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A Review on Abrasive Water Jet Cutting Machining Due to Optimization, Advantages, Weakness and Future Directions

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***Abstract* – Abrasive water jet cutting [AWJC] is the machining technology with distinct advantages over the other non-traditional cutting technologies, such as no thermal distortion, high machining versatility, minimum residual stresses on the work piece and high flexibility and small cutting forces.**

The process parameters which are mainly influenced the quality of cutting in AWJM are pressure of water, stand-off distance, nozzle diameter, traverse speed, an abrasive flow rate and abrasive size. The quality parameters considered in AWJCM are kerf Characteristics (KC), Surface Roughness (SR), Material Removal Rate (MRR), Depth of Cut (DC) and Nozzle wear (NW). Various mathematical models and modern approaches are applied to an optimize process parameters to improve the performance characteristics.

This paper reported on AWJCM research relating to improving performance measures, monitoring and control of the process, optimizing the process variables, applications for different types of materials, advantages and disadvantages of AWJCM, also the future trend of research work in the same area are reported in this paper.

***Keywords* – Abrasive water jet cutting machining, Process parameters, Process optimization, Monitoring, Control, Advantages and disadvantages.**

I. INTRODUCTION

Advanced manufacturing processes is the processes of material removal rate by advanced ways such as chemical dissolution, etching, melting, evaporation, and hydrodynamic action sometimes can be used with assistance of fine abrasive materials. A major advantage of these processes is that their efficiency is independent of work piece material.

When selected and applied properly advanced machining processes, major technical and economic advantages can be achieved. [4], [5]

Advanced manufacturing processes such as water jet cutting are used for the situations in which the traditional methods are not satisfactory, not economical, or even impossible, for many reasons such as: The strength and hardness of the work piece are very high, work piece is too brittle to be machined without damage, the work piece is too flexible or too slender to withstand forces in machining or grinding, or parts are difficult to clamp in fixtures and work holding devices, the shape of the part is complex, Special surface finish and Dimensional tolerance requirements exist that cannot be obtained by other manufacturing processes or are uneconomical with alternative processes and the temperature rise during processing and residual stresses developed in the work piece are not desirable or acceptable. [2]

Cutting is an essential process for manufacturing industry. For many years, research has kept continuing on various cutting processes including thermal and mechanical methods. Also versatile and an effective cutting process, which has been developed in recent years, called water jet cutting technology is explained thoroughly. Moreover, this technology is compared with other traditional and non-traditional cutting methods in some aspects. [3]

A water jet cutter known as water jet machining or water jet, is an industrial tool capable of cutting a wide range of materials using a very high pressure jet of water, or a mixture of water and an abrasive material. The term abrasive jet refers specifically to the use of a mixture of water and abrasive to cut hard materials such as metal or granite, while the terms, pure water jet is the cutting without the use of added abrasives materials, often used for softer materials such as wood or rubber. [1]

Water jet cutting is often used during the fabrication of machine parts. It is good method for materials are sensitive to the high temperatures. Also used in various industries, including mining and aerospace, for cutting, shaping, and reaming. [1]

I.1 the AWJCM process

An abrasive water jet is a jet of water that contains some abrasive materials, like aluminum oxide, silicon carbide, sodium bicarbonate, dolomite and glass with varying grain sizes [6]. High pressure abrasive water jet cutting is essentially an erosion process which involves two distinct mechanisms depending upon whether the work piece is ductile or brittle in nature [7]. In an abrasive water jet cutting process, water goes through the small orifice with very high pressure (normally about 4,000 bars) and enters the mixing chamber with a very high velocity (normally about 900 m/s). In mixing chamber, abrasive particles along with water jet are drawn into the nozzle. This mixture containing water, abrasive particles and air. The air leaves nozzle has a lot of kinetic energy and velocity, the abrasive particles have an effect wearing and machining when they impact work piece surface. [8], [9] . The Schematic diagram of an abrasive water jet cutting system is shown in
Fig.1below:

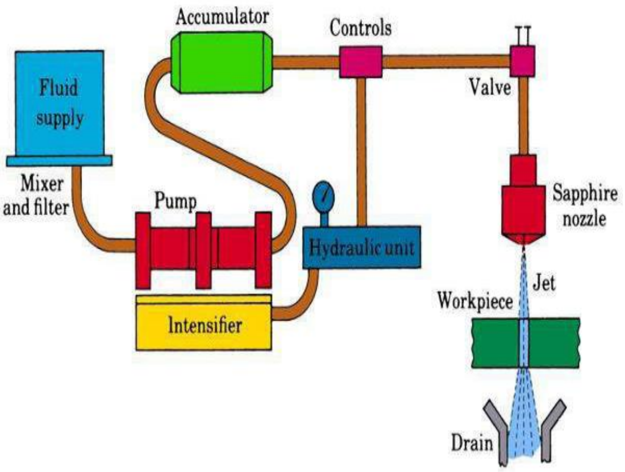

Fig.1. Schematic of an abrasive waterjet cutting system [86].

In addition to water jet cutting advantages it has been proven to be an effective technology high flexibility and small cutting forces [10], [11]. It is superior to many other cutting techniques in processing a variety of materials and has found extensive applications in industry [12]. However, AWJC has some limitations and drawbacks. It may generate some noise and a messy working environment. It may also create tapered edges on the kerf, especially when cutting at high traverse rates [13], [14]. As in the case of every machining process, the quality of the AWJC process is significantly affected by the process tuning parameters [15], [16]. There are numerous-associated parameters in this technique. They are water pressure, waterjet diameter, and nozzle traverse speed, the number of passes, standoff distance, impact angle, diameter of nozzle, nozzle length, mass flow rate, an abrasive particle diameter, an abrasive particle shape and abrasive particle hardness. Among these parameters water, pressure, abrasive flow rate, jet traverse rate, standoff distance and diameter [17], [18].

The technique by using high pressure water for cutting materials was the first time presented in 1968 by a researcher in the USA ,but the fast development of water jet cut method was starting in early 80s [19] .Today is a rapidly developing Technology that is used in industry for processing a variety of engineering materials. It is an emerging technology, which has many advantages over the other non-conventional cutting techniques. [20]
The correct name of abrasive water jet cutting is cutting hydro-abrasive treatment (abrasive water jet). AWJC is a stream of hydro-abrasive, which has enough power to cut through even the toughest materials. [21] Typical water jet cutting machines have a working space from few square feet to hundreds of square feet. At this moment the high pressure water pumps are available from 276 MPa up to 689 MPa. [22]

II AWJM variations

The AWJ machining can be used as: cutting, polishing, drilling, turning and milling.
Cutting: Water jet cutting is a phenomenal cutting process used to cut any profile required for Automobiles, Ships and Aircrafts. On one end of the spectrum, for example, some ceramics and glass thicknesses and compositions are simply too weak to withstand any water jet and would likely shatter if exposed. On the other sides of the spectrum are materials like diamonds, which are too hard to be cut with water jets. In addition to these are hydrophobic elements and moisture sensitive materials, which cannot function if exposed to water. [23]
In polishing process with an abrasive water jet, there are two mechanisms of polishing of the work piece one of them is caused by the plastic deformation mechanism' the impact of the abrasive on the surface of the work piece causes the material to bulge to the sides'. And the other process is to remove the material by the collision impact and shear scribe action of the polishing liquid mixed with the abrasive particles [23].
Drilling advanced materials with solid drill bits is often not possible due to brittleness and hardness of material. Also in drilling has difficulty in producing holes that are less than 0.04 cm in diameter and shallow angle to the surface [24]. By controlling the jet's pressure time profile, and the abrasive flow rate, it is proved that the whole of high quality can be drilled by AWJM [25].
For drilling, small diameter and large aspect ratio holes, AWJM is superior to other fielded tools such as lasers and Electro Discharge Machining (EDM), particularly at a shallow angle [24].
In turning with AWJM, the work piece is rotated while the AWJ is traversed axially as well as radially to produce the required turned surface. Turning with abrasive water jet has been demonstrated as a viable process for difficult to machine materials by Ansari and Hashish [26].Hashish investigated AWJ turning parameters such as jet pressure, the abrasive flow rate, the abrasive particle size, the orifice size and the feed rate [27] .A different method considering the varying local impact angle in AWJ

turning presented to predict the final diameter by Manu and Babu [28].

Milling using AWJM experiments by Hashish indicated that abrasive water jet has great potential in milling application with advantages unmatched by existing techniques [29]. Many researchers demonstrated the capability of AWJ technology for precision milling operations in different materials such as titanium (Ti), aluminum (Al), and ceramics using a mask [30].Paul et al. reported that 0.04 mm depth variation control can be obtained for carbon steel using linear motion milling [31].

III AWJCM applications

Water jet Cutting machining (WJCM) can be cutting all types of non-metallic and metallic materials also has ability to making slot, de burring, etching, and cleaning of metallic and non-metallic materials, below are the examples of materials that can be cut with abrasive water jet:

1-Advanced ceramics materials

Ceramic is a material with high hardness and strength, these properties making it very difficult for processing by traditional processes or leading to high machining costs [32]. As a result, non-traditional cutting technologies have been used for processing ceramics, such as lasers [33], ultrasonic machining [34].electrical discharge machining [35]. Although these processes have been successfully used for machining ceramics, each is associated with its own advantages and disadvantages. Plasma flame and laser cutting leave behind a heavy crust that is extremely hard and these methods do not achieve the accuracy on a 13 mm thick plate [36] .The AWJM process extends the cutting capabilities of EDM and laser for reflective and non-conductive materials [37].Xu and Wang [38].Have carried out an extensive experimental study of abrasive water jet cutting of alumina ceramics considering the effect of small nozzle oscillation on cutting performance.

2-Advanced composite materials

Advanced composite materials, (ACMs) 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 [39] did investigation on the influence of different parameters such as Pressure, Stand of distance (SOD), Time, Abrasive grain size, nozzle diameter on the material removal rate of Fiber Reinforced Polymer (FRP) composite by Abrasive jet machining. Muller F et al [40] did investigation on machinibility of SiC Particle Reinforced Metal Matrix Composites by non conventional machining process such as Electrical 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 [41] did research work on Electrical discharge machining of metal matrix composites. Meaden, et al [42] did research on Laser cutting of titanium metal matrix composites.

3-Marble and granite

Marble and granite have unique characteristics and attractive properties such as high durability and resistance to scratches, cracks, stains, spills, heat, cold, and moisture, granite has been widely used as dimensional stone in public and commercial applications in today's life [43] .The abrasive water jet (AWJ) is a new innovative tool for cutting rocks and rock like materials. It can be used for cutting, pre weakening and drilling of rocks [44] .The technology is a promising tool not only for manufacturing industries but also for the other industries including civil and mining engineering fields due to its distinctive features of precise shape cutting, a good surface finish, smaller kerf widths, extended tool life, complex free form cutting, process automation, no dust, better working conditions, and the environment. These features make the technology an environmentally friendly technique over other traditional cutting processes such as circular sawing in natural stone machining and processing applications [45].

4-Glass

Glasses materials have many applications in engineering, and they can solve many special problems. These materials can work in situations in which plastics and metals cannot work [46]. Micro abrasive jet machining (MAJM) is an economical and efficient technology for micro machining of brittle material like glasses. Fan et al. [47] Developed predictive mathematical models for the erosion rates in micro holes drilling and micro channel cutting on glasses with an abrasive air jet. A study on the material removal rate in AWJ milling of channels on an amorphous glass had been done by Dadkhahipour et al. [48].

5-Alloys

An alloy is a mixture of metal and another alloying element. Alloys are containing 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) some of the most important alloys are brass, bronze, solder, steel and bronze. Vasanth s et al [49], did investigation on machinabiltiy 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 stand-off distance has the most significant role for determining surface quality. M. Uthayakumar et al [50] research work done on machinability of nickel based super alloys. Selected process parameters are water jet pressure, traverse the speed of jet nozzle, and stand-off distance. By varying the selected process parameters they evaluated the difference in kerf width, kerf wall inclination, and material removal rate (MRR).From the experimental results they observed that the jet pressure is the most significant factor influencing the surface morphology and surface quality. K.S. Jai Aultrin et al [50] did research work for the effect of process parameters on Material removal Rate and Surface roughness, for copper 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 stand-off distance and along with their interactions have the a significant effect on SR and the MRR.

IV. MAJOR AREAS OF AWJCM

The researches have organized the various AWJM research into two major areas namely AWJM process modelling and optimization and other one is AWJM process monitoring and control.

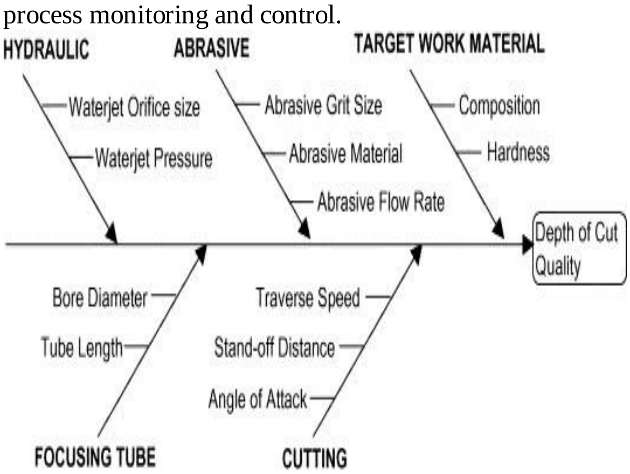

Fig.2. Process parameters influencing the AWJC process [86].

IV-1 AWJCM process modeling and optimization

AWJM process modelling is done in a scientific way to understand the system behaviour. Authors developing many mathematical models to get the better relationship between input and output parameters in terms of mathematical equations. Modelling and optimization is done as per DOE such as Taguchi technique and response surface response methodology. Analysis and a significant effect of each process parameters done by the ANOVA. Other optimization techniques such as artificial neural network (ANN), fuzzy logic (FL), genetic algorithm, a grey relational analysis artificial bee colony (ABC) and simulated annealing are used by some researchers to optimize the process parameters [34]. The influence of process parameters considered such as traverse speed, abrasive flow rate, stand-off distance and water pressure on the depth of cut [35].The work done by researchers on the effects of different process parameters on various quality parameters are discussed below.

IV-1 -1 The effect of the process parameter on the depth of cut.

Sitarama Chakravarthy et al [54], done investigation on optimization of process parameters using fuzzy logic and genetic algorithm for machining granite to a predetermined depth of cut, according to increase the productivity and decrease the cost. Devineni et al [55] did experimental investigation on optimization of the combined effect of process parameters on depth of cut and kerf width by using the abrasive water suspension jets, they observed that depth of cut influenced by the pressure and most significant factor affecting the kerf width is the stand-off distance.Lemma.E et al [56] did research work on abrasive water jet machining by nozzle oscillation technique, they observed that oscillation cutting process more efficient than normal cutting process. Wang, J [57] did research work on the prediction of depth of cut for polymer matrix composites, they developed the empirical model for the prediction of depth of cut and compared with experimental results. D.S. Srinivasu and N. Ramesh Babu, [58] did research on a neurogenetic approach for selection of process parameters by varying the nozzle diameter, they developed an artificial neural network model (ANN) for the prediction of depth of cut by varying the nozzle diameter and process parameters, after that an artificial neural network model (ANN) combined with Genetic algorithm as called nerogentic approach, after that compared with the fuzzy genetic approach for the effectiveness of the desired results. Farhad Kolahan et al [59] did research on the effect of process parameters on the depth of cut while for 6036Taluminium alloy using 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 the relationship between input parameters and output parameters. From the experimental results they observed the best set of process parameters for optimization.

IV-1 -2 Effect of the process parameter on surface roughness

Azmir and Ahsan [60] studied the effect of machining parameters such as hydraulic pressure, abrasive types, stand-off distance, abrasive flow rate, traverse rate, cutting orientation on surface roughness (Ra) by using Taguchi's design of experiments and analysis of variance for glass/epoxy composite laminate. Zohoor and Nourian [61] determined the effect of parameters on the nozzle diameter wear and effect of it on surface roughness and developed regression equations by using response surface methodology. Many researchers also worked on different parameters by using Taguchi method and regression analysis for the optimization of surface roughness on different materials such as granite [62], polymer matrix composite material [63]. Yusup et al in, [64] employed artificial bee colony (ABC) algorithm to optimize the machining control parameters such as traverse speed, water jet pressure, stand-off distance, abrasive grit size and an abrasive flow rate for surface roughness, they have compared the results of ABC with the actual machining, regression, an artificial neural network (ANN), genetic algorithm (GA) and simulated annealing (SA). Ashanira et al. [65] presented a hybridization model of the support vector machine (SVM) and grey relational analysis (GRA) in predicting surface roughness value; they have found that traverse speed is the most influential factor that affects surface roughness while stand-off distance is the

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least influential factor that affects surface roughness. Yuyong et al. [66] calculated cutting speed by ANN model based on water pressure, abrasive flow rate, work piece, thickness and an expecting surface quality grade. They have found that the surface quality of the part can be indirectly controlled by adjusting the cutting speed of water jet. Zain et al. [67] compared the surface roughness value for the experimental, regression analysis, genetic algorithm and simulated annealing, In that study they have selected traverse speed, water jet pressure, stand-off distance, abrasive grit size, and abrasive flow rate as process parameters and AA 7075 aluminium alloy as work piece. Iqbal et al. [68] Developed full factorial design of experiments to investigate the effects of different parameters on the surface finish for AISI 4340 (high strength low alloy steel, hardened to 49HRc) and Aluminum 2219.

IV-1 -3 the effect of the process parameter on the kerf geometry.

Shanmugam et al, [69] did investigation on alumina ceramic to minimize the kerf taper by the technology of kerf taper compensation; from the results they observed that angle has the highest effect on kerf taper. Karakurt et al, [70] did experiments on granite material to find the kerf geometry by selecting the process parameters such as pressure of water, an abrasive flow rate, stand-off distance, traverse speed, by using Taguchi method; they observed most influencing parameters on kerf geometry. Vishal Gupta et al, [71] did research on the effect of process parameters on kerf characteristics, Analysis done by the ANOVA, they observed affecting parameters, by the process parameters top kerf width and kerf taper angle are mostly affected. M.Ramulu et al, [72] did research on the effect of process parameters on surface roughness and kerf taper of the laminate piece, through ANOVA technique; they fined the significant effect of process parameters on surface roughness and developed the mathematical model to predict the surface roughness and kerf taper for cutting piece with 16 mm thickness. J wang et al, [73] did experimental investigation on polymer matrix composite material to study the effect of input process parameters on machinability of kerf characteristics by abrasive water jet machining ,from the experimental results ,recommendations ,are made to optimize process control and process optimization.

IV-1 -4 the effect of the process parameter on the material removal rate.

Lingaraj.N and Gajendran.S [74] did research on optimization of process parameters by using Taguchi multi response method (Weight age Method and Principal Component Analysis) and Response surface methodology, by the three methods compared the experimental results of Surface roughness and MRR. 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 stand-off distance is the sub significant parameter on MRPI. Traverse rate and Abrasive flow rate are the most significant control factors on TPCI and stand-off distance is the sub significant parameter on TPCI. Jagannatha, et al, [75] did investigation on optimization of process parameters by jet of abrasive hot air machining for glass using taguchi method and utility concept, to find the effect of an abrasive hot air jet on Material removal rate (MRR) and surface roughness (Ra), a 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 fewer contributions. D. V. Srikanth et al, [76] worked experiments on Ceramics to assess the influence of Abrasive jet machining process parameters on MRR and Kerf using 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, stand-off distance, Abrasive flow rate and Nozzle diameter, from the results they observed that by the increase in Nozzle diameter, the MRR increases, similarly decrease in the Stand-off distance will decrease the divergence of the work piece holes. When an abrasive flow rate gets higher, first, surface roughness decreases and then after a certain point it increases, [77].

IV-1 -5 The effect of the process parameter on the nozzle wear.

In an abrasive water jet machining the nozzle wear is affect by the mass flow rate, type of abrasive material and water pressure. Jegaraj et al [78] did investigation for the influence of orifice and focusing tube bore variation on the performance of abrasive water jets by cutting 6063 T6 aluminium alloy using Taguchi method and analysis of variance (ANOVA),also Fuzzy approach is used to generate the set of process parameters for the empirical equations. Nanduri et al. [79] worked 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 for wear have been influenced. Hashish, M et al [80] conducted wear tests on soft steel tubes and harder Tungsten carbide tubes by using Aluminium oxide as an abrasive material, a wide range of tool materials such as ceramics and carbides are tested by varying machining parameters.

IV-2 AWJCM monitoring and control

Pavol Hreha, et al [81] describes the causes of arising vibration and acoustic emission, course of vibration and acoustic emission by analyzing their frequency spectrum. The data were collected by touch sensors within controlled experiment, in which the AWJ technology for cutting alloy steel, the experimental data provide information about vibration and acoustic emission spectrum and enable us to find the relation between the surface topography and the emission spectrum. [82]

Developed an analytical model for material removal in an abrasive water jet machining (AWJM) for 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 indicated that a strong relation between the RMS AE signal and the characteristics of AWJM exists. [83] Kovacevic et al 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 [8] did experiments to determine the effect of process parameters such as traverse speed and nozzle diameter are the 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 the required amount in nozzle path.Rabani et al. [84] monitored the input jet energy that produces part erosion using an acoustic emission sensor mounted on the target work piece, while jet feed velocity is acquired online from the machine axis encoders, w the pre evaluation of TRE as a 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 online.

V Advantages of Abrasive water jet cutting machining

1. Method of cutting is an environmentally friendly process that does not produce any harmful fumes.
2. Economically the only input materials used are water and abrasive materials.
3. No thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces, also does not leave a burr or a rough edge and no heat generated during cutting process.
4. very hard ceramic materials, used for both the room and high temperature structural application, was machined by Abrasive water jet cutting machining technique using Silicon carbide grits (80 B.S.) in place of commercially used garnet Sand.
5. Because of that abrasive water jet cutting machining has become one of the leading manufacturing technologies in a relatively short period of time.
6. Cutting without change the properties of the material.
7. Water jet cutting can be easily automated for production use and modern systems are now very easy to learn.
8. The high pressure pump that increases the water pressure to about 4,000, bars. This allows it to cut virtually any material. (Pre hardened steel, mild steel, copper, brass, aluminum; brittle materials like glass, ceramic, quartz, stone).
9. Water jet cutting can be cut thin stuff, or thick stuff.
10. Water jet cutting can be making all sorts of shapes with only one tool.
11. Clean the cutting process without gasses or oils very easy using Water jet machining.
12. Water jet cutting has an ability to produce the smooth surface finish, thus reducing secondary operations.
13. All water jet machining processes are very safe.
14. Waterjets are much lighter than equivalent laser cutters, and when mounted on an automated robot. This reduces the problems of accelerating and decelerating the robot head, as well as taking less energy.
15. The nozzle that adjusts the water jet very precisely and in a targeted way so that it can cut accurately. This nozzle can be equipped with an abrasive mixing line to mix it with the water.
16. Abrasive Water jet Cutting [AWJC] is a rapidly developing technology that is used in industry for a number of Applications including plate profile, cutting and machining of a range of materials.
17. Relatively inexpensive process with reasonably high material removal rate (MRR).

VI Dis-advantages of an abrasive water jet cutting machining

1- The abrasive water jet is not the quickest way to cut, and a long time spent cutting some materials, so this will increase the cost of cutting for those materials.

2-waterjet cutting is that a limited number of materials can be cut economically.

3-Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at a different angle than it enters the part, and can cause dimensional inaccuracy. Decreasing the speed of the head may reduce this, although it can still be a problem.

4- Cutting speeds can be as high as7.5 m/min for reinforced plastics, but much lower for metals. Consequently, the process may not be acceptable for situations requiring high production rates. [85]

VII The future direction of the AWJCM research

Abrasive Water jet cutting machining technology AWJCM has been first of the most Important cutting processes lately because not only is it environment friendly but also for economical reason. It can cut almost any type of materials up to 300 mm with little or no burring and no heat effect on material to be cut. Therefore, it has been a serious competitor for high precision and state of the art cutting processes and is likely to continue its development in the near future.

The AWJCM 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 a single quality characteristic as an objective during optimization of AWJM (like MRR, SR, Kerf

characteristics, depth of cut).Very little literature is available on the Multi objective optimization process.
Now present scholars found it as the direction of future investigation work. No literature review 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 review was available on nozzle wear. Research may be done on the optimization for dimension accuracy, power consumption and multi objective optimization of AWJM process.

IV. CONCLUSIONS

The work presented here is an overview of recent developments of AWJCM, Due to optimization, advantages, weakness and Future directions From above discussion, it can be concluded that:

1. AWJC is the fastest growing cutting machining process.
2. abrasive water jet cutting machining has become one of the suitable manufacturing technologies in many aspects, but the taper is also a unsolved problem with water jet cutting in very thick materials ,this problem can cause dimensional inaccuracy, so more works are required to be done in this area.
3. Little literature available so far shows the standoff distance at the optimal value during the AWJC process by monitoring and control. This kind of work has not been reported for any other parameters. So, more works are required to be done in this area.
4. Little research has been done on the effect of nozzle size and orifice diameter.
5. Most of the research on optimization work has been carried out on process parameters for improvement of a single quality characteristic such as depth of cut, surface roughness, material removal rate, kerf geometry and nozzle wear. There is no research found based on the optimization for dimension accuracy, power consumption and multi objective optimization of the AWJC process. So, this research topic is still open for future research work.
6. Material Removal Rate it will be improve by increasing traverse speed and abrasive flow rate, but the major problem with increasing traverse speed is that surface roughness and kerf quality will be decrease.
7. It is important to find the optimum conditions for process parameters to give better quality of cutting surface. It was found that many researchers did different optimization techniques like Taguchi method, ANOVA and Regression analysis to find out the optimum cutting condition for AWJM operation. But less work has been done on Multi objective optimization of AWJM process. Also very little work has been reported for the effect of nozzle and orifice diameter. So, more work is required to be done in this area.

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