Some Technical Issues and Critical Assessment of Abrasive Water Jet Machining (AWJM) Process

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Abstract: ***This paper is focused on reviewing previously carried out work and written in literature. Non- conventional abrasive water jet technology is being utilized to machine variety of metals, their respective alloys and nonmetals. Mainly concentrated on Titanium alloys and difficulty in its machining. Numerous variables associated with the technology and their consequence on response variable were analyzed and summarized in this review. Paper conclude numerous gaps in research along with future scope.***

Keywords: ***Abrasive water jet machine, Erosion rate, Titanium alloys, Abrasive Mass flow rate***

I. INTRODUCTION

AWJM was first established as technological method in 1930. The non-traditional AWJ Machining practice, grounded on pressured abrasive-waterjets, was commercially used in 1983. AWJM then onward being utilized for direct cutting of castings, plates as well as shaping of sheets, plates, and castings in extensive choice of materials. It found application in a number of diverse industries. As, in the aerospace, automotive, foundry, and ship production. Materials composed with glass, aluminum, Inconel, different grade steel, casted form of iron, titanium, and various composites have been machined with AWJs without affecting their principal properties. Current research happenings are flooring the way for utilizing this know-how in such carving methods as drilling of micro holes, cavities, turning, and milling [1].

Table 1 Independent Variables of AWJM [1]

Parameters of AWJ			Parameters of Machining Application
Hydraulic Parameters	**Abrasive Parameters**	**Mixing Parameters**	
Pressure	Size	Mixing tube diameter	Traverse rate
Water flow rate	Material	Mixing tube length	Number of passes
	Settings (dry, slurry) AMFR		SOD,
			Rotational speed Lateral feed and Dwell period

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The response variables are classified in two category one is quality based another is quantity based. Quality base machining outcomes includes heat affected zone heat-affected zones, embedment and strain hardening, are not noteworthy with veneration to AWJ Machining. Discussion of above said variables is not important. Surface finish, kerf tapering/ width are noteworthy quality variables. Quantity aspect consider material removal rate.

Examples of measures for optimization comprise the following:

I. Least material removal cost
II. Extreme cutting speed
III. Extreme surface finish

The abrasive water jet Machine (AWJM) utilize a gush of mini abrasive particles; presented and entrained in the liquid jet in a way that water jet's thrust is moderately shifted to the abrasive particles. The character of transporter water is principally to accelerate huge numbers of abrasive particles into a high velocity and create an extremely consistent jet [2].

Water stored in reservoir/tank is propelled to intensifier utilizing pump, which rise pressure ranging from 2 MPa to 4 MPa. Accumulator temporarily store pressurized water and supply whenever required for processing without any fluctuation in pressure. Pressure energy is converted into kinetic energy utilizing fine nozzle and generate exit velocity of the order of 1000 m/s. Mixing chamber being inbuilt part of nozzle where abrasives supplied from feed hopper get mixed with pressurized water. Mixed stream entrained onto to specimen which is to be process. Finally drain/ catcher collect water and abrasive which is supplied to tank and hopper [3,4]. At the end of the machining abrasive still possess high level of energy which is subjected to type of application. Containing of this energized abrasive jet is necessary because it may damage machine parts or operator and may violate safety norms. Residual energy is absorbed and dissipated by "Catcher". There are three diverse types of catcher (a) water basin type (b) submerged steel balls (c) TiB_2 plate type [4]. AWJ is a technique to erode materials, in which abrasive particles go into a coherent water jet which are enhanced to high velocities due to pressures. Supersonic jet is generated by fine nozzle. Surface of the specimen is invaded by particles lead by water jet and substantial is detached by erosion procedure. The complex erosion process depends upon numerous variables mentioned in previous section and type of carving materials. Erosion of ductile stuff takes place by ploughing and micro cutting action while brittle material is eroded by crack formation and propagation action

Among all Non-Conventional Machining methods, the AWJM method inherently considered as an environment responsive or green work process. AWJM process does not modify belongings of stuff machined. In contrast with traditional machine-driven cutting systems, AWJM necessitates neither cooling nor lubrication, therefore no chemically polluted chips to be discarded of. In addition, the AWJM process produces no noxious gases and involves negligible pre-processing. Besides, the nominal scrap that remnants are recyclable and chemical infection free, which marks in raw material, energy, and expenditure savings for recyclable ingredients [3].

Titanium being light weight metal offers very good decomposition resistance, a leading strength-to-weight share and decent high-temperature belongings. Untainted titanium shows allotropic behavior, it has HCP crystal at room temperatures which is denoted as α phase while BCC structure (beyond 882° C) denoted as β phase). Strengthening of solid solution as well as phase transformation are greatly influence by Alloying elements. α-β alloys named as Ti-6Al-4V, utmost used in the aeronautical industry. It books for about fifty percent of entire titanium production. Fig. 1.1 shows the phase diagram.

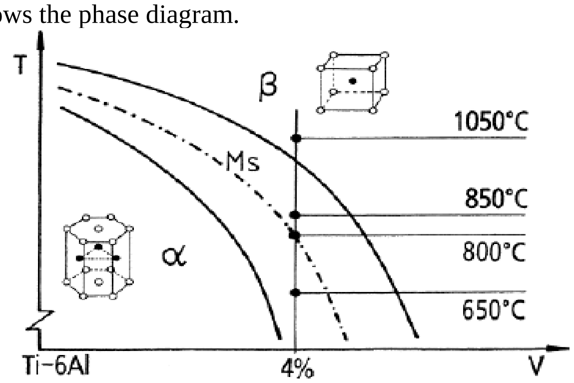

Fig. 1.1Phase Diagram

Machining of said alloys is difficult and key difficulties associated are high machining temperatures and faster wearing of tool. Maximum tool materials rapidly wear even at judicious cutting speeds. To diminish tool wear, present machining exercise limits the speed. Below mentioned factors explain [A– D] [5].

A. Low thermal conductivity of titanium alloys. This is resulting in difficulty in dissipating heat produced speedily; rather, maximum heat is concerted at tool face and cutting edge.
B. Due to alloying tendency, material clog and weld with tool material and enhance tool wear.
C. These alloys show Thermal plastic deformation and produces uneven chips, which are limited to narrow zone.
D. Stresses are focused at cutting edge due to short contact length.

Researchers have developed numerous tool material which can machine materials (having difficulty in machining) at prominent MRR. However, titanium shows chemical reactivity therefore developed tool material are not operative for machining of titanium alloys. Even tool coating seems to be inefficient for the same. Aluminum Oxide coating has less thermal conductivity to that of WC inserts, which restrict heat dissipation from the cutting point which is highly stressed and hot. Consequently, cryogenic machining, which reduces the cutting temperature and boost chemical steadiness of tool and work-piece. It may improve productivity of these alloys [5].

II. LITERATURE REVIEW

Hashish [01] He has tried to summarize the generalized effect of all possible parameters associated with AWJ Machine with the help of experimentation on various alloys. Optimization of parameters with AWJ Machining is exaggerated by various aspects related to different boundaries, impressive properties of jet formation, charges, ecological anxieties, and behavior of the material erosion process. Summary of the significance is given below in table.

Pawar & Rao [02] They Have considered optimization of process parameter of three machines which include non-conventional machine AWJM and conventional grinding and milling machine**.** Teacher learning based optimization technique used to optimize machining parameter. They have also compared optimization result with other optimization technique like GA, SA, PSO etc. Comparison results shows that TLBO is more accurate and superior to others.

Wong et al. [03] They have revealed with the help of experiment result considering SOD and transverse speed as input variables influencing kerf ratio. Delamination s were inclined by flow rate, traverse rate, and pressure. The harm of kerf ratio and delamination may be overcome at lower cutting speed.

Li & Jun [04] They have performed drilling and slotting operation on Ti-6Al-4V. Drilling time and influence of water pressure were investigated for drilling experiment. Impact of water pressure and transverse speed was considered for cutting of slits. They observed that Rise in water pressure and drilling time increasing both diameter and depth but deeper cut found at lower transverse speed. When transverse speed increased discrepancy of depth of cut turn into insignificant.

Hong et al. [05] They studied temperature effect on Stuff possessions and cooling contemplations of Titanium alloy with the help of New cryogenic cooling approach considering economy. Considered machining tactic require least amount of liquid nitrogen which was supplied through micro-nozzle at chip breaker and tool rake. This approach provides the finest tool life than any other carving technology.

Seo et al. [06] They selected Titanium alloy Ti-6Al-4V for machining which was performed at different condition. They used instruments for microstructural features of machined surface which were surface profilometry, SEM and EDX. Variable transverse speed used in experiments and 0.7 mm/s was found to be most suitable speed for the finest surface finish. Material is generally removed by ductile shearing in ductile material while crack propagation in brittle material.

Perec et al. [07] They scrutinized the consequence of Pressure, flow rate of abrasive & transverse speed while machining of alloy steel using AWJM was analyzed in this paper. Results reveals that the pressure was found to be most substantial parameter followed by AMFR and transverse speed.

Santhanakumar et al. [8] They have surveyed the consequence of AWJC variables on the roughness and taper angle of cut as response variables. Selected workpiece was ceramic tiles. Grey base response surface technology used to attain the optimal level of AWJC variables.

It was observed Both the response will improve with rise in flow rate and water pressure and decline with grain size, SOD and transverse speed.

Alberdi et al. [09] They analyzed the consequence of the input variables e.g. stack arrangement, cutting tool and pressure and transverse speed. Response variable were considered over kerf contour, taper angle and roughness of stacks. Stacking was done between CFRP/ Ti-6Al-4V. Taper angle was found positive in Ti-6Al-4V while a negative in CFRP. At 95 mm/min surface roughness was lowered up to 6.5 μm once CFRP/Ti-6Al-4V arrangement was used. The cutting tool was noteworthy for the taper angle attained in Ti-6Al-4V, while it was an insignificant factor for CFRP material. The most substantial aspect for the mean roughness was the traverse rate tailed by stacking and pressure.

Lv. et al. [10] They carried out the investigations in ultrasonic-assisted abrasive water jet machine of erosion. FEM simulation was utilized for machining simulation. Possessions of impact angle and particle form on the destruction rate were considered. Residual stress induced by the erosion in workpiece was compared under the vibration to non-vibration condition. Furthermore, the ultrasonic-assistance destruction processes of numerous particles on the impact areas under different overlapping conditions were simulated. Simulation shows the erosion process can effectively improve by ultrasonic assistance and influence contact process between particles and workpiece. Simulation results shows attainment of extreme destruction rate for blunt particles at impact angle of 90° and for sharp particles it is 30°. MRR was higher under vibration condition with higher consumption of energy.

Bhowmik and Ray [11] They have considered variables which include abrasive grain sizes, AMFR, pressure, SOD, nozzle speed. Green composite was considered as workpiece material and surface roughness as response variable. Fuzzy logic model was proposed with experimentation using AWJM. Optimal variables for AWJM attained 100 mesh AMGS ,3.5 mm SOD, 225 MPa Pressure, 3 g/s AMFR and 225 mm/min was Nozzle Speed. Taguchi analysis was based on average SR. ANOVA investigation outcomes shows that, AMGS and AMFR are the record prompting response variables aimed at green AWJM.

Wu et al. [12] They have presented innovative method for chasing precision of jet lag info in non-transparent material. A series of actions taken to acquire accurate jet lag evidence, which includes embrace stopping cutting process at stable traverse speed phase, monitoring abrasive feeding process and computing jet lag. It was measured using high resolution camera. The measurement outcomes displayed that jet lag may be branded by parabolic curves very well.

Hreha et al. [13] They used PCB IMI type sensor specified as 607A1. The sensor was fitted to stainless steel specimen. They noted vibration during machining. Lesser values of vibrations were noted at higher AMFR. In the high frequency zone high peaks were noticed because of higher AMFR. These results can be utilized for online monitoring of abrasive water jet machine.

Phokane et al. [14] They presented the enquiry on SR, tribology and wear characteristics. Brass material was considered to produce miniature gears utilizing abrasive water jet machine. Surface roughness was directly influenced by rise in pressure and AMFR. Decrease in SOD improve the surface finish. Pressure was recognized as the greatest noteworthy factor disturbing the SR.

Fowler et al. [15] They uncovered the fact that no of passes does not affect surface morphology. Grit embedment was higher in forward milling while it was lower in backward. With a higher jet, transverse speed milling direction does not influence grit embedment.

Fowler et al. [16] They revealed the effect of transverse speed, milling direction, grit size and no of passes while machining titanium alloy with AWJ-CDM. Surface waviness increase with no of passes while surface roughness is independent of the same. Higher transverse speed results in lower MRR. The MRR, surface roughness and waviness were lower for minor grit.

Hascalik et al. [17] They performed Machining under varying traverse speeds utilizing (AWJM). Three zone IDR (initial damage region) at a shallow attack angle, SCR (smooth cutting region) at large attack angle. RCR (rough cutting region) jet upward deflection zone. The traverse speed seems to be a substantial variable SCR depth.

Fowler et al. [18] They have considered process variables under examination traverse speed, shape and abrasive particles hardness. With rise in particle hardness material erosion rate and surface roughness improved. Surface waviness was unaffected due to shape & particle hardness.

Kong and Axinte [19] They revealed about geometrical accuracy, surface texture and surface morphology with newly defined width to nozzle fraction and depth to thickness fraction along with the ability of AWJ to machine Titanium Aluminum alloys. The machining variables to attain the best kerf in terms of geometrical correctness & surface quality has been instituted (pressure 50 KPa, MRR 220 mm^3/min, AFR 0.773 kg/min and SOD 1 mm).

Boud et al. [20] They performed test at traverse speeds of 50&400 mm min^{-1} on Ti-6Al-4V. 14 mm titanium plate five garnet abrasives were employed. These abrasives were taken from dissimilar source. Cutting efficacy and grade of grit embedment found same for the all abrasive types., irrespective of morphologies (connected to dissimilar sources), hardness and rupture loads.

Yue et al. [21] They utilized radial mode AWJ turning process to machine alumina ceramic. Consequences of pressure, jet speed, AMFR, surface speed and nozzle tilting angle were investigated using ANOVA and SAO. ANOVA gives satisfactory prophecy of MRR and SR. SAO provides the optimum set of input variables.

Yuvaraj and Kumar [22] They have revealed optimized groupings of the AWJ process variables as pressure 300 MPa, traverse rate 120mm/min, AMFR 360 g/min, and SOD 1mm. said combination gives maximum cut depth and erosion rate while minimum SR, taper ratio, and top kerf width.

Ibraheem et al. [23] They noticed that Cutting process of GFRP utilizing AWJC, cutting feed, SOD, pressure, and AMFR were dominant parameters. AMFR was higher while pressure and SOD were lower, which resulted improved response. The targeted responses include accuracy in dimension, cost reduction and cut quality. The productivity at with very low level of degree of delamination was obtained.

Kumar and Shukla [24] They resulted in noteworthy distinction of crater geometry for impact of initial seventeen particles. They considered velocity and taper angle as input variables.

The FE model propose a chief extension over the models as revealed in reported work till then. They utilized this model first time for titanium alloy. This model helps in restraining trials required. Later on, an attempt will be passed out to progress a full model to simulate AWJ.

Momber and Kovacevik [25] They found artificial rock material very sensitive to the test parameters. Influence of these parameters found to be non-linear. Saturation cut depth was attained at extreme pressure, low transverse speed and extreme abrasive flow rate.

A. Abbreviations and Acronyms

Abbreviations	Description
AMGS	Abrasive Material Grain Size
AMFR	Abrasive Mass flow Rate
AWJC/AWJM	Abrasive Water Jet Cutting/Machining
CDM	Control Depth Milling
CFRP	Carbon Fibre Reinforced Plastic
DOP	Depth of Penetration
EDX	Energy Dispersive X-Ray
GA	Geometrical Algorithm
IDR	Initial Damage Region
JKER	Jet Kinetic Energy Rate
MRR	Material Removal Rate
PSO	Particle Swan Optimisation
RCR	Rough Cutting Region
SA	Statistical Algorithm
SAO	Situation Action Outcome
SCR	Smooth Cutting Region
SEM	Scanning Electron Microscope
SOD	Stand-off Distance
SR	Surface Roughness
TLBO	Teaching Learning Based optimisation
TCR	Taper Cut Ratio

Table III Significance of Awj Parameters On Machining Results[01, 27, 28]

	AWJ Variables						
Input► Output▼	**Pressure**	**Water jet orifice dia.**	**Mixing tube diameter**	**Mixing tube length**	**Abrasive mass flow rate**	**Particle diameter**	**Material**
Material Removal Rate	Most	Most	More	Less	Most	More	More
Depth of Cut	Most	Most	More	Nil	Most	More	More
Width of Cut	Less	Nil	Nil	More	Less	Nil	Nil
Surface Waviness	More	More	Less	Less	More	Less	Less
Surface Roughness	More	More	Nil	Nil	Less	Most	More
Cost of Cutting	Less	Less	Less	Less	More	Nil	Nil

Table- IV Literature Review Table

Year and author	Material	Input parameter	Output parameter	Technique used	Results and discussion
Hashish 1991 [1]	Inconel, cast iron and others	Detailed study of all possible parameters	MRR, Surface roughness, surface waviness, depth of penetration, width of cut and running cost		Optimization of parameters with AWJ carving is exaggerated by various aspects related to different boundaries, impressive properties of jet formation, charges, ecological anxieties, and behavior of the material erosion process.
Pawar and Rao 2012 [2]		Water jet pressure, nozzle diameter, feed rate of nozzle, mass flow rate (water &abrasives)	MRR	TLBO	Three carving processes are optimized using TLBO algorithm. Comparison results with other techniques like PSO, GA, SA, etc. shows that TLBO is more accurate and superior to others.

Wong et al. 2016 [3]	FRP hybrid composite	AMFR, pressure, SOD and transverse rate	Kerf ratio and delamination factor	RSM	1. kerf ratio was chiefly inclined by the SOD and traverse rate. 2. Delamination of individual sides were by input variables as considered by author except transverse rate. 3. The harm of kerf ratio and delamination may be overcome at lower cutting speed.
Li et al. 2015[04]	Ti-6Al-4V	Water pressure, drilling time and transverse speed	Depth cut and hole diameter		Rise in water pressure and drilling time increasing both diameter and depth but deeper cut found at lower transverse speed.
Hong et al. 2001 [05]	Ti-6Al-4V	Temperature	Material belongings and cooling attentions	New cryogenic cooling and Design Execution	1. Economical cryogenic carving approach utilizes minimal measure of fluid nitrogen through smaller scale spout between chip breaker & tool rake. 2. This approach offers the greatest tool life than any other production method.
Seo et al. 2003[06]	Ti-6Al-4V	Pressure, garnet size, SOD and traverse speed	Profiles, kerf geometries and microstructure	Surface profilometry, SEM and EDX	1. The transverse speed of 0.7mm/s was seen as most suitable speed for the best surface finish. 2. Presented resulting action of abrasive particles for material removal process. 3. Ductile material erodes by ductile shearing while brittle by crack propagation.
Perec et al. 2017 [7]	Alloyed steel	Pressure, AMFR and transverse speed	SR	Taguchi	Pressure is found to be most noteworthy parameter trailed by abrasive flow rate and transverse speed.
Santhanakumar et al. 2015[8]	Ceramic tiles	abrasive grain size, AMFR, SOD water pressure & jet traverse rate	SR and taper angle in cut	Taguchi L_{27} and Gray based RSM	1. Both the response will improve with rise in flow rate and water pressure & decrease in grain size SOD and transverse speed.
Alberdi et al. 2015 [9]	CFRP/Ti-6Al-4V stacks	Stack configuration, pressure traverse feed rate, AMFR and cutting tool	Taper angle, kerf profile and SR	ANOVA	1. Taper angle is found positive in Ti-6Al-4V and negative in CFRP for all cutting circumstances. 2. Surface finish is greatly influenced by feed as compare to stacking and pressure.
Lv et al. 2015 [10]	Ceramic	Impact angle & particle shape	MRR	FEM	1. Simulation results shows attainment of extreme destruction rate for blunt particles at impact angle of 90° and for sharp particles it is at 30°. 2. MRR was higher under vibration condition with higher consumption of energy.
Bhowmik and Ray 2019 [11]	Green composite (sundi wood dust with epoxy resin)	AMGS, pressure, SOD, AMFR and nozzle speed	Surface roughness	Taguchi and FUZZY Logic	1. Optimum input variables for green AWJM obtained at using Taguchi method. 2. AMGS and AMFR are most significant parameter as per ANOVA analysis.
Wu et al. 2014 [12]	Glass, circular copper sample	AMFR and transverse speed	Jet lag	ANOVA	The measured outcomes presented about jet lag which may be categorized by parabolic curves.

Rheha et al. 2014 [13]	Metal	AMFR, transverse cutting speed and focusing tube diameter	Vibration	LabVIEW 8.5 software	1. Lesser variables of vibrations were noted at higher AMFR. 2. In the high frequency zone high peaks were noticed because of higher AMFR. 3. These results can be utilised for online monitoring of abrasive water jet machine
Phokane et al. 2018 [14]	Miniature brass gear	Water pressure, AMFR and SOD	SR	Taguchi, PSO	1. Surface roughness was directly influenced by rise in pressure and AMFR. 2. Decrease in SOD improve the surface finish. 3. Pressure was recognized as the greatest noteworthy factor disturbing the SR
Fowler et al. 2005[15]	Ti-6Al-4V	Transverse speed and no of passes	Surface morphology		1. Surface morphology was unaffected by multiple passing of jet. 2. Grit embedment is higher in forward milling while it is lower in backward milling. 3. With a higher jet, transverse speed milling direction does not influence grit embedment.
Fowler et al. 2005 [16]	Ti-6Al-4V	Effect of transverse speed, milling direction, grit size and no of passes	Surface morphology	AWJ-CDM.	1. Surface waviness improve with no of passes while surface smoothness is independent of the same. 2. Higher transverse speed results in lower MRR. 3. For small grit MRR, surface roughness and waviness were reduced.
Hascalik et al. 2007[17]	Ti-6Al-4V	Transverse speed and angle of attack	Damaged region (IDR)		In this paper, the author identified three zone 1) IDR at shallow attack angle. 2) SCR at large attack angle. 3) RCR at jet ascendant deflection zone. 4) The traverse speed seems to be a noteworthy variable on SCR depth.
Fowler et al. 2009[18]	Ti-6Al-4V	Traverse speed, and abrasive particles shape and hardness			1. With increase in particle hardness MRR and SR increases. 2. Surface waviness is unaffected by particles shape and hardness.
Kong and Axinte 2009 [19]	Ti-6Al-4V	Width to nozzle ratio and depth to thickness ration	Geometrical accuracy, surface texture and surface morphology		1. The carving variables to attain the best kerf in geometrical correctness & surface eminence instituted. 2. Said combination may accomplish reasonable results.
Boud et al. 2010[20]	Ti-6Al-4V	Traverse speeds, garnet size and abrasive type.	Grit embedment, surface morphology		The cutting efficacy and grit embedment grade were nearly same for each abrasive type utilized, irrespective of morphologies (associated to diverse sources), hardness and rupture loads.
Yue et al. 2013[21]	Alumina ceramic	Water pressure, AMFR, jet feed rate surface speed and nozzle tilting angle	MRR	ANOVA and SAO method in RSM	1. Radial mode AWJM turning process can be utilised to accomplish higher erosion rate. 2. ANOVA provide satisfactory prediction of MRR and SR. 3. SAO method gives optimised process parameters.
Yuvaraj and Kumar 2015 [22]	AA5083-H32 Aluminium alloy	Pressure, TR, AMFR & SOD	DOP, Cutting rate, SR, TCR and top kerf width	TOPSIS, ANOVA	1. Enhanced groupings of the AWJ process variables as pressure 300 MPa, speed 120 mm/min, AMFR 360 g/min, and SOD 1mm. 2. Combination gives maximum cut depth and erosion rate while minimum SR, taper ratio, and top kerf width.

Ibeaheem et al. 2014[23]	GFRP composite	cutting feed, fibre density, pressure, SOD, and AMFR	Surface roughness, tensile strength, dimensional accuracy and cost	ANOVA and Numerical Optimization	A higher level of cutting feed and AMFR to a lower pressure level & SOD prevail upon improved cut quality, dimensional correctness, least expanse, and maximum yield, with very low level of degree of delamination.
Kumar and Shukla 2011[24]	Ti-6Al-4V	Velocity and impact angle	Erosion rate, no of particles and crater sphericity	FEA simulation	1. They resulted in noteworthy distinction of crater geometry for impact of initial seventeen particles. 2. They considered velocity and taper angle as input variables. 3. The FE model propose a chief extension over the models as revealed in reported work till then. 4. They utilized this model first time for titanium alloy. 5. This model helps in restraining trials required.
Momber and Kovacevic 1997 [25]	Artificial rock	Pressure, transverse speed and AMFR	Depth of cut and specific energy	Regression analysis	1. The material was found very sensitive to the test parameters. 2. The influence of input variables was found to be non-linear. 3. Saturation cut depth was achieved at extreme pressure, low transverse speed and high AMFR.

III. RESULTS AND DISCUSSION

Study of written work provides the understanding of AWJM. Literature also reveal the scope of work and gap in the previous study. Some of the identified gaps are listed below.

3.1 RESEARCH GAPS:

1. Literature shows that there is scope of study the combined effect of machining variables on more than one output variable.
2. Machining of Ti-6Al-4V alloy using AWJM may be studied with more input parameters and their effect on various output parameters.
3. Vibration analysis can be utilised for condition monitoring of AWJM, to control AMFR.
4. Stacking of different materials and effect of performance parameters can be considered for further study of AWJM.
5. Consequence of machining variables on the surface roughness of miniature brass gears and can be manufactured other materials.

3.2 SCOPE OF WORK:

After reviewing, it was observed that optimization of process variables while machining of Ti-6Al-4V alloy utilizing AWJM has very good scope of research as listed in the research gap [29, 30]. Out of the specified gaps the problem is may be selected. Material may be selected on the basis of properties, applications, and difficulty level of machining using conventional technique. Numerous optimization techniques are listed in the review out of which one or more may be selected for analyzing and summering the experimental data.

IV. CONCLUSION

Literature in tabular form has summarized the material utilized by numerous researchers for AWJM. Various technique for result analysis also listed along with input process variable and response variable. Research gaps provide glance of future scope out of which problem may be identified and studied.

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