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A REVIEW ON CURRENT INVESTIGATION AND ENLARGEMENT OF ABRASIVE WATER JET MACHINING

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ABSTRACT: Abrasive water jet is a novel machining process; it can cut all type of hard materials accept diamond and carbide. A narrow stream of high velocity water mixed with abrasive particles gives relatively inexpensive and environment friendly production with reasonably high material removal rate. This paper reviews the research work carried out from the inception to the development of AWJM within the past time. Abrasive water jet machining has become one of the leading manufacturing technologies in a relatively short period of time. A wide range of AWJM industrial applications for different category of material are reported with variations. This paper reviews the research work carried out from the inception to the development and Parametric Study of AWJM within the past decade. It reports on the AWJM research relating to improving performance measures, monitoring and control of process, optimizing the process variables. A wide range of AWJM industrial applications for different category of material are reported with variations.

I. INTRODUCTION

Water jet cutting machines started to operate in the early 1970s for cutting wood and plastics material and cutting by abrasive water jet was first commercialized in the late 1980s as a pioneering breakthrough in the area of unconventional processing technologies. 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. AWJ is one of the most modern methods used in manufacturing industry for material processing [1].Laser cutting is not recommended because of heat generation during the process. Water cutting is recommended because of low production cost and short preparation time [23]. The basic principles of AWJM were reviewed in details by Member and Kovacevic. This technology is less sensitive to material properties as it does not cause chatter, has no thermal effects, impose minimal stresses on the work piece, and has high machining versatility and high flexibility [2]. Abrasive Water Jet (AWJ) technology has demonstrated to be an interesting manufacturing process for space, aircraft, boat and automotive sectors due to its specific advantages when machining composite materials. However, AWJ cutting of composite laminates possesses several challenges [3].Abrasive water jet machine technology is less sensitive to material properties as it does not cause chatter, has no thermal effects, impose minimal stresses on the work piece, and has high machining versatility and high flexibility [4].it is sometimes difficult to adjust the parameters of the models according to the actual situation of the machining process[5].This paper provides a review on the various research activities carried out in the past time on AWJM. It first presents the process overview based on the widely accepted principle of high velocity erosion and highlights some of its applications for different category of material. The core of the paper identifies the major AWJM academic research area with the headings of AWJM process modeling and optimization, AWJM process monitoring and control. The final part of the paper suggests future direction for the AWJM research. Cutting of sandwich materials represents a big challenge for any conventional technology [29].Abrasive waterjet (AWJ) technology offers flexibility required to produce complex shapes on difficult-to-machine as well as exotic materials without inducing thermal damage [30].In turning operation, the workpiece is rotated while the AWJ is traversed in axial and radial directions to produce the required geometry [32].Abrasive waterjet turning of results in a small mechanical effected zone within the same range of material removal rate in comparison to conventional turning [40].

A. AWJM PROCESS

An abrasive water jet is a jet of water that contains some abrasive material. Abrasives are particles of special materials like aluminum oxide, silicon carbide, sodium bicarbonate, dolomite and/or glass beads with varying grain sizes[1]. A schematic of the waterjet cutting system is shown in Figure 1. The system consists of a double-acting intensifier pump, 1, that produces high pressure water. This is accomplished using the piston, 2, which is driven forward (to the right) and backward (to the left) by a hydraulic actuator. The flow of high pressure water is regulated by the check valves, 3 and 5. The flow of low pressure water is regulated by check valves, 4 and 6. High pressure water is delivered to the attenuator, 7 and is output through the nozzle, 8. During steady-state operation of the system the piston is driven forward and backward. As the piston begins a forward stroke (from left to right) we assume that all the check valves are closed. The check valves 3 and 5 are closed because the pressure in the attenuator will be greater that the pressure in the pump. Eventually the pressure in A will exceed the pressure in the attenuator causing check valve 3 to open. Simultaneously, check valves 4 and 6 remain closed, while check valve 6 opens to allow low pressure water to fill chamber B. After moving a stroke distance s0, the piston stops and reverses direction. At this point all the check valves will again close. The behavior of the system during the backward stroke of the piston is similar to the forward stroke. During this backward stroke the piston will compress the water in chamber B. Check valve 5 will eventually open allowing high pressure water to flow from B. Simultaneously, check valves 3 and 6 will remain closed, while check valve 4 will open to allow low pressure water to fill chamber A. During the time interval that the check valves 3 and 5 are closed, high pressure water is delivered to the nozzle from the attenuator. The pressure in the attenuator will fall until check valve 3 or 5 opens allowing high pressure water to be delivered from the pump. The net effect of this system dynamic is that there are fluctuations in the pressure of the water flowing through the nozzle [31].

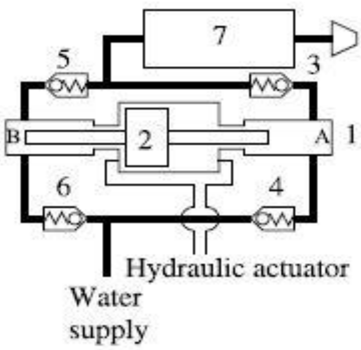

Fig. 1. Water jet cutting system. [31]

II. AWJM APPLICATIONS

This section discusses the viability of the AWJM process in the machining of the various materials used in industrial application. [1]

A. Aluminum

Aluminum is a silvery-white metal. It is non-magnetic and an excellent electrical conductor. Aluminum used in commercial applications has small amounts of silicon and iron (less than 1%) added, resulting in greatly improved strength and hardness. As a result of its low density, low cost, high ductility and corrosion resistance aluminum is widely used around the world. During cutting of aluminum with PAM and EDM heat is generated, in AWJM no or less heat is generated.M. Chithirai Pon Selvan at el did experiment on aluminum surface roughness by ANOVA and M. Chithirai Pon Selvan at el found that Surface roughness constantly decreases with mass flow rate increase and by increasing a jet pressure surface become smoother[6].Leeladhar Nagdeve at el did the experiment by changing material removal rate and mass flow rate by using Taguchi approach Leeladhar Nagdeve at el found that by increasing material removal rate it can decrease the kerf tapper and Material removal rate can increase by increasing mass flow rate and speed[7].As expected for aluminium 6061 T6, the maximum erosion rate occurred between impact angles of 20–30 degrees [33].

B. Glass

Glass products have applications in design engineering, and they can solve many special problems. These materials can work in situations in which plastics and metals would fail and need to be part of designer’s repertoire. Abrasive jet machining (AJM) is an economical and efficient technology for machining of brittle material like glasses. A.A. Khanat el concluded that, Taper of cut increases with increase in SOD. Garnet abrasives produce a larger taper of cut followed by Al2O3 and SiC. This is due to higher hardness of SiC compared to Al2O3 and garnet. Taper of cut also increases with increase in work feed rate. But taper of cut reduces with increase in pressure. A higher pressure increases the kinetic energy of the abrasives and the divergence of the jet is reduced that causes a decrease in taper of cut. An increase in SOD increases the focus area of the jet and increases the average width of cut. But increase in feed rate reduces the average width of cut since the surface to be cut is exposed to the jet for a shorter time. A higher jet pressure increases the kinetic energy of the abrasive particles and enhances their cutting ability. As a result, increase in pressure causes increase in the average width of cut. SiC is harder than Al2O3 and garnet. As a result, its cutting ability is also higher than that of Al2O3 and garnet. Therefore, the average width of cut produced by SiC is higher than those produced by Al2O3 and garnet.The surface roughness of AWJ machined glass/epoxy laminates and can be used for determining cutting parameters for tailored surface quality. [8]

C. High Speed Steel

High speed steels are highly alloyed and used in many applications where high wear resistance is needed .These steels could be considered as being a composite material where large primary carbides are dispersed in a martens tic matrix containing a much finer dispersion of small secondary carbides. The secondary carbides provide precipitation hardening of the martens tic matrix. The primary carbides, mainly MC and M6C-types, are harder than the matrix and they enhance the abrasive wear resistance of steels containing a high fraction of these carbides. E. Badisch at el did experiment Highest abrasive wear was found for SiC abrasives, where in addition to the martens tic matrix also the primary carbides are worn by the harder abrasive particles.Soft ZrO2 was not suitable to rank different high speed steels since only ploughing of the martensitic matrix occurs whereas the primary carbides cause blunting of the cutting edges of the abrasive. Among the abrasives used within this study, only Al2O3 was suitable to separate high speed steels with respect.To abrasion resistance. This is due to the hardness of Al2O3 which is well adjusted to both primary carbides and martensitic matrix of these steels. [9]

D. woods

Water jet machining has been used in the wood industry over the past several years. Compared with traditional Milling, water jet machining has the following advantages:1) it can mill or cut any type of curves, even with a Small radius; 2) it renders wood products with more accurate dimensions and smoother surfaces; 3) it eliminates crushing and tearing of wood; and 4) it reduces trim waste and particle contamination. Zheng Wang did the experiment and found that combination of iroku wood is most optimal for yielding the best surface. Water pressure is most significant, abrasive size; density comes after on effects of product quality [10].

E. Granite Rock

Owing to its 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. Izzet Karakurt at el did and concluded that when jointly considering the effects of the operating variables, it can be concluded that the standoff distance and the traverse speed have more significant effects on the kerf widths. Therefore, short standoff distances and higher traverse speeds are recommended to obtain narrow kerfwidths. The correlation analysis showed that the water absorption, the unit weight, the micro hardness, the maximum grain size of rock-forming minerals and the mean grain size of the rock have significant correlations with the kerf widths of the tested rocks [11].

F. Inconel 718

Experimental work was carried out in order to characterize the AWJ process for the production of pockets in Inconel 718. G.A Escobar-Palafox at el did the experiment with the help of ANOVA method and they found that higher abrasive rates are needed to achieve a high depth of cut with lower feed rates. The main factor controlling the undercut is the water pressure. Undercut decreases with decreasing nozzle diameter[12].

G. Ceramic

Producing the desired dimensions and surface finish of ceramic components is most commonly conducted by grinding with a diamond wheel. However, diamond grinding tools often produce unreliable and uneconomical machining results. Processing of the ceramic byAJM resulted in significant improvements in surface finish and strength improvements of 15% over ground and lapped samples. AJM has a high potential for the surface finishing of brittle ceramic materials [36].Aluminum oxide (WA) has insufficient Hardness, silicon carbide (GC) successfully produce smooth faced dimple at low removal rate, and synthetic diamond (SD) is possible choice [37].

III. MAJOR AREAS OF AWJM RESEARCH

The authors have organized the various AWJM research into two major areas namely AWJM process modeling and optimization together with AWJM process monitoring and control.

A. Effects of the process parameter on surface roughness

Veselko Mutavgjica at el didexperiment to derive conclusions based on the measured surface roughness, in which manner certain machining parameters affect surface roughness of the workpiece, examined for various materials of different thickness. Veselko Mutavgjica at el concluded that Increase in the abrasive flow rate, and, likewise, increase in water pressure, provide improved results of surface roughness. The impact of the distance of the abrasive nozzle on the example of aluminium workpiece produced optimal value which, according to experimental investigation, amounts 3, 2 mm. Surface roughness of machining increases when traverse speed ncreases [13].surface roughness plays an important role in wear resistance, tensile, ductility, and fatigue strength for machine parts [28].Abrasive recharging is recommended for better surface roughness [24]. Increase in water pressure is associated with a decrease in surface roughness. Surface roughness constantly decreases as mass flow rate increases. Use more mass flow rate to decrease roughness. Water pressure and abrasive mass flow rate have similar effect on surface roughness [10].In case of aluminium Surface roughness increase with increase in standoff distance. This is shown in Fig. 2 Generally, higher standoff distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment. Therefore, increase in the standoff distance results an increased jet diameter as cutting is initiated and in turn, reduces the kinetic energy of the jet at impingement. So surface roughness increase with increase in standoff distance. It is desirable to have a lower standoff distance which may produce a smoother surface due to increased kinetic energy. The machined surface is smoother near the top of the surface and becomes rougher at greater depths from the top surface [10]. The ABC technique is capable in estimating the lowest value of surface roughness compared to machining experimental [26]. Tests performed by using garnet and colemanite powders with different traverse rates revealed that increase in traverse rate increases surface roughness [27]. By employing accurate work holding devices that can maintain flatness [38].

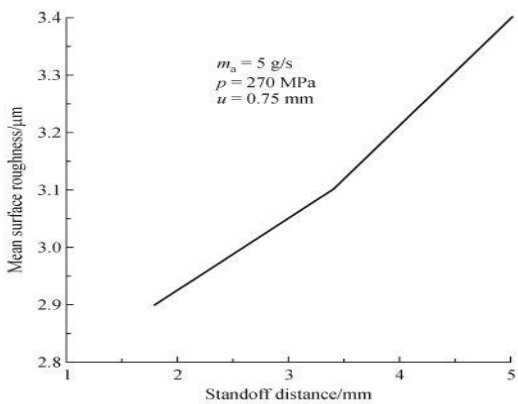

Fig 2. Standoff distance versus surface roughness [10]

B. Effects of the process parameter on depth of cut

Gokhan Aydin at el did experiment and concluded that increasing the traverse speed and decreasing the abrasive size resulted in decreases in the cut depths, while an increase in the abrasive mass flow rate and water pressure led to slow increases in the cut depths. Additionally, it was seen that the cut depths were not prominently affected by the standoff distance [14]. It was found that increasing of the traverse speed and decreasing of the abrasive size decreased the cut depths of all granites tested. The cut depths of the granites increased marginally with an increase of the abrasive flow rate, while the standoff distance did not have a discernible effect on the depth of cut. It was determined that the traverse speed was statistically the most significant factor influencing the cut depth granites [15]. The response surface for h in terms of water pressure and focusing nozzle diameter is shown in Figure 3(a). From this figure it can be observed that h increases with an increase in water pressure. However, the increasing the diameter of focusing nozzle would increase the depth of cut until 1.2 and then has a reverse effect on h since behind this diameter the cutting energy would decrease. Response surface of h versus jet traverse rate and abrasive flow rate is shown in Fig. 3(b). From the figure it can be seen that a high jet traverse rate and abrasive flow rate combination leads to high h. similarly, from Fig. 3(c) it can be observed that high h is obtained at high water pressure and high jet traverse rate combination. High values of water pressure and jet traverse rate lead to an efficient cutting energy which improves the h. Depth of cut increases by increasing any of the three factors (P, V, Mf), but it can be seen that V has the highest effect on h. The effect of jet pressure depends on the jet traverse level.[20] Due to the water cushion effect, when the computation time reaches a certain value, the cutting depth tends to be stable [25]. Study shows that if the cutting parameters are properly selected nozzle oscillation can increase the depth of cut by much as 82% [35].

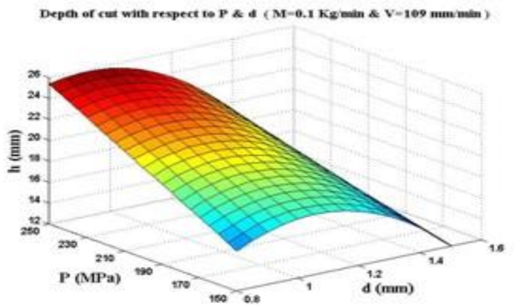

Fig. 3(a)[20]

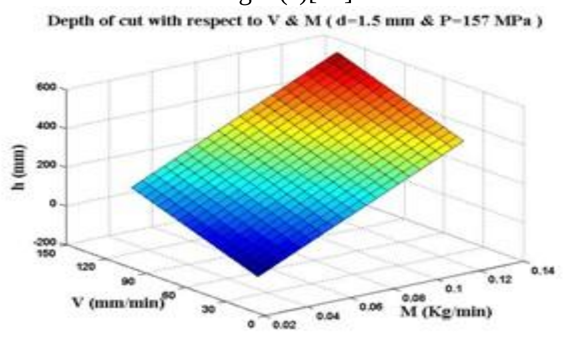

Fig.3(b)[20]

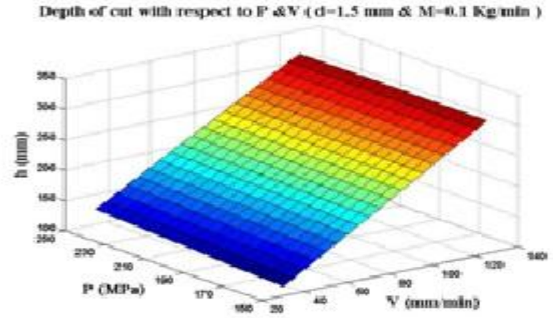

Fig.3(c)[20]

C. Effects of the process parameter on kerf geometry

Form of cutting kerf is one of the main problems effecting on the accuracy of abrasive waterjet cutting. Form of the kerf is always very complex, but basically it can be considered like two tapered plains [16].Increasing the pressure decreases the taper angle of the kerf because of the fact that at lower federates the abrasive jet is able cut through more wide the material at the bottom side as well. Increase of the abrasive mass flow rate decreases the taper too[16].Figure 3 shows kerf geometry.

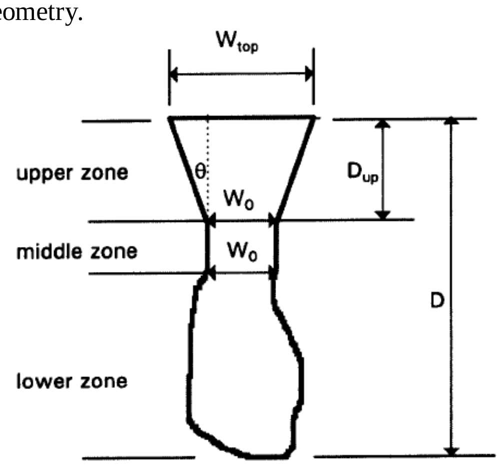

Fig 3. A schematic diagram of kerf geometry. [17]

The cut surface in this experimental study could be divided into three zones. In the upper zone, which has a smooth surface and no visible striations and pits, the kerf width tapers and the width at the bottom of this zone is the minimum cut width. In the Middle zone, which has obvious striations but no pits, the kerf width stays the same and also equals the minimum cut width. Finally, in the lower zone, which is characterized by a lot of pits, the kerf curvature changes greatly and the ballooning effect is profound. The two main process input parameters--water pressure and traverse speed--have greater effects on the lower and middle zones than on the upper zone. The ratio Dup/D decreases as water pressure increases or traverse speed decreases [17].By lowering the traverse rate straight kerf can be achieved [21]. In case of granitic rock standoff distance and the traverse speed have more significant effects on the kerf widths. Therefore, short standoff distances and higher traverse speeds are recommended to obtain narrow kerf widths [22].The taper reduces with an increase in the abrasive water jet kinetic energy. It shows clearly that at higher hardness of abrasive particles tends to produce lower taper ratio[4].By properly selecting the kerf-taper compensation angle, nozzle traverse speed can be increased to increase the cutting rate and abrasive mass flow rate can be reduced to reduce the process costs, while achieving small kerf taper angles [34].The taper angle may be a function of the absolute traverse feed rate more than a function of its respective percentage to the separation speed [39].

D. Effects of the process parameter on material removal rate
Pressure is most significant factor on material removal rate during abrasive water jet machine, Abrasive flow rate and transverse rate are sub significant in influencing.

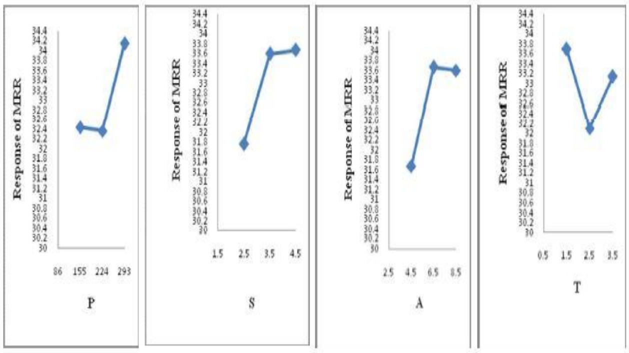

Fig 4 Main influence of each parameter on MRR [7]

level conditions are shown in figure 4. According to figure 4 the MRR increases with four major parameter P, S, T, A. MRR is maximum in the case of pressure at level 3 (293), in the case of SOD at level 3 (4.5), in the case of Abrasive flow rate MRR will be maximum at level 2 (6.5), and in the case of Traverse rate at the level 1 (1.5) in Aluminium [7]. In case of plaster of Paris as the particle size increases, the MRR at the center line of the jet increases; but the increase in MRR nearer to the periphery is very less [18]. The fracture toughness and hardness of the target materials toughness and hardness, are critical parameters affecting the material removal rate in AJM in ceramic material [19]. The influence of orifice and focusing nozzle diameter variation on the material removal rate of abrasive water jet in cutting 6063-T6 aluminum alloy by full factorial experiments. They have observed that rate of material removed decreases with an increase in the size of orifice and have found to be substantially low with an orifice size of 0.4 mm [1].

IV. FUTURE DIRECTION OF AWJM RESEARCH

The major research areas in AWJM are discussed in previous sections. Researchers have contributed in different directions but due to complex nature of the process a lot of works are still required to be done. The AWJM process is a suitable machining option in meeting the demands of today's modern applications. The AWJM of the modern composite, glass and advanced ceramic materials, which is showing a growing trend in many engineering applications, has also been experimented. It has replaced the conventional means of machining hard and difficult to cut material, namely the ultrasonic machining, laser beam machining and electro discharge machining, which are not only slow to machining but damage the surface integrity of the material. In addition, the AWJM process has sought the benefits of combining with other material removal methods to further expand its applications and improve the machining characteristics. The optimization of process variables is a major area of research in AWJM. Researchers have excluded many important factors such as nozzle size and orifice diameter during study which otherwise would affect the performance characteristics differently. Most of the literature available in this area shows that researchers have concentrated on a single quality characteristic as objective during optimization of AWJM. Optimum value of process parameters for one quality characteristic may deteriorate other quality characteristics and hence the overall quality. No literature is available on multi-objective optimization of AWJM process and present authors found it as the main direction of future research. Also, various experimental tools used for optimization (such as Taguchi method and RSM) can be integrated together to incorporate the advantages of both simultaneously. No literature available so far for multi response optimization of process variables and more work is required to be done in this area. Several monitoring and control algorithms based on the explicit mathematical models, expert's knowledge or intelligent systems have been reported to reduce the inaccuracy caused by the variation in orifice and focusing tube bore. Very little literature available so far shows the standoff distance at the optimal value during the AWJ cutting process using the generated sound monitoring and not for any other parameters. So, more work is required to be done in this area [1].

V. CONCLUSIONS

- The work presented here is an overview of recent developments of AWJM and future research directions. From above discussion it can be conclude that:
- It was shown that here has been considerable interest in the use of waterjet cutting technology Waterjets are a versatile, non-traditional machining tool that are currently used in many different industrial operations. Waterjet machines have found their way into a variety of applications such as cleaning processes, mining and demolition, industrial machining and impulse fragmenting. These machines have been used to cut numerous materials such as rock, wood, paper, composites, glass, textiles and food.
- Except of cutting abrasive water jet can also use in turning, milling, drilling. This method shows the benefit in compare of other machining methods like laser beam machining and electron beam machining.
- It was shown that Intensive literature surveyed on water jet pressure but relatively lesser work has been done on Orifice diameter, generally used orifice diameter is 0.25 mm. Very few researchers

have worked on Granitic Rocks material as work material. Orifice of AJM is highly effective component of the machine and it is being less focused by researchers.

- 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 any research paper found based on the optimization for the power consumption, dimension accuracy and multi-objective optimization of AWJM process. So, this area is still open for future research work.

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