

Advance Manufacturing Processes Review Part III: Abrasive Jet Machining (AJM)

Swapnil Umredkar¹, Vallabh Bhojar²

¹UG Student, Mechanical Engineering Department, G. H. Raisoni College of Engineering, Maharashtra, India

²UG Student, Mechanical Engineering Department, G. H. Raisoni College of Engineering, Maharashtra, India

Abstract - This paper presents an extensive review of Abrasive Jet Machining which defines the current state of research and development in the abrasive jet machining process. The AJM process is especially useful in machining brittle materials and is rarely employed for machining ductile materials. Early researches in this field had mostly been experimental investigations on the basic processes. The few attempts to theorize the mechanics of material removal used very crude models or prototype in order to conceptualize the process parameters. The present research work is aimed mainly at proposing a suitable theory, which explains the mechanics with the process flow of AJM. To inculcate this, the established theories of elasticity and fluid flow have been employed for AJM. AJM can be used in various operations such as deburring, polishing, cutting etc., that can be carried out effectively and efficiently, to close tolerances. Further difficulties and future development in abrasive jet machining are also projected in this review. This review paper will help researchers, students, manufactures to understand AJM process and certain advancements widely.

Keywords: Abrasive Jet Machining, Machining, Advance machining, AJM

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, manganese 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.

2. DEFINITION 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.

3. ADVANTAGES 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.

4. CLASSIFICATION 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.

5. MACHINING 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)

6. ABRASIVE JET MACHINING

It is the mechanical method of metal removed by using sharp edged abrasive striking on a workpiece surface with high speed. The process is different from conventional sand blasting, due to the fact that abrasives are much finer and process is controlled efficiently. The abrasive jet machining can effectively machine hard and brittle materials like glass, silicon, tungsten and ceramics, refractory materials, super alloys, etc.

7. AJM HISTORY

1. This novel technology was first demonstrated by Franz to cut laminated paper tubes in 1968.
2. first introduced as a commercial system in 1983.
3. In the early 1990s, water jet pioneer Dr. John Olsen began to explore the concept of abrasive jet cutting as a practical alternative for traditional machine shops.
4. Ultimate goal was to develop that could eliminate the noise, dust, and expertise demanded by abrasive jets at that time.

8. LITERATURE SURVEY:

1. S. Rajendra Prasad, Dr. K. Ravindranath, Dr. M.L.S. Devakumar reviewed on advanced approaches in abrasive jet machining and discussed in the advanced areas of space, missile and nuclear technologies, there arise a need for machining components to maintain exact sharp edges, high accuracy, and precisely sized components. In the present era of modern machining, these requirements can be achieved with the help of advanced machining process like Abrasive Jet Machining (AJM). This paper presents an extensive review of the current state of research and development on abrasive jet machining process and concluded an extensive review of the research and development in the AJM has been conducted in this paper. It was shown that AJM 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 un-conventional methods make it a new choice in the machining industry. It is concluded that wide experimental investigations are required to fully understand the relationship between important AJM parameters, namely Air pressure, nozzle size and shape, abrasive mass flow rates and process output in greater detail for aluminum, brass, cast iron, ceramics, copper, composites, granite, mild steel, stainless steel and titanium as the right choice of process parameters is very important for good cutting performance[1].

2. Matthew W. Chastagner and Albert J. Shih, studied abrasive jet machining for edge generation and discussed the edge with a consistent and precise shape is important for highly stressed mechanical components. This study investigates the generation, measurement, and definition of edges. Abrasive jet machining, a flexible process ideal for difficult-to-reach areas, is applied for edge generation. A conoscope laser with small, 25 μm spot size is scanned across the edge for measurement. A B-spline curve is applied to fit the edge profile by an optimization method. Silicon carbide media, 50 μm average size, was used to erode a 90° edge on a workpiece of Inconel 718. Effects of blasting time, stand-off distance between edge and nozzle, and orientation of a nozzle are studied. It is found that the edge radius is limited to below 0.15 mm using abrasive jet machining. Under long blasting durations, the edge radius does not change, but collateral damage around the edge is significant. Long standoff distances and high angles of blasting are beneficial in reducing the level of collateral damage. Edge radius is commonly used as the only parameter to quantitatively describe the edge profile. This study demonstrates that a B-spline can provide a better fit and geometrical description of the edge profile and concludes AJM for edge generation, conoscope laser for edge profile measurement, and B-spline and curve fitting methods for better representations of the developed edge. Based on the results of the AJM Inconel

718 samples, radii below 0.14 mm can be developed on 90° edge. For extended blasting times, the edge radius did not change much, but the collateral damage increased rapidly. The nozzle angle and stand-off distance to the edge have proven to be important in reducing the collateral damage to the edge. For the distances and angles studied, the radius size did not appear to be dependent on distance and angle. However, the collateral damage depth increased and the distance of the damage decreased as l was decreased or as α was increased. Therefore, if small amounts of damage on adjacent surfaces are acceptable, it is best to place the nozzle away from the sample and at a specific angle. Also, a B-spline was demonstrated to have a better fit than the arc. However, how to accurately describe and quantify the edge profile is still a challenging research topic. This study indicates that a new technical challenge is in the generation of large edge radiuses. AJM has limited capability to generate large edge radius. Mechanical methods, such as brushing or grinding, with flexible supports are candidate processes to create edges with large radius [2].

3. Anil Jindal studied on advanced approaches in abrasive jet machining (AJM) and discussed abrasive Jet Machining (AJM) can be used for achieving highly accurate, sharp edges and precisely sized components for space, missile and nuclear industries. Abrasive Jet Machining (AJM) is an advanced machining process requiring low capital cost and operational cost because the investment cost on various equipments is less as compared to other non-traditional machining process. Abrasive Jet Machining (AJM) provides a better surface finish. In this paper, the extensive review and development on the Abrasive Jet Machining (AJM) are studied and concluded in the study, it has shown that increasing the nozzle feed rate and stand-off distance results in improved surface roughness. The increase in pressure and abrasive flow rate results in improved MRR. It is quite possible to reduce noise and vibration problem in AJM. The spindle speed and abrasive flow rate have an impact on material removal volume affecting the machining depth during AJM. With the decrease in abrasive grain size, the surface roughness decreases. However, with the increase in machining time, the surface roughness decreases significantly. The improper mixing chamber construction causes various problems such as humidification, noise and vibrations resulting in decrease in machining efficiency [3].

4. Asst. Prof. S.T. Nangare, D.D. Patil, A.A. Nikam, A.B. Nangare reviewed setup for abrasive jet machine and discussed as abrasive jet machining (AJM) is similar to sand blasting and effectively removes hard and brittle materials. AJM has been applied to rough working such as deburring and rough finishing. With the increase of needs for machining of ceramics, semiconductors, electronic devices and L.C.D., AJM has become a useful

technique for micromachining. The abrasive jet machining is a method based on the effects of the fine abrasive particles transported and directed to the work piece surface by means of compressed air jet. The nozzle shape, size, nozzle tip distance are the most important parameters in abrasive air-jet machining equipment. Materials with high wear resistance will have great potential as abrasive air-jet nozzle materials. Abrasive jet machining is an effective machining process for processing a variety of Hard and Brittle Material. And has various distinct advantages over the other non-traditional cutting technologies, such as, high machining versatility, minimum stresses on the work piece, high flexibility no thermal distortion, and small cutting forces. This paper presents an extensive review of the current state of research and development in the abrasive jet machining process [4].

5. Bhaskar Chandra and Jagtar Singh, studied effect of process parameters of abrasive jet machining and discussed abrasive jet machining (AJM) is similar to sand blasting and effectively removes hard and brittle materials. AJM has been applied to rough working such as deburring and rough finishing. With the increase of needs for machining of ceramics, semiconductors, electronic devices and L.C.D., AJM has become a useful technique for micromachining. This paper deals with various experiments which were conducted to assess the influence of abrasive jet machining (AJM) process parameters on material removal rate and diameter of holes of glass plates using aluminium oxide type of abrasive particles. The experimental results of the present work are used to discuss the validity of proposed model as well as the other models. With the increase in nozzle tip distance (NTD), the top surface diameter and bottom surface diameter of hole increases as it is in general observation of abrasive jet machining process. As the pressure increases, the material removal rate (MRR) is also increased and concluded various results of experiments have been conducted by changing pressure, nozzle tip distance on different thickness of glass plates. 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 Roopa Rani and S. Seshan 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 [5].

6. D. Johnbasha, N. Amara Nageswararao, K. Nagendra Prasad, Sk. Mahaboob johny carried out investigation of machining parameters in abrasive jet machining on ti-6al-4v using GRA and PCA and discussed abrasive Jet Machining (AJM) is an unconventional machining process which is to drilling of metals and non-

metals. In this paper drilling was done on Ti6Al-4V with unlike SOD's, Pressures and Nozzle Diameters in order to determine the process capability of AJM. AJM removes metal from the work piece through the action of focused beam of abrasive loaded gas. Micro particles are propelled by a pressurized air of velocity due to this reason AJM applicable for cutting, etching, drilling, polishing and cleaning. In this paper optimization of process parameters of Abrasive Jet Machining of Ti-6Al-4V by Taguchi methodology is presented. The Values obtained in Taguchi Analysis was compared with the Analysis of Variance (ANOVA). Various levels of Experiments are conducted using L27 Orthogonal Array for both MRR and Kerf [6].

9. PRINCIPAL OF AJM:

The fundamental principal of this process involves the use of high-speed steam of abrasive particles carried by a high-pressure air/gas on the work surface through a nozzle. It is a process that removes material from a workpiece with the help of abrasive particles. The metal removes occur due to erosion caused by the abrasive particles implanting the work surface at high speed. With repeated impact of abrasive, small bits of material get loosened and a fresh surface is exposed to the jet. The process differ from sand blasting is that in AJM the abrasive particles has much smaller diameter of about 0.025 mm. The process consists of mixture of fine abrasive particles and gas at high pressure. The material removes takes place because of chipping action. As the particle impact the surface, it causes a small fracture of the work surface which results in removal of heat. The gas stream carries both the abrasive particles and the fractured particles away. The abrasive particles carried by high pressure gas/air at a velocity of 200 to 400 m/sec and standoff distance between nozzle tip and workpiece is kept about 0.7 to 1.0 mm.

10. WORKING OF AJM:

The gas is supplied under pressure (2 to 8 kg/cm²) and after filter and regulator, it is passed to a mixing chamber containing abrasive particles vibrating at 50 c/sec. From the mixing chamber, the gas along with the abrasive particles of size 10-50 μm passes on to a nozzle having its tip of tungsten carbide and diameter of 0.45 mm, with a velocity of 150-300 m/sec. The relative motion between nozzle and workpiece is obtained by cams, pantographs to control the size and shape of cut. The nozzle tip distance is of order of 0.81 mm. The high velocity jet of abrasives impact on the workpiece surface. It removes the material due to sharp edges hits a brittle and fragile material. The lodged out or wear particles are carried away by the air or gas.

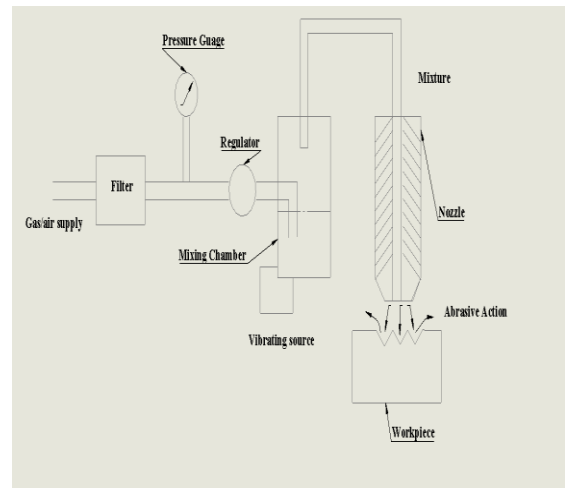


Figure 1: Setup for Abrasive Jet Machining

11. ADVANTAGES OF AJM:

1. There is no direct contact between tool and workpiece.
2. Normally inaccessible portions can be machined with fairly good accuracy.
3. The process has the ability to cut intricate shaped holes in hard brittle materials.
4. Amount of heat generated is not appreciable.
5. Low initial cost is required.
6. It has ability to cut delicate and heat-sensitive materials without any damage.
7. Brittle materials of thin section can be easily machined.
8. Abrasive jet machining provides cool cutting action. Very less amount of heat is produced during process.

12. DISADVANTAGES OF AJM:

1. The machining accuracy is poor.
2. Low metal removal rate.
3. Once used, abrasive particles cannot be used.
4. Material removal rate is slow and its application is therefore limited.
5. Not suitable for machining of ductile material.
6. Relatively poor machining accuracy.
7. Nozzle wear rate is high.
8. A suitable dust collection system is required there is a possibility of sticking abrasive grains is softer materials.
9. Applications of AJM:
10. Fine drilling and micro drilling.
11. Deburring, etching and cleaning of hard and brittle materials, alloys and non-metals.
12. Machining of semiconductor.
13. Machining brittle and heat sensitive materials like glass, quartz, ceramics, etc.
14. Frosting and abrading of glass articles.
15. Frosting and abrading of glass articles.

13. PROCESS PARAMETERS OF AJM:

- **Nozzle:**

1. The abrasive particles are directed into the work surface at high velocity through nozzles. They are made of hard resistant materials like tungsten carbide or synthetic sapphire. The rate of material removal and the size of the machined area are influenced by the distance of the nozzle from the workpiece. The material removal rate initially increases with increase in the distance of nozzle from the workpiece because of acceleration of particle after leaving the nozzle.
2. Its shape is circular, 0.3-0.5 mm internal diameter or rectangular (0.08mm 0.51 mm to 6.61mm 0.51 mm).
3. The tip distance is 0.25-15 mm.
4. The life of WC is 12-30 hour and sapphire is 300 hours.
5. The operating angle is 60° to 90° to the surface.
6. Stand-off distance – 0.5 to 5mm.

- **Abrasives:**

1. Commonly used abrasive is aluminium oxide (AL₂O₃), silicon carbide (SiC) and dolomite, other materials are sodium bicarbonate, glass bead, etc.
2. Abrasive particle grain size is a dominant factor in AJM. Size in the range of 10-50 µm gives best results.
3. Abrasive flow rate has influence on material remove rate and it is desirable to use of the lowest acceptable flow rate to conserve abrasives and also to increase the life of the nozzle.
4. The mass flow rate is 3-20 g/min.

- **Carrier gas:**

1. Air, nitrogen(N₂), carbon dioxide (CO₂) is generally used as a carrier gas. The pressure is in the range of 2-8 bar. Higher pressure results in high nozzle wear a lower pressure results in reduced material removal rate.
2. The air density is 1.3 kg/m³, velocity 150-300m/s.
3. Flow rate is around 30 L /min.

14. CONCLUSION

The few attempts to theorize the mechanics of material removal used very crude models or prototype in order to conceptualize the process parameters. The present research work is aimed mainly at proposing a suitable theory, which explains the mechanics with the process flow of AJM. Abrasive Jet Machining is one of the widely used unconventional machining method that is capable of producing the complex shapes and structures. With the time there is lot of improvements in the AJM and its assisted processes as well as optimization techniques, which made some new research scopes in the AJM.

Developments in modeling techniques have made new research scopes in the AJM and improves the performance of AJM process.

15. REFERENCES

- 1) Prasad, S. R., Ravindranath, D. K., & Devakumar, D. M. L. S. (2016). A Research Review on Advanced Approches in Abrasive Jet Machining. *IOSR Journal of Mechanical and Civil Engineering*, 16(053), 57–62. <https://doi.org/10.9790/1684-16053045762>
- 2) Chastagner, M. W., & Shih, A. J. (2007). Abrasive jet machining for edge generation. *Transactions of the North American Manufacturing Research Institution of SME*, 35, 359–366.
- 3) Jindal, A. (n.d.). *Study on Advanced Approches in Abrasive Jet Machining (AJM)*. 25(63019), 105–111.
- 4) Prof, A., Patil, S. T. N. D. D., & Nangare, A. A. N. A. B. (n.d.). *Develop a Setup for Abrasive Jet Machine Research Review Paper*. 657–661.
- 5) Chandra, B. (2011). A Study of effect of Process Parameters of Abrasive jet machining. *International Journal of Engineering Science*, 3(1), 504–513.
- 6) Johnbasha, D., Nageswararao, N. A., Prasad, K. N., & Mahaboob, S. (2016). *Investigation of Machining Parameters in Abrasive Jet Machining On Ti-6Al-4V USING GRA AND PCA*. 1139–1144.
- 7) Tech, M., Engineering, C., & Technology, C. (2019). A Literature Review on Parameters Influencing Abrasive Jet Machining and Abrasive Water Jet Machining. *Journal of Engineering Research and Application*, 9(1), 24–29. <https://doi.org/10.9790/9622>
- 8) Panda, R. C., Singh, G., & Kumar, R. (2018). *STATISTICAL PARAMETRIC STUDY OF ABRASIVE*. 5(1), 20–24.
- 9) Madhu, S., & Balasubramanian, M. (2015). A Review on Abrasive Jet Machining Process Parameters. *Applied Mechanics and Materials*, 766–767, 629–634. <https://doi.org/10.4028/www.scientific.net/am.m.766-767.629>
- 10) Melentiev, R., & Fang, F. (2018). Recent advances and challenges of abrasive jet machining. *CIRP Journal of Manufacturing Science and Technology*, 22, 1–20. <https://doi.org/10.1016/j.cirpj.2018.06.001>

- 11) Ramachandran, N., & Ramakrishnan, N. (1993). A review of abrasive jet machining. *Journal of Materials Processing Tech.*, 39(1-2), 21-31. [https://doi.org/10.1016/0924-0136\(93\)90005-Q](https://doi.org/10.1016/0924-0136(93)90005-Q)
- 12) Melentiev, R., & Fang, F. (2018). Recent advances and challenges of abrasive jet machining. *CIRP Journal of Manufacturing Science and Technology*, 22, 1-20. <https://doi.org/10.1016/j.cirpj.2018.06.001>
- 13) Verma, A. P., & Lal, G. K. (1984). An experimental study of abrasive jet machining. *International Journal of Machine Tool Design and Research*, 24(1), 19-29. [https://doi.org/10.1016/0020-7357\(84\)90043-X](https://doi.org/10.1016/0020-7357(84)90043-X)
- 14) Sutar, S., & Jagtap, K. R. (2017). Review on Abrasive Jet Machining. *VJER-Vishwakarma Journal of Engineering Research*, 1(3), 226-230.
- 15) Pawar, T., Wagh, S., & Shinde, R. (2015). Literature Review on Abrasive Jet Machining. *International Journal of Engineering Research and General Science*, 3(3), 1047-1051. Retrieved from https://www.academia.edu/33506905/Literature_Review_on_Abrasive_Jet_Machining
- 16) Pawar, T., Wagh, S., & Shinde, R. (2015). Literature Review on Abrasive Jet Machining. *International Journal of Engineering Research and General Science*, 3(3), 1047-1051. Retrieved from https://www.academia.edu/33506905/Literature_Review_on_Abrasive_Jet_Machining
- 17) Kulischenko, W. (1976). *Abrasive Jet Machining*. <https://doi.org/10.31399/asm.hb.v16.a0002156>
- 18) Advanced Manufacturing Processes, Dinesh Lohar, Tech-Max publications
- 19) Advanced Manufacturing Processes, Prashant Ambdekar, S. Agrawal, Nirali Prakashan

BIOGRAPHIES



Mr. Swapnil Umredkar is currently pursuing B.E. in Mechanical Engineering. He is **Ex- DRDO Intern**. His research focus on Lean Manufacturing, Aviation advancements with keen interest in Manufacturing and Advance Manufacturing Processes



Mr. Vallabh Bhoyar is currently pursuing B.E. in Mechanical Engineering. He is **Ex-HNI Intern**. His research focus on Experimental and Analytical investigation of gears, plastic gears, manufacturing and advance manufacturing processes