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A Review on Unconventional Machining Process

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***Abstract*: Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Abrasive Water Jet Machining is an effective technology for processing various materials. In AWJM process the work piece material is removed by impact erosion of high velocity jet of water mixed with abrasive particles. There are so many process parameters affect quality of machined surface cut by AWJM. Important parameters which are mainly affect the quality of cutting are traverse speed stand of distance abrasive flow rate and also types of abrasive. Titanium Alloy Grade 5 was considered work piece material and Garnet 80 mesh as abrasive particle. For present work three parameters namely traverse speed, stand of distance, abrasive flow rate considered as input parameters with three levels and Taguchi's L9 Orthogonal Array (OA) was considered for experimentation. Total 9 experiments are conducted to evaluate responses, such as Metal Removal Rate (MRR) and surface roughness (Ra), Kerf width. Experiments were carried out on German made S3015 AWJM. Minitab software is used to the experimental results for estimating optimum parameter setting to obtain maximum MRR and minimum Ra, Kerf. A mathematical model is developed by means of linear regression analysis to establish relationship between control parameters and Output parameter (MRR and Ra, Kerf). The developed model predicts MRR with reasonable accuracy.**

***Keywords*: Machining process.**

1. Introduction

A. *Technological Development*

In this era of fastest growing technological development and advancement in manufacturing technology needs quick and better results. Nonconventional machining processes enable us to get consistency and accuracy in our desired manufacturing techniques. In the field of engineering, development of such techniques has led to revolution in the field of manufacturing. Tasks which are assumed to be impossible in past can be done within fraction of seconds. Machining of many metals which needed too much time and used to be too laborious are now simplified.

B. *Non-Traditional Machining*

However, development of newer methods has always been the endeavour of engineering personnel and scientists. The main ideas behind such endeavours have generally been the economic considerations, replacements of existing manufacturing methods by more efficient and quicker ones, achievement of higher accuracies and quality of surface finish, adaptability of cheaper materials in place of costlier ones and developing methods of machining such materials which cannot be easily machined through the conventional methods etc. Of all this reasons, the last one has contributed considerably to the post-war developments in machining methods, particularly because of the use of a large number of 'hard to machine' materials in the modern industry. A few of such materials are tungsten, hardened stainless steel, uranium, beryllium and some high strength steel alloys. The increasing utility of such materials in the modern industry has forced research engineers to develop newer machining methods, so as to have full advantage of these costly materials. The use of such costly and hard-to-machine material is quite common in aircraft industry, research equipment, nuclear plants, missile technology, sophisticated equipment manufacturing industries etc. To meet the needs of such industries, whereas on one hand newer materials have been developed at the same time a number of newer machining methods have been evolved for machining of these materials. These machining methods are known as Unconventional or Non-traditional Machining Methods.

C. *Classification of Unconventional Machining Processes*

Advanced machining processes are mainly on the basis of the nature of energy employed in machining process. They are:

1) *Chemical Processes*
   1. Chemical Milling (CHM)
   2. Photochemical Milling (PCM)
2) *Electrochemical Processes*
   1. Electro-Chemical Machining (ECM)
   2. Electro Chemical Grinding (ECG)
3) *Electro-Thermal Processes*
   1. Electrical Discharge Machining (EDM)
   2. Electron Beam machining (EBM)
   3. Plasma Arc Machining (PAM)
   4. Laser Beam Machining (LBM)
4) *Mechanical Processes*
   1. Ultrasonic Machining (USM)
   2. Abrasive Jet Machining (AJM)
   3. Water Jet Machining (WJM)
   4. Abrasive Water Jet Machining (AWJM)

D. *Introduction to AWJM*

AWJM is a well-established non-traditional machining process. Abrasive water jet machining (AWJM) is a process of material removal from a work piece by the application of high

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speed stream of abrasive particles carried with water from a nozzle.

Abrasive water jet machining (AWJM) is a mechanical material removal process used to erode holes and cavities by the impact of abrasive particles of the slurry on hard and brittle materials. Since the process is non- thermal, non-chemical and non-electrical it creates no change in the metallurgical and physical properties of the work piece.

The cutting ability of water jet machining can be improved drastically by adding hard and sharp abrasive particles into the water jet. Thus, WJM is typically used to cut so called “softer” and “easy-to-machine” materials like thin sheets and foils, non-ferrous metallic alloys, wood, textiles, honeycomb, polymers, frozen meat, leather etc., but the domain of “harder and “difficult-to machine” materials like thick plates of steels, aluminum and other commercial materials, metal matrix and ceramic matrix composites, reinforced plastics, layered composites etc. are reserved for AWJM.

1) Machine

Water Jet Germany Private Limited is promoted by professional Engineers having more than 25years experience in manufacturing Water jet machines. Water Jet Germany Private Limited designs and manufactures complete machines, highly durable which can work continuously - 24 hours a day and requires least maintenance.

The Abrasive Water Jet Machine German made S3015 is shown in figure. The system consists of CNC control unit, abrasive delivery system and catch tank. It is controlled with CNC program through control unit. It has catch tank at bottom which collects water and abrasive particles after impinges on work piece. The machine moves 3 meters in X-direction and 1.5 meters in Y-direction.

Fig. 1. CNC controlled abrasive water jet machine

2) Automatic Abrasive Delivery System

Automatic abrasive delivery system supplies the abrasive particles to the bucket without shortage of supply and it gives an indication to the operator when the abrasive is empty in delivery tank. Automatic abrasive delivery system is shown in figure.

3) Catch Tank

Catcher once the abrasive jet has been used for machining, they may have sufficiently high level of energy depending on the type of application. Such high-energy abrasive water jet needs to be contained before they can damage any part of the machine or operators. “Catcher” is used to absorb the residual energy of the AWJM and dissipate the same.


Fig. 2. Automatic abrasive delivery system

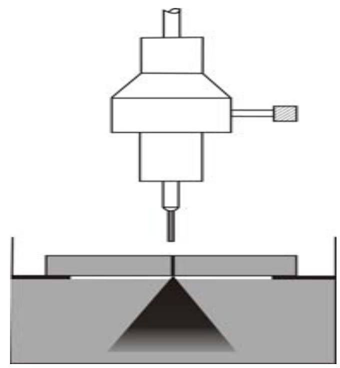
Fig. 3. Water basin

4) High Pressure Pump

Water Jet Germany Private Limited uses KMT Water Jet Systems GmbH’s high pressure pumps for their machines. KMT Water Jet Systems GmbH is a pioneer in the field of Water jet cutting and manufactures the best UHP pumps in the world and their systems are known for ease of use, intelligent design and reliability. With over 40years experience in the Water jet cutting industry KMT Water Jet Systems GmbH provides the state of the part High Pressure Pumps with a pressure range up to 6,200 bar (90,000 PSI).


Fig. 4. KMT Streamline SL-V 50- high pressure pump

E. Basic Principle of AWJM

Water jet machining is an erosion process technique in which water under high pressure and velocity precisely cuts through and grinds away minuscule amounts of material. The addition of an abrasive substance greatly increases the ability to cut through harder materials such as steel and titanium. Water jet Machining is a cold cutting process that involves the removal of material without heat.

This revolutionary technology is an addition to non-traditional cutting processes like laser and plasma, and is able to cut through virtually any material. The water jet process is combined with CNC to precisely cut machine parts and etch designs. Since water jet machining is done with abrasives, it is often synonymous with abrasive jet cutting. The combination of compressor, plumbing and cutting heads accomplishes the pressure and velocity to attain the cutting ability.

High-pressure compressors create a jet of water under extreme pressure that exceeds the speed of sound. This slim jet of water produced from a small nozzle creates a clean cut. Before cutting, the materials are carefully laid on top of slates over or submerged in the catch tank.

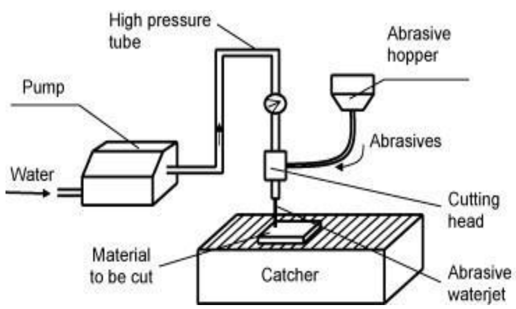

Fig. 5. Schematic diagram of basic principle of AWJM

Abrasive water jet uses the technology of high-pressure water typically between 2500-4000 bar, to create extremely concentrated force to cut stuff. A water cutter pressurizes a stream of pure water flow (without abrasive) to cut materials such as foam, rubber, plastic, cloth, carpet and wood. Abrasive jet cutters mix abrasive garnet to a pressurized water stream to cut harder materials. Examples are stainless steel, titanium, glass, ceramic tile, marble and granite. Water jet metal cutting machine yields very little heat and therefore there is no Heat Affected Zone (HAZ). Water jet machining is also considered as "cold cut" process and therefore is safe for cutting flammable materials such as plastic and polymers. With a reasonable cutting speed setting, the edges resulting are often satisfactory.

In Abrasive Water Jet Machining, the abrasive particles are mixed with water and forced through the small nozzle at high pressure so that the abrasive slurry impinges on the work surface at high velocity. Each of the two components of the jet, i.e., the water and the abrasive materials have both separate purpose and a supportive purpose.

The primary purpose of the abrasive material in the jet stream is to provide the erosive forces. The water in the jet acts as the coolant and carries both the abrasive material and eroded material to clear of the work.

F. *Work piece*

The work piece material may be of any size and shape. It is held by means of a fixture. Many of the difficult to work materials may be machined by abrasive water jet machining. The abrasive water jet machining technique is especially suited for hard materials like tungsten carbide, titanium carbide and ceramics.

Materials which exhibit high hardness and which have high impact brittleness can be successfully machined by this technique. Such materials are germanium, ferrites, glass and quartz. These materials often cannot withstand the forces needed for ordinary mechanical working. For present work Titanium Alloy Grade-5 is considered as work piece.

G. *Abrasive Slurry*

The slurry used in this process is a mixture of abrasive particles and a liquid component, mainly water. The ratio of abrasive to liquid can vary from 1: 6 to 1: 14 (by volume). Slurry is to be fed through the nozzle, which directs the abrasive slurry centrally to the work piece. The slurry serves several purposes. It carries and distributes the abrasive grains on the work surface thus, removes the waste material and cools the work piece avoiding thermal stresses.

The abrasives normally used in the process are boron carbide (cubic boron nitride), silicon carbide, aluminium oxide, garnet. For present work Garnet 80 Mesh is used.

H. *Advantages of AWJM*

- Extremely fast set-up and programming
- Very little fixturing for most parts
- Machine virtually any 2D shape on any material
- Almost no heat generated on the part
- Machine thick plates
- Gasket Cutting
- Fibre glass Cutting
- Cold cutting process and no thermal stresses
- Can cut almost all materials
- Environment friendly process

I. *Disadvantages of AWJM*

- Metal removal is less
- Process is not applicable for ductile materials
- Process produces a taper cut

J. *Applications of AWJM*

Due to the uniqueness of abrasive water jet cutting, there are many applications where it is more useful and economical than standard machining processes. In this section, some of the major applications and uses of abrasive water jet cutting are given. Abrasive water jet machining is used mostly to cut stronger materials such as steel, and even some tool steels can be cut.

- Letter cutting in steel, brass
- Cutting of bullet proof glass
- Fabrication of steel products

Though the applications are somewhat limited listed below are some of the applications.

1) *Manufacturing Industry*

The abrasive water jet machining is used to cut any profile required by Automobiles, Ships and Aircrafts. The glass industry calls for artistic work on different glass materials.

2) *Construction Industry*

To cut ceramic tile, mosaic and marble or granite for home/commercial building or even pavement decoration the abrasive water jet cutting often referred as marble cutter or graphite cutting machine or granite cutter, can be effectively used.

3) Environmental issues and future

Nowadays, every manufacturing process is being re-evaluated in terms of its impact on the environment. For example, use of conventional coolants in machining and grinding is being looked upon critically from the point of view of its impact on environment. The environmental issues relevant to AWJM are,

- Water recycling
- Spent water disposal
- Chip recovery and no harmful effect

2. Literature Review

The research contributions available around 20 articles are reviewed on the AJM and AWJM on various materials and methods are discussed. Though lot of work has been in progress there is a necessity in the investigation of performance characteristics of AWJM. Therefore, the present work is taken-up.

Punit Grover, et.al [1] presented study of Aluminium oxide Abrasive on Tempered Glass in Abrasive Jet Machining Using Taguchi Method, in which they used Pressure, Angle between the work piece and nozzle jet & Abrasive mesh size as input parameters. After the Experiment they conclude that the larger is better result for calculating MRR value also they AJM process using the conceptual signal to noise ratio approach, regression analysis and analysis of variance.

U.G. Gulhane et. al [2] presented analysis of Abrasive Jet Machining parameters on MRR and Kerf width of Ceramic material. They consider nozzle diameter, pressure & stand of distance as input parameters, after experiment they conclude that the nozzle diameter is the most influential factor when it comes to the MRR and Stand of Distance is the most influence factor when it comes to the average kerf width.

R. Vadgama, et.al [3] have described in their paper about effect of material removal rate during machining on glass of 3 mm, 4 mm, 6mm by Abrasive Jet Machine (AJM). Input parameters are stand-off distance and pressure. The material removal rate was considered the quality characteristics with the concept of "larger-the-better". The responses measured are MRR. They have used Taguchi technique for the optimization of process parameters.

N. S. Pawar, et.al [4] have described in their paper a number of investigations carried out Sea sand as abrasive material using silicon carbide and mild steel nozzle in vibrating chamber on Abrasive Water Jet Machining. In this experiment glass is used as work piece. Input parameters are abrasive size, stand-off distance and pressure. The material removal rate (MRR) is increasing with change in pressure and stand-off distance is also variable. The hardness of material of nozzle plays a key role with resp. to its erosion wear in the AJM process.

Sachin Kumar, et.al [5] has been studied that MRR of soda lime glass at different parameters on Abrasive Jet Machining. Input parameters are pressure, angle, abrasive size, nozzle tip distance and L9 Orthogonal Array is used for finding of Metal Removal Rate (MRR).

D. V. Srikanth, et.al [6] Conducted experiments and ANALYZE the influence of process parameters on MRR and Kerfs width in abrasive jet Machining of Ceramic tile. The results of experiments was analyse. It is observed that by increasing nozzle diameter the MRR increases, similarly decrease in Stand-off distance will reduce the divergence of the hole produced.

K. Siva Prasad, et.al [7] have conducted an experiment on Fibre Reinforced Polymer (FRP) composites using Al2O3 SIC Glass beads Crushed glass Sodium bi carbonate with abrasive size 10-50 microns and abrasive floe rate as 2-20 gm/min on Abrasive Jet Machining. WC/Sapphire is used for nozzle material with diameter 0.2 to 0.8 mm. The responses measured are MRR. They have used Taguchi technique for the optimization of process parameters.

Gaurav Mahajan, et.al [8] conducted an experiment on glass work piece using silicon carbide as abrasive material by Abrasive Jet Machining. Input parameters are**,** type of abrasive, stand-off distance, abrasive size- 80, velocity, mixing ratio. The effect of their process parameters on the material removal rate (MRR), top surface diameter and bottom surface diameter of hole obtained were measured and plotted. These were compared with the Standard results and with it was observed that as nozzle tip distance increases, the top surface diameter and bottom surface diameter of hole increases as it is in the general observation in the abrasive jet machining process. As the pressure increases material removal rate (MRR) was also increased.

Pradeep Kumar Sharma, et.al [9] have described in this paper that the effects of parameters of AJM machining on material removal rate (MRR, gm/min) overcut (mm) and taper cut (mm) during machining of glass fibre reinforced plastic. An AJM setup has been fabricated for this purpose. Tungsten carbide nozzle having diameter 1.2mm, 1.5mm, 2.3mm is used and Taguchi's L9 Orthogonal Array is used for experimentation.

M. Rajyalakshmi, et.al [10] described that n all the machining processes the quality of the work piece is depends on various design parameters. The process parameters which mainly affect the quality of cutting in AWJM are Hydraulic pressure, traverse speed, stand-off distance, abrasive flow rate types of abrasive, etc., The quality parameters considered in AWJM are Material Removal Rate (MRR), Surface Roughness (SR), Depth of Cut, kerf Characteristics and Nozzle wear, parameters can also be considered for optimization, which influence the quality parameters. They used Taguchi's design of experiments and analysis of variance (ANOVA) to the performance.

S. Kalirasu et.al [11] his paper aims to address the responses of the AWJM parameters to two different reinforcement sources, viz., bi-directional glass mat (synthetic) and coconut sheath (natural) fibre, in a polymer matrix composite. GM and CS were used as reinforcement in a thermoset unsaturated polyester matrix, for the fabrication of the composite plate. A higher crack resistance was found in the glass mat composites due to their better interfacial adhesion capability. The machining quality of the cut (kerf taper angle and surface roughness) was analysed, using the multi-objective response based on the L 9 (3 4) orthogonal array, using the Taguchi-based experimental grey relational analysis.

Tarun Batra et.al [12] have described in his paper that the effects of various input parameters in abrasive Jet machining (AJM) on the output parameter (Metal Removal Rate MRR) This paper presents an extensive review of the current state of research and development in the abrasive jet machining process. Further difficulties and future development in abrasive jet machining are also projected. This review paper will help researchers, students, manufactures to understand policy makers widely

M. Chithirai Pon Selvan, et.al [13] investigated the effects of process parameters on depth of cut in abrasive water jet cutting of cast iron. Four different process parameters were undertaken for this study; water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance. Experiments were conducted in varying these parameters for cutting cast iron using abrasive water jet cutting process. The influence of these process parameters on depth of cut has been studied based on the experimental results. In order to correctly select the process parameters, an empirical model for the prediction of depth of cut in abrasive water jet cutting of cast iron is developed using regression analysis. This developed model has been verified with the experimental results that reveal a high applicability of the model within the experimental range used.

Cristian Birtu et.al [14] has described in his article presents aspects regarding an innovative Nonconventional technology: abrasive water jet cutting. There are presented aspects regarding technique of abrasive water jet cutting (principle, parameters, and theoretical considerations about them), equipment (with emphasis on very high pressure pump) and performance of this technology (materials possible to be cut, cutting parameters for some materials). The work presented in this paper is done at ICTCM Bucharest on experimental abrasive water jet equipment. This research work had the purpose to identify, as much as possible, specific aspects of the technology, equipment and phenomena of this technology. It served to further developments of both equipment and technology, in order to identify all possible applications of this technology in different industries.

Shunli Xu, et.al [15] in his thesis presents a comprehensive study on the controlled nozzle oscillation technique aiming at increasing the cutting performance in AWJ machining. In order to understand the current state and development in AWJ cutting, an extensive literature review is carried out. It has found that the reported studies on controlled nozzle oscillation cutting are primarily about the use of large oscillation angles of 10 degrees or more. Nozzle oscillation in the cutting plane with such large oscillation angles results in theoretical geometrical errors on the component profile in contouring. Particularly, there is no reported research on the integration of nozzle oscillation technique into AWJ multi-pass cutting, which is expected to significantly enhance the cutting performance.

Parteek et.al [16] have described in his project that deals with the fabrication of the Abrasive Jet Machine and machining on tempered glass, calculating the material removal varying various performance parameters like pressure, angle & abrasive grit size so on. Before performing, the experiment fabrication done on AJM which are also discussed. The different problem faced while machining on tempered glass are also discussed. Taguchi method and ANOVA is used for analysis of metal removal rate.

L. Nagdeve et.al [17] have studied this paper, Taguchi method is applied to find optimum process parameter for Abrasive water jet machining (AWJM) Further experimental investigation were conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on MRR and surface Roughness (Ra) of aluminium. This paper analysis of the Taguchi method reveals that, in general the standoff distance significantly affects the MRR while, Abrasive flow rate affects the surface Roughness. However, experiments are carried out using (L9) orthogonal array by varying pressure, Stand-off distance, Abrasive flow rate and Traverse rate respectively.

G. Kandpal Chandra, et.al [18] have described studied in this paper investigated the testing and ANALYZE various process parameters of abrasive jet machining. It was observed that as nozzle tip distance increases, material removal rate (MRR) increases as it is in the general observation in the abrasive jet machining process. As the pressure increases material removal rate (MRR) is also increased as we found in AJM process. Similarly, as abrasive particle size increases MRR increases.

Veselko Mutavgjic, et.al [19] have studied the experimental investigation is to conduct research of the machining parameters impact on surface roughness of the machined parts, and derive conclusions referring to the manner in which certain machining parameters affect surface roughness. Experimental investigation was conducted in the way that samples of two different materials were cut on the machine using different machining parameters. Measurement of different surface roughness parameters has been conducted after the cutting.

Anu Tomy et.al [20] This paper highlights comprehensive literature study carried out on AJM process-essential components, performance parameters, optimization, experimentations, modelling and simulation and its various applications. The details of the collected literatures are presented systematically into four categories namely modelling, experimental setup, experimentation and applications. This paper tried to stitch out the various research works that was carried out so far. The capability of AJM to machine various materials made it to use in different application field. From this review, an idea of AJM and its various aspects that was reviewed by many papers was concluded. The outcome of this review can be listed as the various modelling works that was carried on the AJM process which includes the variations of process parameters with respect to the various responses were discussed. The experiments were conducted on commercially available setup as well as developed setup. It is seen that in commercial setups, only the specified parameters prescribed by the manufacturer can be used. But in developed setups different parameters can be incorporated according to our requirements.

Summary:

By reviewing different papers it is found that optimal parameter combination for different materials is not same. For different material there will be different parameter combinations for different output parameters. So, for present work we considered Titanium Alloy Grade-5 as Work material and Garnet 80 mesh as abrasive material.

3. Conclusion and Future Work

A. Summary

Accompanying the development of mechanical industry, demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, those materials are difficult to be machined by traditional machining methods. Hence to overcome this problem the Abrasive Water Jet Machine [AWJM] is applied and Titanium alloy Grade 5 material was selected to perform the experiments because of its high hardness, toughness.

Taguchi's Orthogonal Array based on robust design is one of the important methods, which is used for optimization of process parameters of AWJM. Although a wide variety of the techniques are developed over the years, it seems that reliable and widely suitable quantitative process parameters optimization method has not been evolved so far due to the difficulties in direct observation of improving accuracy using on-line methods, hence there is a need for indirect methods.

For the present study, the objective functions were formed based on Taguchi's quadratic loss function for performance characteristics, i.e., surface roughness and MRR. After the objective functions are formed, control factors and their levels were identified. The control factors considered for the study were Traverse Speed, Abrasive Flow Rate and Standoff Distance. Three levels for each control factor were used. Based on the above said number of control factors and their levels, L'9 orthogonal array was selected from the Standard orthogonal array table to conduct the matrix experiment. The matrix experiment was conducted for the Titanium Alloy Grade 5 material. The size of the work piece used for the experiment was 100X100X10 mm. The machine used to conduct the experiment was S3015 AWJM CNC machine. The response variable measured to perform the analysis was surface roughness and MRR. After the experiment conducted, response variable is tabulated and analysis was conducted. To conduct the Taguchi analysis, Statistical MINITAB 16 software was used. Based on this analysis, process parameters were optimized. After that the rank table from the MINITAB 16 was used to determine the relative magnitude of each factor on objective functions.

B. Conclusion

Based on the results and discussion the following conclusions are drawn.

- It is observed that the effect of Traverse Speed is maximum on MRR followed by Standoff distance, and Abrasive flow Rate.
- The optimal parameter setting for maximum MRR is obtained at Traverse Speed 8mm/s, Standoff distance 2mm, Abrasive flow Rate 200 mm/s.
- It is observed that the effect of Abrasive flow rate is maximum on Ra followed by Standoff distance, and Traverse Speed.
- The optimal parameter setting for good surface finish is obtained at Abrasive flow rate 150mm/s, Standoff distance 1mm, and Traverse Speed 70mm/sec.
- The optimal parameter for minimum kerf width is obtained at Stand-off distance 1mm, Traverse speed 80 mm/sec and Abrasive flow rate 150mm/sec.
- The developed regression equation is used to predict the MRR with 6.77% error.
- The developed regression equation is used to predict the Ra with 4.26% error.
- The developed regression equation is used to predict the kerf width.

C. Future Work

1. The work can be extended by considering the other parameters like Nozzle diameter, Abrasive size, Water pressure etc.
2. The work may be continued, for machining different materials for finding optimal combination of parameters and also by varying the abrasive materials.
3. The present work is carried out by Taguchi's analysis; further this work can be extended by considering any combination of Fuzzy control, Grey Relational analysis with Taguchi's orthogonal array technique.
4. The present work is carried out by Multiple Regression analysis to estimate the MRR and Ra. Further this work can be extended by considering Analysis of Variance (ANOVA).

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