoff distance and the traverse speed have more significant effects on the kerf Widths.

Kechagias et al, (2012) cutting TRIP 700 CR-FH and TRIP 800 HR-FH steel sheets square but differ in thickness by AWJM using process parameter Taguchi orthogonal arrays used to measure performance kerf geometry and surface roughness it is observed that Nozzle diameter is one of the most important parameters that affects the mean kerf width and surface roughness

Libor et al, (2016) cutting Rocks.by AWJM using process parameter Tool used digital Vernier calliper image processing software measure the performance on Taper of kerfs he was found the taper changes with increasing traverse speed from the divergent to the convergent.

Alberdi et al, (2010) has carried out experiment experiments milling on 7075-T651 aluminium which is mostly applicable in aircraft structures such as wings and fuselages by AWJM using process parameter pressure, abrasive mass flow rate,

Li and Wang (2015) has carried out experiment on drilling (or piercing) and slotting titanium to measure the profile and diameter of The holes. Drilling depth Mitutoyo digital calliper used It was found that both the hole depth and diameter An increase in the water pressure increased both the hole depth and the hole diameter slower traverse speed resulted in a deeper Depth of cut. The kerf showed a taper shape with a wider entry on top, and the width decreased as jet cut into the material.

Azmir et al, (2009) has done work of investigation on abrasive water jet machining of cutting E-glass fibres TGF 800composite.use Garnet and aluminium oxide. Were considered as the most significant Control factor in influencing Ra and TR, respectively.

Srikanth and Rao (2014) Drilling of glass thickness 3mm, 4mm In this experiment optimization of process parameters Metal Removal and kerf analysis obtained in Taguchi Analysis was compared with the Analysis of Variance .

Babu And Chetty (2006) cutting Aluminium. His aim was to assess the influence process parameter methodology used Taguchi's Method and Analysis of Variance he was observed Using single mesh abrasives, a practitioner not only can cut faster but also achieve reduced Surface roughness.

Wang et al, (2014) investigated the machinability and kerf characteristics of Alumina ceramic and a polymer matrix composite Cutting The kerf taper angle also increases with the water pressure. The effect of traverse speed on the top kerf width, bottom kerf width and kerf taper that the top and bottom kerf widths increase with an increase in the standoff distance.

Mustafa et al, (2014) effects Effect of Traverse Speed 80, 130, 180, 230, 280, and 330mm/min are assessed on surface roughness of the machined job, the kerf taper ratio, and kerf wideness In the study Inconel 718 Nickel-Based Super alloy materials performance measure Scanning electron microscope (SEM) and atomic force microscope it is observed that the surface roughness and kerf taper ratio tended to increase with traverse speed

Yue et al, (2015) has done work of investigation on abrasive water jet machining turning on Alumina ceramic Aluminium. Using 80 mesh Garnet abrasive. He was observed The MRR is influenced principally by the water pressure P and the next is abrasive mass flow rate

Parmar et al, (2014) has done work of investigation on abrasive water jet machining AL-6351 Aluminium alloys cutting which the mostly applicable is in Aircraft parts like wings, marine, piping and tubing for industrial work .using Garnet 120, 80mesh abrasive. He was observed Traverse Speed is the most significant control factor for Surface Roughness (Ra)

Srinivas and Babu et al. (2015) has done work of investigation on abrasive water jet machining Tiles Corian aurora Drilling hole using Garnet 120, 80mesh abrasive. He was observed an increase in the abrasive flow rate results in more kinetic energy for material removal, by minimizing the kerf angle.

Patel and Gothwal (2015) has carried out experiment experiments on cutting Titanium by AWJM Using abrasive Al2O3.material Optimization maximum material removal rate Particle Swarm Optimization used It is observed MRR is higher in PSO results than GA results.

Also there is change in abrasive water jet nozzle diameter which leads to higher MRR.

Palleda (2007) he was doing experimentation Drilling on Glass using Silicon carbide of 180 grit size the objective of this study the effect of using different chemicals on material removal rate he was observed material removal to be the highest in the case of a slurry mixed with polymer

Boud et al. (2014) has carried out experiment experiments on cutting Titanium by AWJM using process parameter Federate, Pressures, standoff distance using fanjet nozzle Optimization maximum material removal rate multi-pass machining used It is observed higher MRR is possible for single pass machining, as compared to multi-pass machining

Fowler et al. (2009) The effect of particle hardness and shape when abrasive water jet milling titanium alloy Ti6Al4V the effects of milling parameters on the surface characteristics are investigated when milling a titanium alloy (Ti6Al4V) with different abrasives, namely white and brown aluminium oxide, garnet, glass beads and steel shot. Material removal rate and surface roughness increased when particle hardness is increased Shape factor

Doreswamy et al. (2015) carried out work Graphite/glass/epoxy composite Cutting length of 20mm cut to find the effect of jet operating pressure, federate, standoff distance (SOD) Optimized process parameters kerf analysis using garnet and carbide nozzle methodology used Taguchi & ANOVA They observed that The kerf width increased with an increase in operating pressure but it decreased with increase in feed rate

Schwartzentruber and Papini (2015) examined the parameters that affect target damage during piercing operations in borosilicate glass The effects of stand-off distance (SOD), dwell time and pressure for three nozzles sizes were compared. 80 mesh garnet use Increasing the SOD had a significant effect on hole size and hole aspect ratio with a trend indicating that increasing SOD increased size while improving aspect ratio

Prasad et al, (2015) carried out work to optimize the metal removal rate (MRR) of Stainless steel 403 in abrasive water jet machining using ANOVA and Taguchi method. The MRR is optimize by using three parameters water pressure, abrasive flow rate and stand-off distance and L9 orthogonal array of Taguchi method used to analyse the result. They concluded that the water pressure (WP) was the most influencing factor for stainless steel 403

Nagdeve et al, (2012) investigates Cutting Aluminium. Garnet mesh size of 80implementation of taguchi approach for optimization he was found Pressure is the most significant factor on MRR, In case of surface Roughness Abrasive flow rate is most significant control factor

Rao et al, (2014) carried out work to optimize the metal removal rate (MRR) Cutting of Mild Steel which is used structural steel using l80 mesh garnet in abrasive water jet machining using ANOVA and Taguchi method. The MRR is optimize L9 orthogonal array of Taguchi method used to analyse the result. They concluded Traverse Speed (S) is the most significant factor on SR during AWJM.

Rao et al, (2012)carried out work to Optimize Face Milling Process Milling Inconel 718 optimize the metal removal rate using l80 mesh garnet and carbide nozzle material in abrasive water jet machining using ANOVA and Taguchi method. The MRR is optimize by using three parameters Traverse speed, feed and depth of cut Taguchi method with grey relational analysis.

Azmir et al, (2007) has carried out experiment experiments on cutting of Kevlar 129 composite abrasive Garnet mesh size of #80 by AWJM using process parameter Methodology used Taguchi & grey relational analysis to Optimization surface waviness he was observed The traverse rate is the most significant machining parameter on both Ra and TR

Santhanakumar et al, (2015) has carried out experiment experiments on cutting of Ceramic Tiles cutting abrasive Garnet mesh size Garnet mesh size of #80, #100#120 &sapphire nozzle of diameter 0.76 mm .by AWJM using process parameter abrasive grain size, abrasive flow rate, standoff, water pressure and jet traverse rate Methodology used Taguchi's L27 orthogonal array Grey-Based Response Surface to Optimization Of surface roughness

Unde et al, (2015) Experimental Investigations into Abrasive Water jet Machining of Carbon Fiber Reinforced Plastic is focused on to evaluate the technological factors affecting the machining quality of CFRP laminate using response surface methodology. It is recommended that, in AWJM, higher jet pressure, less standoff distance, and Moderate feed rate will give desirable results

Aultrin and Anand (2014) investigated work on Copper Iron Alloy Cutting 80 mesh garnet size 150mm x 50mm x 50mm Using RSM and Regression Analysis. on metal removal rate (MRR) and surface roughness (SR) of the Copper Iron alloy using regression analysis he has concluded pressure and mass flow rate increases MRR also increase and SR is good, mf increase do decrease again MRR increase and SR is good

Hoogstrate et al,(2002) he was studied water pressure beyond 400 MPa Cutting performance Cutting Material thickness 10 mm AISI Stainless Steel using garnet abrasive of mesh 150 he was found results Increase of pressure will increase the cutting ability of the following advantages Increased cutting speeds or depths of cut. Increased efficiency. Reduced abrasive usage, reducing the cost

Hussein et al. (2005) he was studied GFRP Composite glass fiber-reinforced plastic type 3240 drilling hole which is used optimization of hole methodology use DOE, Anova, Statically analysis Cutting feed, stand of distance, jet pressure, and abrasive mass flow rate are influential parameters in the cutting process

Natarajan and Sen (2014)Investigation of Process Parameters jet penetration, material removal rate, taper ratio, roughness AWJM) Process for D2 Steel Cutting garnet abrasive with different abrasive mesh sizes cutting trapezoidal shape with a maximum thickness of 80 mm Using Taguchi design , relational method and ANOVA test .

Sharma et al,(2011)has carried out experiment experiments on cutting 5– 10 cm thick coal cutting abrasive Garnet & nozzle of diameter 1mm by AWJM using process parameter Methodology used Taguchi—Fuzzy model to Multi response optimization of process parameters he was found parameter which makes a large effect on the kerf width is the standoff distance

Trivedi et al, (2016) has carried out experiment experiments on cutting austenite steel (AISI 316L) cutting which is mostly used in hot water tanks, bridge components 5– 10 cm thick coal cutting abrasive Garnet 80 mesh surface roughness tester used optimization on cutting Performance on surface finish he was found (1) TR is the most significant parameter to influence the surface roughness (*R*a).

Yuvaraj and Kumar (2015) has carried out experiment experiments on cutting aluminium alloy Cutting which is mostly used marine, automotive, aerospace, railway applications cutting abrasive Garnet 80 mesh & tungsten carbide nozzle diameter 1.1 mm He was observed P was found to be the most significant factor in the multi performance characteristics

Zhong and Han (2015) has carried out experiment on Borosilicate glass 25mm in diameter turning process cutting abrasive 100 mesh-size Olivine & sapphire by AWJM using process parameter he was found The results showed that higher traverse rates were associated with an increase in material removal rate and thus an increase in surface roughness Good surface finish was achieved at lower Traverse speeds and higher turning speeds.

Manimaran and Kumar (2013) has carried out experiment on AWJM using process parameter work speed, depth of cut, and cooling environments Multi responseOptimization of process parameters methodology using Taguchi

Iqbal et al. (2011) has carried out experiment on two ductile materials: AISI 4340 cutting by AWJM using process parameter effects Multi response methodology using Taguchi's design Full factorial design ANOVA analysis he was found It was found that cutting feed and thickness were highly influential parameters, while abrasive mixing rate is influential upon surface Roughness only.

Paul et al, (1998) has carried out experiment on C-37 Steel (low carbon steel) rectangular pocket milling by AWJM using process parameter abrasive particles, the traverse speed, the stand-off distance and the transverse feed Cutting abrasive Garnet 60mesh & sapphire nozzle Optimization of process variation in the depth of the pocket seems to decrease at higher transverse feed, water pressure, higher transverse speed and lower Mass flow rate of the abrasive particle.

Srinivasan et al, (1998) has carried out experiment on Aluminium-silicon carbide particulate metal matrix composites CUTTING trapezoidal shaped specimens by proper choice of abrasive mass flow rates and jet traverse speeds are of considerable importance over the other parameters like water jet pressure

Aydin et al**, (**2013) has carried out experiment on Granitic rocks thickness of 3 cm, length of 20 cm and width of 10 cm Cutting depth by AWJM using of process parameters variation in the cut depth of the penetration methodology using Taguchi, regression analysis he was found cut depths decreased with increasing traverse speed and decreasing abrasive Size.

Escobar et al, (2012) has carried out experiment on Inconel 718 pocket milling 20 x 20 mm pocket geometry methodology using statically analysis he was found Water pressure has a non-linear behaviour and is of paramount importance for controlling the depth of cut and geometrical errors.

Zhang et al, (2013) has carried out experiment on Aluminium 6061T Cutting Optimization of process parameters variation in front profile methodology using Orthogonal array L9, Dial indicator he was found Profiles Of the cutting front are real parabolic curves. Therefore, using a parabolic curve to fit the AWJ cutting front is good enough.

Shaikh and Ambardekar(2015)has carried out experiment on Metal-Polymer-Metal Laminate Cutting 15 number of cuts by maintaining pitch distance at least 2 mm102*50*10 mm (DOE)he was found Based on analysis of variance, abrasive water jet pressure and traverse rate are most significant over Stand-off distance. As water jet pressure increases, depth of cut increases. As traverse rate increases, depth of cut decreases

Ebeid et al, (2014) has carried out experiment on aluminium alloy (30x120x250 mm). Alumax Milling Process Parameters surface roughness, depth of cut and material removal rate methodology using Artificial Neural Networks he was found based the results show that the increase of traverse speed decreases depth of cut, MRR and surface roughness.

Zhong and Han(2003)has carried out experiment on Aluminium plates of 1000 series were cut into 300mm x200mm size Four Water jet Nozzles cone-jet and fan-jet nozzles, As water jet pressure increases, depth of cut increases. As traverse rate increases, depth of cut decreases

Nanduri et al, (2002)The effects of system and geometric parameters on abrasive water Jet nozzle wear Nozzle wear phenomenon in the abrasive water jet (AWJ) system was investigated by accelerated testing of nozzles through systematic variation of the nozzle geometric and AWJ process parameters

Lemma et al, (2005) Maximum depth of cut and mechanics of erosion in AWJ oscillation cutting of ductile materials presents a semi-empirical model that can be used for predicting the maximum depth of cut in both oscillation and normal cutting

Kolahan and Khajavi (2009) studied the effects of process parameters settings on Abrasive Water jet machining of 6063-T6 aluminium alloy have been investigated.

Statistical regression analysis have been employed to develop mathematical models

Aich et al, (2014) carried out experiments on cutting of borosilicate glass by AWJM. Depth of cut is measured with different machine parameter settings as water pressure, abrasive flow rate, traverse speed and standoff distance

Kara Kurt et al, (2011) he was carried experiment Granite Cutting 3cm different mesh abrasive Garnet Mesh 80,100 and nozzle diameter 1.1mm work on optimization of kerf angle abrasive water jet machining process parameters using Taguchi's Method, From ANOVA it is found that most significantly affecting on kerf angle of granite traverse speed and stand of distance, water pressure increase kerf angle

Alberdi et al (2013) he was found

machinability model in composite materials

The results show that composite materials have a significantly higher machinability index than metals which means that composite materials can be cut significantly faster than metals The machinability model can be used to adapt the traverse feed rate for the required roughness

Narayana et al, (2012) investigated work on optimization process parameters are chosen as abrasive flow rate, pressure, and standoff distance. From ANOVA it is found that water jet pressure has more significant effect on kerf width and MRR rather than abrasive flow rate and standoff distance.

4. SUMMARY OF LITERATURE

So many investigations so far had done on AWJM process. Study of process parameters such as abrasive flow rate, traverse speed, standoff distance, pressure, abrasive size, orifice diameter and performance measures as Surface roughness (SR), Material removal rate (MRR), kerf width, Depth of cut (DOC) is carried out more by researchers. From the literature review it is observed that mostly combinations of process parameters like abrasive size, traverse speed, standoff distance and performance measures as DOC, SR, and MRR are investigated. MRR or production is improved by increasing the traverse speed and abrasive flow rate but major problem with increasing traverse speed is that surface roughness and kerf quality are decreased. By increasing abrasive flow rate MRR increases but, decrease surface roughness. So it is important to find the optimum conditions for AWJM operation.

5. Future scope

But less work has been reported Inconel, ceramic and drilling on Multi-objective optimization of AWJM process. Also very little work has been reported on effect of nozzle and orifice diameter. So, more work is required to be done in this area. Selection of the proper process parameter is the important task for the proper experimentation. Several parameters directly and indirectly affect the cutting process, actual machine constrained and literature review provides support to selection process

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