Advance Manufacturing Processes Review Part II: Water Jet Machining (WJM)

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Abstract – *Water jet has been in existence and practised for over twenty years, but it is yet to reach its full potential in the construction and manufacturing industry. The paper presents aspects regarding an innovative nonconventional technology. Many research works have been done in the field of Water Jet Machining; however, these is always a scope for research in any particular field. Many research works have been put forward on the basis of changing the process parameter also many have been put forward by the use of optimization techniques, etc*

Keywords — *water jet, abrasive, nonconventional, technological, construction, innovative, industry*

1. INTRODUCTION

Machining process removes certain parts of the work piece to change them to final product. The traditional processes of machining are turning, milling, drilling, grinding, broaching, etc. Traditional, also termed as conventional, machining requires the presence of a tool that is harder than the work piece to be machined. This tool should be penetrate in the work piece to be certain depth. Moreover, a relative motion between the tool and workpiece is responsible for forming or generating the required shape. The end of second world war brought a new revolution in the engineering industry. Many new materials were developed to fulfil the need of aircraft industry, missile technology, space research equipment and nuclear industry. These materials like carbide, tungsten, ceramics, tantalum, beryllium, uranium, nitro-alloy etc. Are extremely hard and sometimes unmachinable by traditional machining processes. The traditional process is not suitable for the machining in following cases:

1. Workpiece materials of greater hardness
2. New materials with high strength, heat resistance such as titanium alloys, mnemonic alloys, etc.
3. Complex and intricate shapes with high accuracy.

Also, these materials mentioned above, possess high strength to weight ratio, hardness and heat resisting qualities making it sometimes impossible for machining. When conventional methods are tried, it is difficult, time consuming and economical to machine the workpiece material. This adds to the fact that during conventional machining processes an increase in hardness of workpiece material results in decrease in economic cutting speed. This needed the development of improved cutting tool material. For such conditions, inspite of recent developments, traditional methods of machining are uneconomical, time consuming and degree of accuracy and surface finish and poor. The newer machine processes, so developed are often called 'Modern Machining Methods' or non–traditional machining processes or unconventional machining processes. These are unconventional in the sense that conventional tool is not utilize for cutting the material. It employs some form energy like mechanical, chemical, thermal, electro-chemical etc. for cutting the material. Also, the absence of tool workpiece contact or relative motion, makes the processes a non-traditional one.

1.1Definition of non-traditional machining process

It is defined as a group of processes that removes excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combination of these energies without use of sharp cutting tools which are required in traditional machining processes.

1.2Advantages of non-traditional machining over conventional machining processes

1. Applicable to all materials: these methods are not affected by hardness, toughness and brittleness of work materials.
2. Intricate shape machining: it can produce complex-intricate shape on any workpiece material.
3. Extreme hard material machining: hard to machine materials like tungsten, uranium, tantalum can be machined.
4. No mechanical contact: material is removed without mechanical contact with the workpiece and tool.
5. Easy compatible: it can be combined with CNC and minicomputer controls for automation.
6. High accuracy: high accuracy to close tolerance is easily obtained in these methods.
7.

1.3Classification of non-traditional machining processes

1. Type of energy used to shape materials.
2. The basic mechanism of material removal.
3. The source of energy for material removal.
4. Medium of transfer of these energies.

1.4Machining processes

1. Mechanical Processes
    a) Abrasive Jet Machining (AJM)
    b) Ultrasonic Machining (USM)
    c) Water Jet Machining (WJM)
    d) Abrasive Machining (AWJM)
2. Chemical Processes:
    a) Chemical Milling (CHM)
    b) Photochemical Milling (PCM)
3. Electrochemical Processes:
    a) Electrochemical Machining (ECM)
    b) Electrochemical Grinding (ECG)
    c) Electro Jet Drilling (EJD)
4. Thermal/Electrothermal Processes:
    a) Electro Discharge Machining (EDM)
    b) Laser Beam (LBM)
    c) Plasma Arc (PAM)
    d) Electron-Beam (EBM)
    e) Ion-Beam (IBM)

Dr. Norman Franz is regarded as the father of the water jet. He was the first person to study the use of high-pressure water as a cutting tool. If we want to clean the area outside the home/office/school we throw water with high pressure so that the dirt gets washed away. A stream of water generated through a pipe that flows with high pressure washes away the mud. Similarly, a jet of water may be used to cut a sheet of metal. If the jet of water is directed on the metal sheet is such a way that on striking on the surface, the high velocity flow is virtually flow is virtually stopped, then most of the kinetic energy of the water is converted into pressure energy that induces high stresses in the material. The water jet is nothing but passing the water in small diameter nozzle to increase its velocity. The high velocity water jet with the velocity upto the twice speed of the sound when strikes on the workpiece removes material easily.

The key element in water jet machining (WJM) is a water jet, which travels at velocities as high as 900 m/s. When the stream strikes a workpiece surface, the erosive force of water removes the material rapidly. The water, in this case, acts like a saw and cuts a narrow groove in the workpiece material. Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallisation, hardening, reduced weldability and machinability are reduced in this process. A high pressure, high velocity jet of water has two properties which makes it useful in machining:

1. Destructive power
2. Precision cutting tool

WJM is suitable for cutting plastics, foods, rubber insulation, automotive carpeting and headliners, and most textiles.

2. LITERATURE REVIEW:

Abhishek Dixit, Vikas Dave, M.R. Baid reviewed the water jet machining it states that use of water jet has been in existence for over twenty years, but it is yet to reach its full potential in the construction industry. This study examines the role of water jet in heavy construction in general and particularly how it affects the regional contractors in the northeast. A survey was conducted among 215 civil contractors of the Northeast region of the United States and the results were documented in various categories. The paper presents aspects regarding an innovative nonconventional technology, abrasive water jet machining. The study also presents results regarding other technological operations possible to be performed with abrasive water jet. It appeared after studying the advantages and disadvantages of the waterjet, that this is a tool that the construction industry should find very useful. Unfortunately, this does not seem to be the case. Many of the regional companies do not seem to have any significant knowledge of the waterjet, thus remaining unwilling to employ this technology. The responses that we have received have left us with the inability to comment on the cost effectiveness of the water jet in the construction industry. The majority of companies that we contacted do not employ the water jet in their companies, nor do most of them have any knowledge of the abrasive water jet. These companies seem to be conservative to new technology and unwilling to take risks. This may also be due to the fact that many companies are unwilling to invest in a new technology that is not widely used. The contractors that do employ the abrasive water jet technology did not provide us with the percentage of cost benefit to their company [1].

Jiazhong Xu, Bo You, Xiangbing Kong carried out the Design and Experiment Research on Abrasive Water-jet Cutting Machine Based on Phased Intensifier states that to solve the problem of water pressure fluctuation caused by the traditional double-acting intensifier, the paper has designed abrasive water-jet cutting machine based on phased intensifier as well as open numerical control system. The structure of cutting machine as well as the hardware structure and working principle of phased intensifier are introduced. The phased intensifier employs a constant pressure variable capacity pump to provide power, compressed air to push piston back, PLC to control working sequence of two pistons, making the structure of mechanism and control system to be simplified. Experimental research on several typical materials cut by water-jet cutting machine equipped with phased intensifier is conducted, which is valuable for design, manufacture and technological application of high-pressure water equipment. It is practically proved that this system can work stably, with fluctuation rate of water pressure no more than 2.0%, as well as good cutting quality and high production efficiency [2].

Sudhakar R. Lohar, Pravin R. Kubade reported current research and development in abrasive water jet machining (AWJM) states that Abrasive Water jet machining (AWJM) is a non-conventional manufacturing process, where material is removed from the work piece by impact erosion of pressurized high velocity water stream mixed with high velocity grit abrasives on a work piece. 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 out from the inception to the development of AWJM within past few years. It reports on the AWJM research relating to performance measures improvement, monitoring and process control, process variables optimization. A wide range of AWJM industrial applications for variety of materials are reported with variations. The paper also discusses the future trend of research work in the area of AWJM [3].

M. M. Korat, Dr. G. D. Acharya reviewed on current research and development in abrasive waterjet machining states that abrasive waterjet machining (AWJM) is an emerging machining technology option for hard material parts that are extremely difficult-to-machine by conventional machining processes. A narrow stream of high velocity water mixed with abrasive particles gives relatively inexpensive and environment friendly production with reasonably high material removal rate. Because of that abrasive waterjet machining has become one of the leading manufacturing technologies in a relatively short period of time. This paper reviews the research work carried out from the inception to the development 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. The paper also discusses the future trend of research work in the same area. And concluded that the work presented here is an overview of recent developments of AWJM and future research directions. From above discussion it can be concluded that:

1. It was shown that AWJM process is receiving more and more attention in the machining areas particularly for the processing of difficult-to-cut materials. Its unique advantages over other conventional and unconventional methods make it a new choice in the machining industry.
2. Apart from cutting, AWJM is also suitable for precise machining such as polishing, drilling, turning and milling. The AWJM process has sought the benefits of combining with other material removal methods to further expand its applications.
3. Very little literature available so far shows the standoff distance at the optimal value during the AWJ cutting process by monitoring and control. This kind of work has not been reported for any other parameters. So, more work is required to be done in this area.
4. In most of research work, mainly traverse speed, waterjet pressure, standoff distance, abrasive grit size and abrasive flow rate have been taken into account. Very little work has been reported on effect of nozzle size and orifice diameter [4].

Gurusamy Selvakumar* and Shanmuga Sundaram Ram Prakash carried on experimental study on abrasive water jet machining of AA5083 in a range of thicknesses includes the objective of this study is to present the optimal machining parameters for abrasive water jet machining (AWJM) of Aluminium alloy 5083 (AA5083) by employing artificial neural networks (ANN) modelling for various material thicknesses. Al 5083 alloy finds vast applications in ship building, rail cars, and vehicle bodies and exclusively for cryogenic applications. The experimental work was carried out by using Taguchi L18 orthogonal array to study the influence of the process parameters such as jet diameter, stand-off distance and abrasive flow rate for various ranges of thicknesses over the process yields namely material removal rate (mrr), surface roughness and taper error. Technological table for optimal machining of AA5083 alloy in AWJM was reported for ready to use in industry and conclude that the experimental study on abrasive water jet machining (AWJM) of AA5083 is reported. The influence of process parameters on MRR, Ra and taper error were reported by adopting Taguchi methodology. Based on the experimental data, ANN prediction was performed. Based on the thickness of the job, the ANN predictions were grouped and Pareto optimisation technique was applied to achieve optimal machining conditions. Technology tables for various thicknesses were reported for optimal processing of AA5083 in AWJM. The reported handy technology table can be easily used even by a semi-skilled or unskilled worker [5].

Ajit Dhanawade, Ravi Upadhyai, Arunkumar Rouniyar and Shailendra Kumar carried out experimental study on abrasive water jet machining of PZT ceramic includes presents research work involved in abrasive water jet machining of PZT ceramic material. Process parameters namely stand-off distance, water pressure and traverse rate are considered in the present study. Response surface methodology approach is used to design the experiments. Relative significance of process parameters and their influence on kerf properties are identified on the basis of analysis of variance. It is found that water pressure and traverse rate are most significant parameters followed by stand-off distance. On the basis of experimental analysis, regression models are developed to predict kerf taper and depth of cut. The models are developed with respect to significant parameters, interaction and quadratic terms. It is found that model predictions are in congruence with experimental results. Multiresponse optimization of process parameters is also performed using desirability approach in order to minimize kerf taper and maximize depth of cut. Kerf wall features of machined surfaces are observed using scanning electron microscope. The findings of present study are useful to improve kerf properties in abrasive water jet machining of PZT ceramic materials and conclude that plausible trends of kerf taper and depth of cut in AWJM of PZT ceramic have been analysed in the present work. Following are the findings of the present study(i) Traverse rate and water pressure are the most significant factors followed by stand-off distance to control kerf taper. (ii) Kerf taper decreases with increase in water pressure and decrease in traverse rate and stand-off distance. (iii) Water pressure is most significant parameter followed by traverse rate and stand-off distance to control depth of cut. (iv)Depth of cut increases with increase in water pressure and decrease in stand-off distance and traverse rate. Regression models are developed to predict kerf taper and depth of cut. It is found that model predictions are in good agreement with experimental results. The percentage error between predicted and experimental results is around 5. Further multi-response optimization of process parameters is performed to minimize kerf taper and maximize depth of cut [6].

C. Thiruvasagam, R. Rathish, N. Balakrishnan, K. Karuthapandi, R. Kaviyathevan, S. Kalishwaran, P. Ashok studies the engineering and manufacturing departments are constantly on the look of edge. The water jet machining process provides many unique capabilities and advantages that can prove very effective cost. Learning more about water jet technologies will give us an opportunity to put these cost cutting capabilities to work. The water jet washes away the materials that “ERODES” from the surface of the work piece. The crack caused by the water jet impact is exposed to water jet. The extreme pressure and impact of particles in the following stream cause the small crack to propagate until the material cut. Water Jet Machining (WJM) is the process of material removal from a work piece by the application of a high-speed stream of abrasive particles carried in a gas medium from a nozzle. The material removal process is mainly by erosion. The WJM will chiefly be used to cut shapes in hard and brittle materials like glass, ceramics etc. Care has been taken to use less fabricated components rather than directly procuring them, because, the lack of accuracy in fabricated components would lead to a diminished performance of the machine [7].

3. EQUIPMENTS OF WJM:

1. Reservoir: it is used for storing water that is to be used in the machining operation.
2. Hydraulic pump: the hydraulic pump is powered from electric motor and supplies the water from the reservoir.
3. Intensifier: it is connected to pump. It pressurizes the water acquired from the pump to a desired level.
4. Accumulator: the accumulator maintains the continuous flow of the high-pressure water and eliminates pressure fluctuations. It is used for temporarily storing the pressurized water.
5. Control valve: it controls the direction and pressure of pressurized water that is to be supplied to the nozzle.
6. Flow regulator: it is used to regulate the flow of water.
7. Nozzle: it renders the pressurized water as a water jet at high velocity. The nozzle provides a coherent water jet stream for optimum cutting of low-density material that is considered unmachinable by conventional methods.
8. High-pressure tubing: high pressure tubing transports pressurized water to the cutting head. Typical tube diameters are 6 to 14 mm and is made from stainless steel. The equipment allows for flexible movement of the cutting head.
9. Catcher: the catcher acts as a reservoir for collecting a machining debris entrained in the water jet. Moreover, it reduces the noise levels associated with the reduction in the velocity of the water jet.

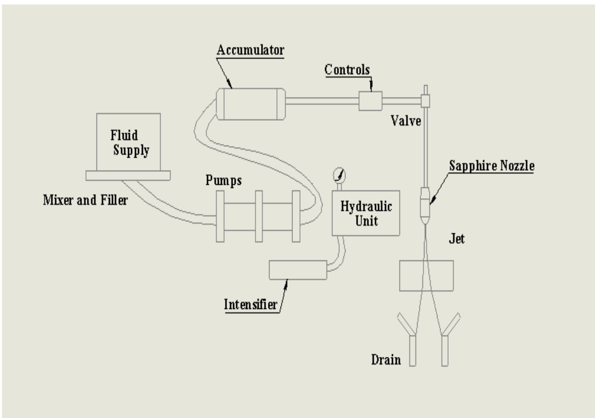

Figure 1: Setup of Water Jet Machining

4. WORKING OF WATER JET MACHINING:

1. Water from the reservoir is pumped to the reservoir is pumped to the intensifier using a hydraulic pump.

2. The intensifier increases the pressure of the water to the required level. Usually, the water is pressurized to 200 to 400 MPa.
3. Pressurised water is then sent to the accumulator. The accumulator temporarily stores the pressurised water.
4. Pressurised water then enters the nozzle by passing through the control valve and flow regulator.
5. Control valve controls the direction of water and limits the pressure of water under permissible limits.
6. Flow regulator regulates and controls the flow rate of water.
7. Pressurised water finally enters the nozzle. Here it expands with a tremendous increase in the kinetic energy. High velocity water jet is produced by the nozzle.
8. When this water jet strikes the workpiece, stresses are induced. These stresses are used to remove material from the workpiece.
9. The water used in the water jet machining may or may not be used with stabilizers. Stabilizers are substances that improve the quality of water jet by preventing its fragmentation.

5. ADVANTAGES OF WJM:

1. It allows more accurate cutting of soft material.
2. The burr produced is minimum.
3. Grinding and polishing are eliminated, reducing secondary operation.
4. The burr produced is minimum.
5. The tool does not wear and therefore, does not need sharpening.
6. Cuts can be started at any location without the need for predrilled holes.
7. WJM has excellent precision. Tolerances of the order of ±0.005” can be obtained.
8. There is no deflection to the rest of the workpiece.

6. DISADVANTAGES OF WJM:

1. Only soft materials can be machined.
2. It is not suitable for mass production because of high maintenance requirements.
3. Very thick materials cannot be machined and only a limited number of materials can be cut economically.
4. Not suitable for mass production because of high maintenance requirement.
5. Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at different angle than it enters the part, and cause dimensional accuracy.

7. APPLICATIONS OF WJM:

1. It is used for machining circuit boards.
2. It is used to cut rubber, wood, ceramics and many other soft materials.
3. Water jet machining is used to cut thin non-metallic sheets.
4. It is used in food industry.

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