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Modeling and Fabrication of Abrasive Jet Machine

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Abstract: AJM has become a very useful method for micro machining. It has enormous number of distinct advantages over the other non-traditional cutting and drilling methods, that include high machining versatility and minimum stresses on the substrate. This abrasive jet machining project is used for drilling holes on brittle materials like glass. Holes can be created in brittle material and glass with the usage compressed air and abrasive particles. A compressor used is connected through high pressure pipe to the control valve. Control valve controls the air through pipes to the nozzle. A pressure gauge is attached to measure the pressure through the pipes. Pressure relief valve is also used which is attached between control valve and nozzle which performs the cleaning of air that passes to the mixing chamber. Mixing chamber is used mix clean air with the abrasive particle at a high pressure. The abrasive particle can be introduced from the upper inlet of the mixing chamber. A nozzle is connected to the end of the mixing chamber where discharge takes place. Nozzle has the function of increasing the velocity of high pressurized discharged air that is mixed with the abrasive particle. This discharged air is impacted on the material which is held by the vice. Thus, the desired hole is obtained.
Keywords: Abrasive jet machining, Standoff Distance, Nozzle diameter, Air pressure, Material Removal Rate, Over Cut, Flow rate.

I. INTRODUCTION

Abrasive jet machining (AJM) is one of the advanced machining processes (mechanical energy based) in which a high velocity jet of abrasives is used to remove material from work surface by impact that leads to the erosion of material from workpiece. The abrasive jet is obtained by accelerating fine abrasive particles in highly pressurized gas which is also known as carrier gas. A nozzle is used whose function is to convert the pressure energy into kinetic energy and also has the role of directing the jet towards work surface at a particular angle known as impingement angle.

Upon impact, hard abrasive particles gradually remove material by the erosion process and sometimes assisted by brittle fracture. AJM differs from age old sand blasting technique by a notable level in terms of accuracy and precision. AJM utilizes various abrasives including alumina, silicon carbide, glass beads, sodium bicarbonate, etc.; whereas sand blasting predominantly utilizes only silica sand (SiO2). Although purposes of both the processes are quite similar, cutting parameters can be controlled in AJM and thus it can provide better accuracy and precision.

II. LITERATURE SURVEY

A. Dr.M. Sreenevasa Rao, Sarkar and Pandey reviewed that the rate of MRR and penetration increases upto an optimum point after which, it will result in a gradual decrease. J. Wolak and K.N. Murthy investigated that for ductile materials maximum MRR is obtained at impingement angle of 15-20, whereas for brittle material maximum MRR is obtained at impingement angle normal to surface.
B. Dr.A. K. Paul & P. K. Roy (1987) concluded that MRR increases with increase in grain size of abrasive particles and nozzle diameter. They also concluded that with increase in Stand-off Distance MRR increases.
C. Mr. Bhaskar Chandra observed that with the increase in pressure, the MRR also increases.
D. Jukti Prasadn Padhy concluded that Stand-off Distance and pressure are both significant for MRR.
E. El- Domiaty concluded that greater the nozzle-diameter, more amount of abrasives can flow. Hence, more MRR and vice versa.
F. V. C. Venkatesh observed that wear is maximum at the exit of nozzle and moderate in mixing chamber and minimum at nozzle inlet.
G. P. K. Ray & Dr. Alepaul reported a study on the results of machining under various conditions, compared the values and defined SOD as the main factor for material removal rate and plotted the graphs. In precision work, a higher pressure and a lower stand-off distance may be adopted to attain a, higher accuracy and penetration rate.

The literature study of Abrasive Jet Machine reveals that the Machining process was started a few decades ago. Till date there has been a through and detailed experiment and theoretical study on the process. Most of the studies argue over the hydrodynamic characteristics of abrasive jets, hence ascertaining the influence of all operational variables on the process effectiveness including abrasive type, size and concentration, impact speed and angle of impingement. Other papers found new problems concerning carrier gas typologies, nozzle shape, size and wear, jet velocity and pressure, stand-off-distance (SOD), or nozzle-tip-distance (NTD). These papers express the overall process performance in terms of material removal rate, geometrical tolerances and surface finishing of work pieces, as well as in terms of nozzle wear rate. Finally, there are several significant and important papers which focus on either leading process mechanisms in machining of both ductile and brittle materials, or on the development of systematic experimental-statistical approaches and artificial neural networks to predict the relationship between the settings of operational variables and the machining rate and accuracy in surface finishing. (Ref-9) The erosion of brittle materials by solid micro-particles is a complex process in which material is removed from the target surface by brittle fractures. The rate of material removal is one of the most important quantities for a machining process. Predictive mathematical models for the erosion rates in micro-hole drilling and micro-channel cutting on glasses with an abrasive air jet are developed. A dimensional analysis technique is used to formulate the models as functions of the particle impact parameters, target material properties and the major process parameters that are known to affect the erosion process of brittle materials. The effect of various parameters like abrasive mass flow rate, air pressure and stand off distance on erosion rate is shown by following graphical presentation.

III. EXPERIMENTAL METHODOLOGY

A. *Working Principle Of Abrasive JET Machine*

Abrasive Jet Machining (AJM) is one of the mechanical energy based modern machining processes where material is removed by controlled micro-cutting action caused by the impact of a concentrated high-velocity (100 – 300m/s) jet of abrasive grits accelerated by dehumidified pressurized gas (10 – 15bar). A nozzle directs the abrasive jet in a controlled way onto the work surface. Air is directly taken from atmosphere then, it is filtered and compressed to a high pressure with the help of a high-pressure compressor. Loose abrasive particles having predefined sizes are mixed with this pressurized gas in a certain proportion (mixing ratio) and this mixture is then allowed to strike the surface of the workpiece in the form of jet at a desired incident angle, incident at a very high velocity. A nozzle converts the pressure energy of the mixture into kinetic energy.

B. *Component Details*

1) *Compressor:* A Compressor is defined as a machine that is used for the supply of air or any other gases at an increased pressure. It compresses the gas to a pressure of 5-10 bar. A Compressor unit comprises of components like drier and filter to remove dust particles and moisture to avoid jamming or condensation during the process of compression.

a) *Compressor Specification*

Motor HP – 7.5hp or 5.5k
Max W/Pr – 12 kgf/cm2
Max pressure – 12kg/cm2 or 175psi
Unit RPM – 1050
Dimensions – 1600*630*1120 (L*B*H)
Tank capacity – 220 litres
Displacement – 700 lpm or 24.7 cfm
Weight – 275 kg

2) *Flow Control Valve:* Flow Control Valves are used to control the volume flow rate of compressed gas so as to maintain the mixing ratio. It is used to stop the excess flow of compressed air in the circuit.
3) *Mixture Chamber:* The purpose of a mixing chamber is that, it carries out the mixing of abrasives with the pressurized carrier gas. As the carrier gas and abrasives are introduced into the chamber, the chamber is vibrated to obtain a homogeneous mixture, which increases the working efficiency of the AJM.
4) *Nozzle:* A Nozzle is used to manage the flow of substances (abrasive particles here). They are also used to control the direction of fluid or air flow. They can be obtained in varying cross-sectional area as per the requirement. A Nozzle converts pressure energy of abrasives into the kinetic energy. Thus, high velocity jet is obtained.

5) *PU Fittings:* PU fittings are used to connect different sections of pipes or tubes. Here, we have a pneumatic system so, PU fittings with characteristics like tighter sealing and lower pressure requirements are used. They offer the combined properties of both plastic and rubber. They offer abrasion and tear resistance properties as, they are very necessary in AJM.
6) *Bench Vice:* The function of Bench vice is to hold the workpiece underneath, with better gripping. The Bench vice we have used in AJM is a simple, compact and reliable to operate. It is mounted on the wooden block provided in our project.
7) *MS Frame:* MS frames are used to construct the supporting block design on which the above components are to be mounted. Frames are to be designed in such a way that, it does not vibrate or displace during the working of AJM. The different dimensions of the frame used in our system are:-

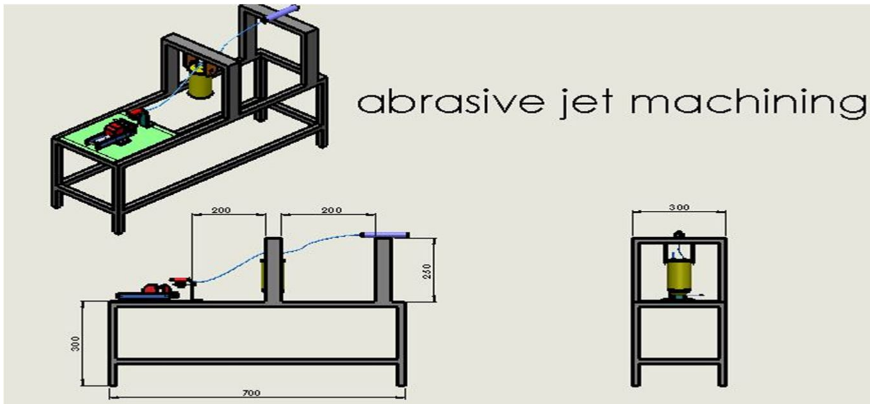

Fig. 1. Assembly Drawing

C. *Design Of Abrasive JET Machine*

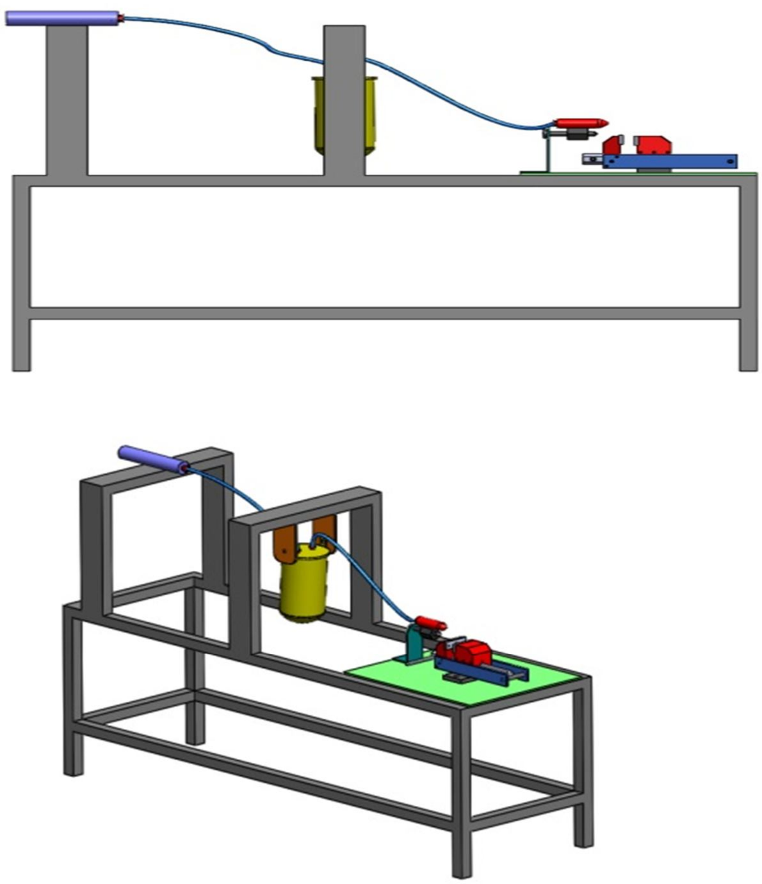
Fig. 2. Working Model

D. System Working

The project is designed by following compressor, mixing chamber, inlet and outlet pressure gauges, nozzle and bench vise. Dry air is filtered and compressed by passing it through that filter and compressor. A pressure gauge and a flow regulator are used to set the pressure and regulate the flow rate of compressed air. Compressed air is then regulated into the mixing chamber. In mixing chamber, the abrasive powder is introduced. The abrasive powder and compressed air are rigorously mixed in the chamber. The mixture passes through the outlet pressure gauge where the difference between the inlet pressure and outlet pressure can be noticed and also helps to identify the leaks in the system. The mixture is then sent to the nozzle. The nozzle enhances the velocity of the mixture, at the expense of the pressure. A fine abrasive jet is stroked by the nozzle. This jet results in removal of material from the work piece.

E. Assembly Of Working Model

The Assembly of our Abrasive Jet Machine consists of following parts:

1) Multi-Stage Compressor
2) Flow Control Valve
3) Two Pressure Gauges
4) Mixing Chamber
5) Bench Vice
6) Nozzle
7) Frame

The Compressor used in this Abrasive Jet Machine can supply air upto the pressure of 25 bar. But, the maximum air pressure at which the AJM is operated is 10 bar. All the components are connected using high pressure pneumatic pipes. The maximum pressure these pipes can withstand is 10 bar. After this limit, failure in pipe occurs. A Flow Control Valve is plugged with the compressor and the other end is connected to the inlet of mixing chamber. A pressure gauge is used to measure the inlet pressure of air (Pi) into the system between this circuit. The outlet of the mixing chamber (i.e. from where the mixture of abrasive and compressed air will pass) is connected to the Nozzle. Another pressure gauge is placed on this connecting circuit to measure the outlet pressure (Po). The Nozzle is clamped onto the same work surface as the Bench vice. All the components except the Compressor, Flow Control Valve and pressure gauge (inlet) are mounted on the frame designed. The assembly structure used is very simple and reliable as per the comparison done with other AJMs.

a) Workpiece Material: Glass
Thickness: 5mm
Abrasive: Glass Beads
Nozzle Diameter: 1.5mm

Table 1.1 Work Material Glass with Abrasive Glass Beads

SR. NO	PRESSURE (bar)	FLOW RATE (mm^3/sec)	MRR (mg/min)	EROSION RATE
1	5 bar	930.667 mm^3/sec	4.1242 mg/min	0.007874
2	6 bar	1019.5 mm^3/sec	5.58 mg/min	0.010526
3	7 bar	1100.5 mm^3/sec	7.2618 mg/min	0.013698
4	8 bar	1177.166 mm^3/sec	16.0644 mg/min	0.030303

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GLASS

Regression Analysis: Pressure versus MRR

The regression equation is

Pressure = 4.704 + 0.2176 MRR

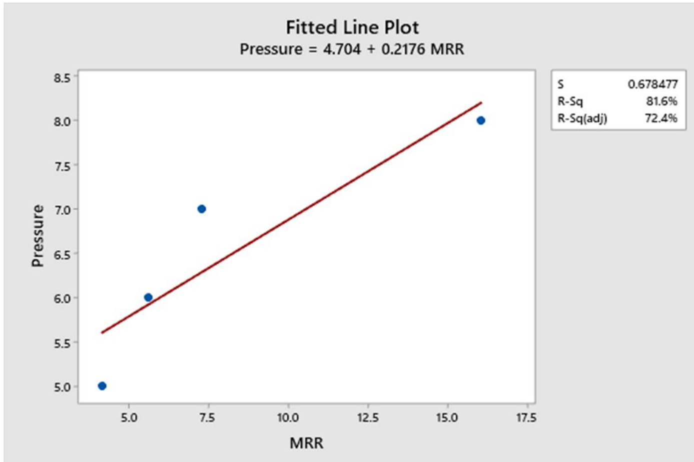

Fig. 3. Pressure versus MRR

Regression Analysis: Pressure versus Erosion

The regression equation is

Pressure = 4.699 + 115.4 Erosion

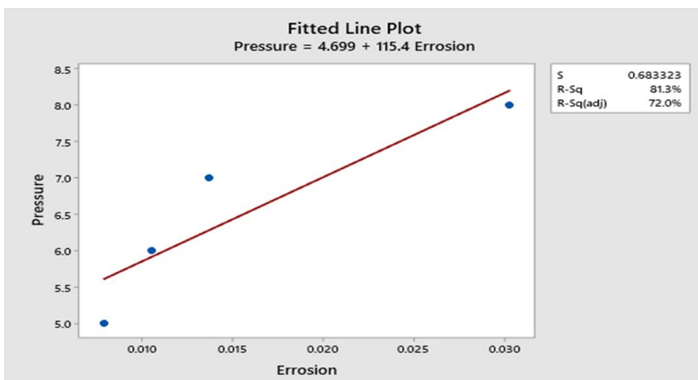

Fig. 4. Pressure versus Erosion

GLASS

Regression Analysis: Pressure versus Flow Rate

The regression equation is

Pressure = - 6.368 + 0.01217 Flow Rate

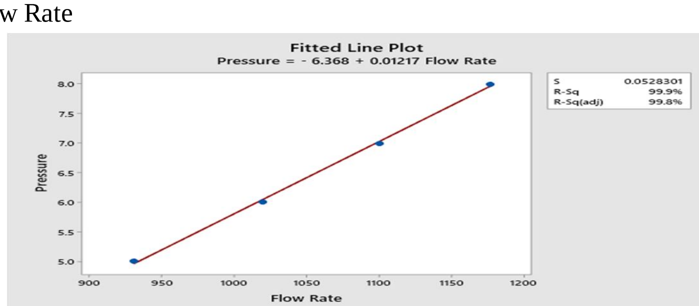

Fig. 5. Pressure versus Flow Rate

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GLASS

Regression Analysis: Flow Rate versus Erosion

The regression equation is

Flow Rate = 911.3 + 9338 Erosion

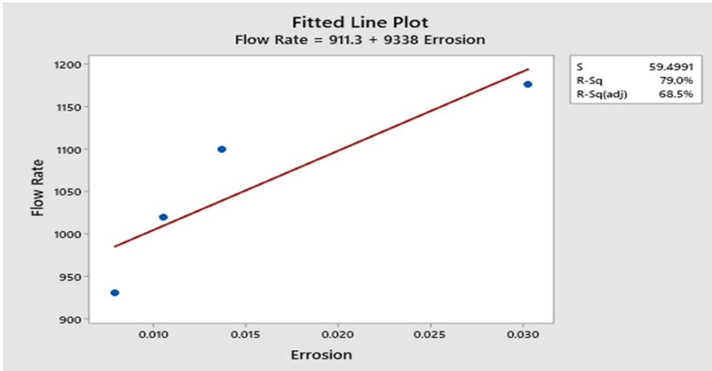

Fig. 6. Flow Rate versus Erosion

GLASS

Regression Analysis: Flow Rate versus MRR

The regression equation is

Flow Rate = 911.6 + 17.60 MRR

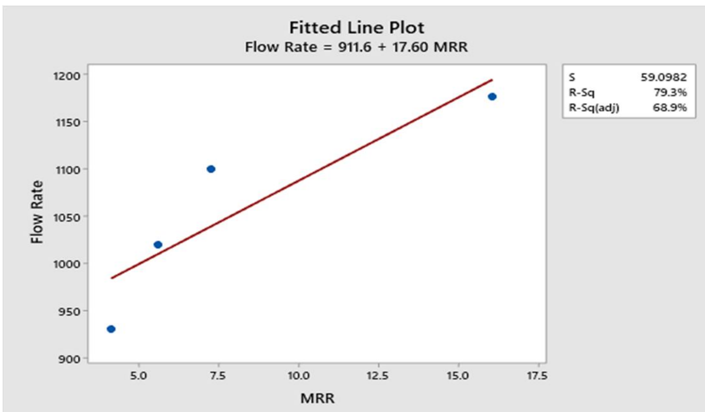

Fig. 7. Flow Rate versus MRR

GLASS

Regression Analysis: MRR versus Erosion

The regression equation is

MRR = - 0.03226 + 531.4 Erosion

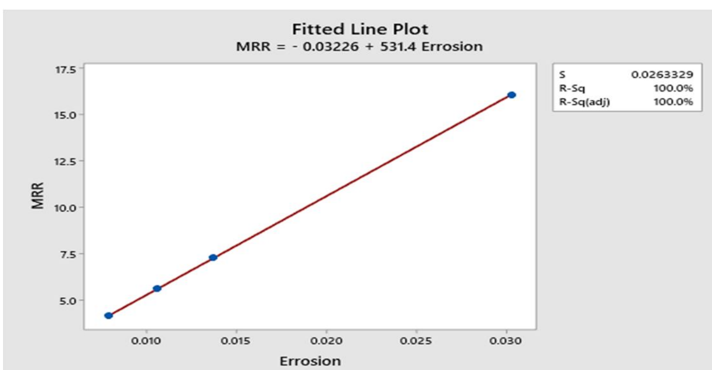

Fig. 8. MRR versus Erosion

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b) Workpiece Material: Ceramic Tiles
Thickness: 5mm
Abrasive: Glass Beads
Nozzle Diameter: 1.5mm

Table 1.2 Work Material Ceramic with Abrasive Glass Beads

SR. NO	PRESSURE (bar)	FLOW RATE (mm^3/sec)	MRR (mg/min)	EROSION RATE
1	5 bar	930.667 mm^3/sec	27.9 mg/min	0.10526
2	6 bar	1019.5 mm^3/sec	53.01 mg/min	0.2
3	7 bar	1100.5 mm^3/sec	66.27 mg/min	0.25
4	8 bar	1177.166 mm^3/sec	106.03 mg/min	0.4

CERAMIC TILE
Regression Analysis: Pressure versus Flow Rate
The regression equation is
Pressure = - 6.368 + 0.01217 Flow Rate

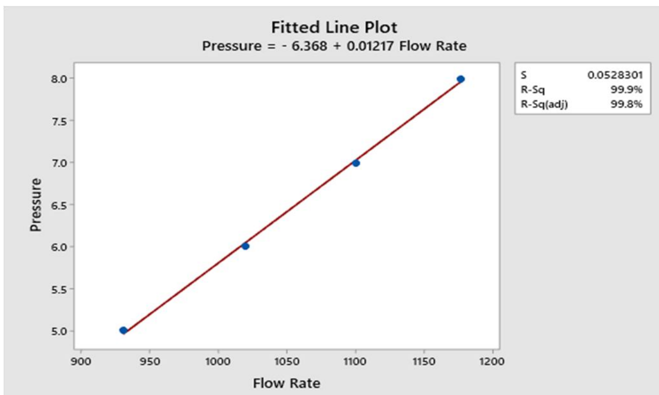

Fig. 9. Pressure versus Flow Rate

CERAMIC TILE
Regression Analysis: Pressure versus MRR
The regression equation is
Pressure = 4.046 + 0.03877 MRR

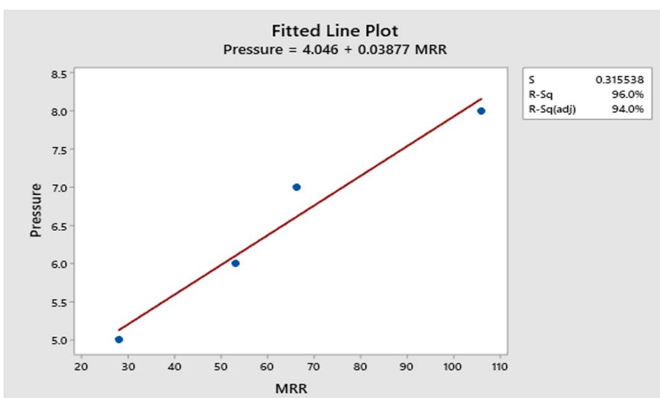

Fig. 10. Pressure versus MRR

CERAMIC TILE

Regression Analysis: Pressure versus Erosion

The regression equation is

Pressure = 4.046 + 10.28 Erosion

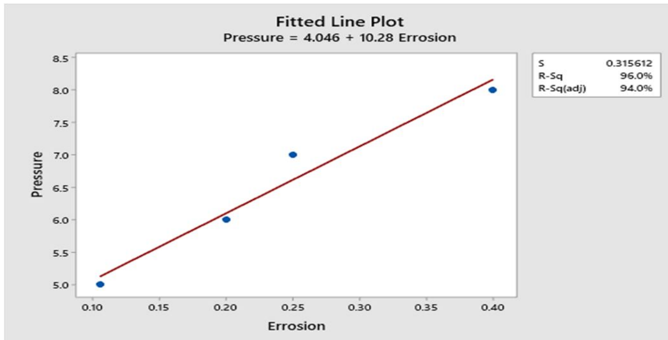

Fig. 11. Pressure versus Erosion

CERAMIC TILE

Regression Analysis: Flow Rate versus Erosion

The regression equation is

Flow Rate = 856.3 + 840.1 Erosion

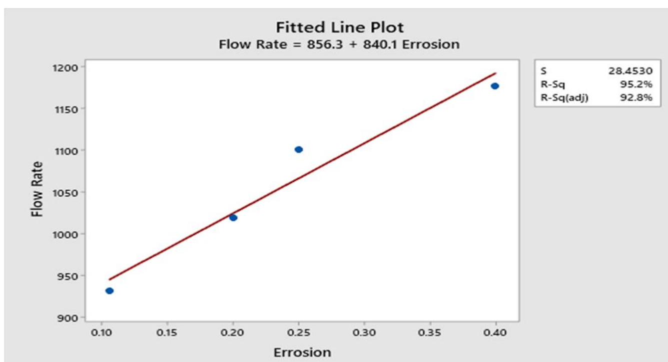

Fig. 12. Flow Rate versus Erosion

CERAMIC TILE

Regression Analysis: Flow Rate versus MRR

The regression equation is

Flow Rate = 856.3 + 3.169 MRR

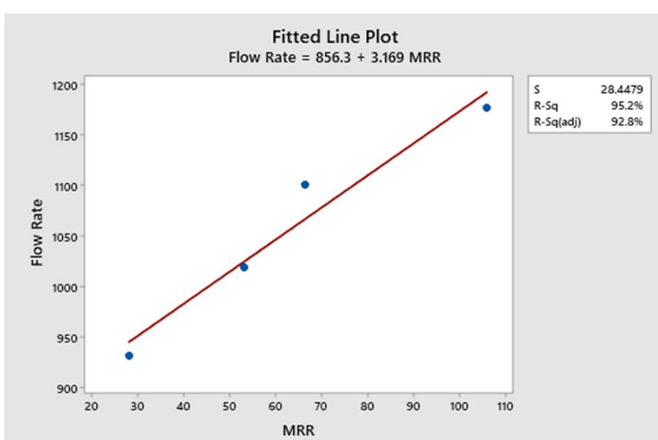

Fig. 13 Flow Rate versus MRR

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CERAMIC TILE
Regression Analysis: MRR versus Erosion
The regression equation is
MRR = - 0.003739 + 265.1 Erosion

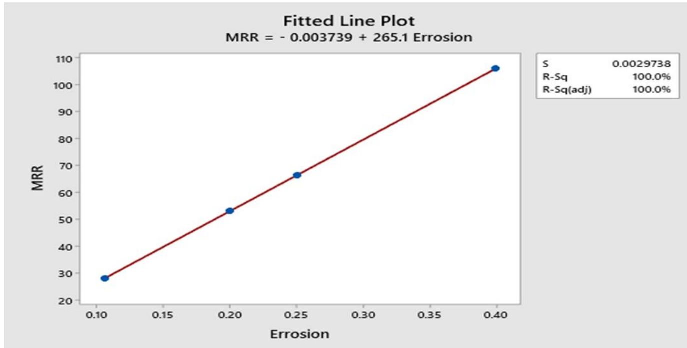

Fig. 14 MRR versus Erosion

c) Workpiece Material: Galvanized Iron (GI)
Thickness: 0.5625mm
Abrasive: Glass Beads
Nozzle Diameter: 1.5mm

Table 1.3 Work Material Galvanized Iron with Abrasive Glass Beads

SR. NO	PRESSURE (bar)	FLOW RATE (mm^3/sec)	MRR (mg/min)	EROSION RATE
1	5 bar	930.667 mm^3/sec	1.12 mg/min	0.001
2	6 bar	1019.5 mm^3/sec	1.45 mg/min	0.001
3	7 bar	1100.5 mm^sec	1.92 mg/min	0.001
4	8 bar	1177.166 mm^3/sec	2.59 mg/min	0.001

GI
Regression Analysis: Pressure versus MRR
The regression equation is
Pressure = 2.959 + 2.000 MRR

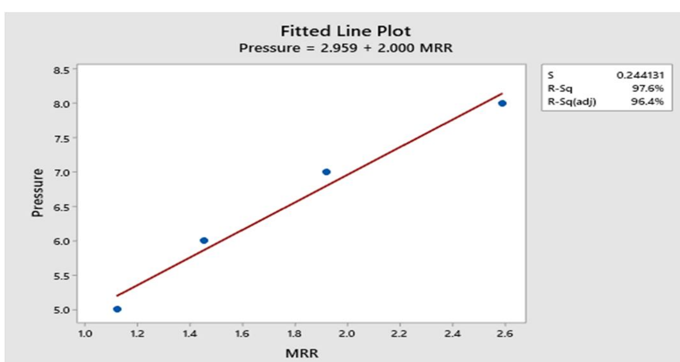

Fig. 15 Pressure versus MRR

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GI
Regression Analysis: Pressure versus Flow Rate
The regression equation is
Pressure = - 6.368 + 0.01217 Flow Rate

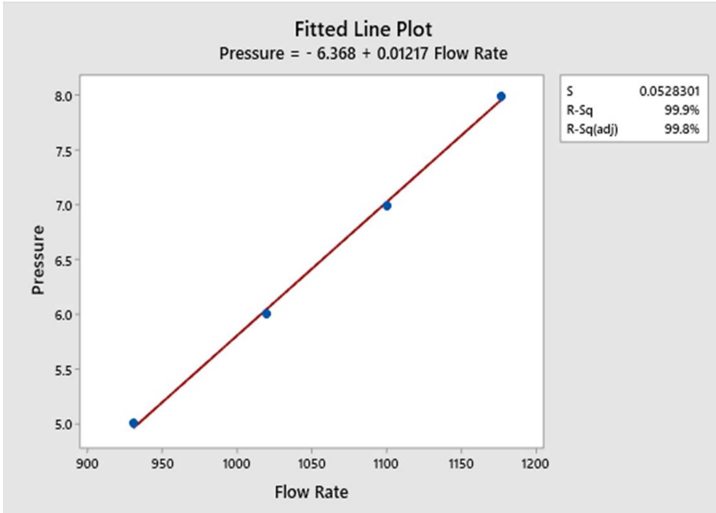

Fig. 16 Pressure versus Flow Rat

Regression Analysis: Flow Rate versus MRR
The regression equation is
Flow Rate = 767.9 + 163.3 MRR

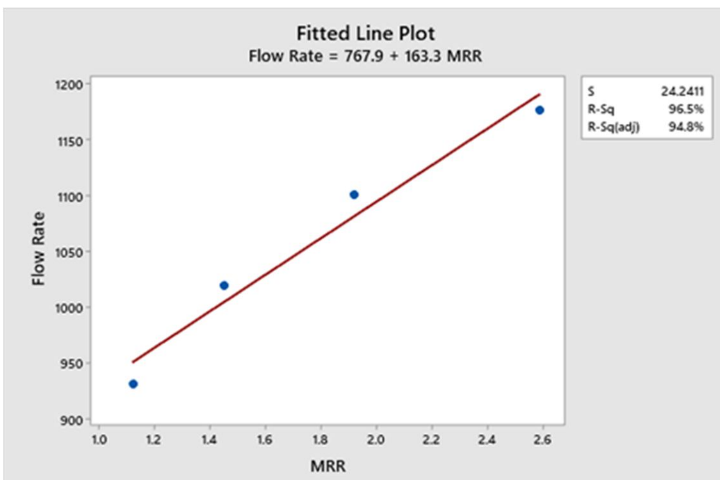

Fig. 17 Flow Rate versus MRR

IV. FUTURE SCOPE

According to the various research papers studied by us, a lot of work has been done on abrasive particles, its geometry and various other parameters that are associated with machining processes. AJM process is gaining a lot of attention in the machining areas, particularly for the processing of materials that are difficult to be machined. Its unique advantages over other varied conventional and non-conventional machining methods make it a good choice in the manufacturing industry. A significantly less research has been carried out on the study of the effect of abrasive flow rate on the performance criteria. Hence there is scope for improvement for the study of the effect of abrasive flow rate on performance characteristics. The invalid build up in the construction of mixing chamber leads to various problems such as abrasive powder stratification, powder compaction, powder humidification etc. This affects the machining results undesirably.

V. CONCLUSION

In this project a complete design of the Abrasive Jet Machine is given. The total assembly is designed taking in account of currently available components in the market. The designing and assembling of very large number of components was a tremendous task and was completed on time. However, because of some parts couldn't be purchased the whole assembly was limited to some basic manufacturing operation. The project can go beyond its current position and capabilities by introducing automation into it. This can be done by using various methods like, using a stepper motors or DC servo motors interfaced with standard PCI controllers or standalone controllers. 2-D profiles can be converted into standard G-codes and M-codes and that can be sent to the machine to perform automated machining.

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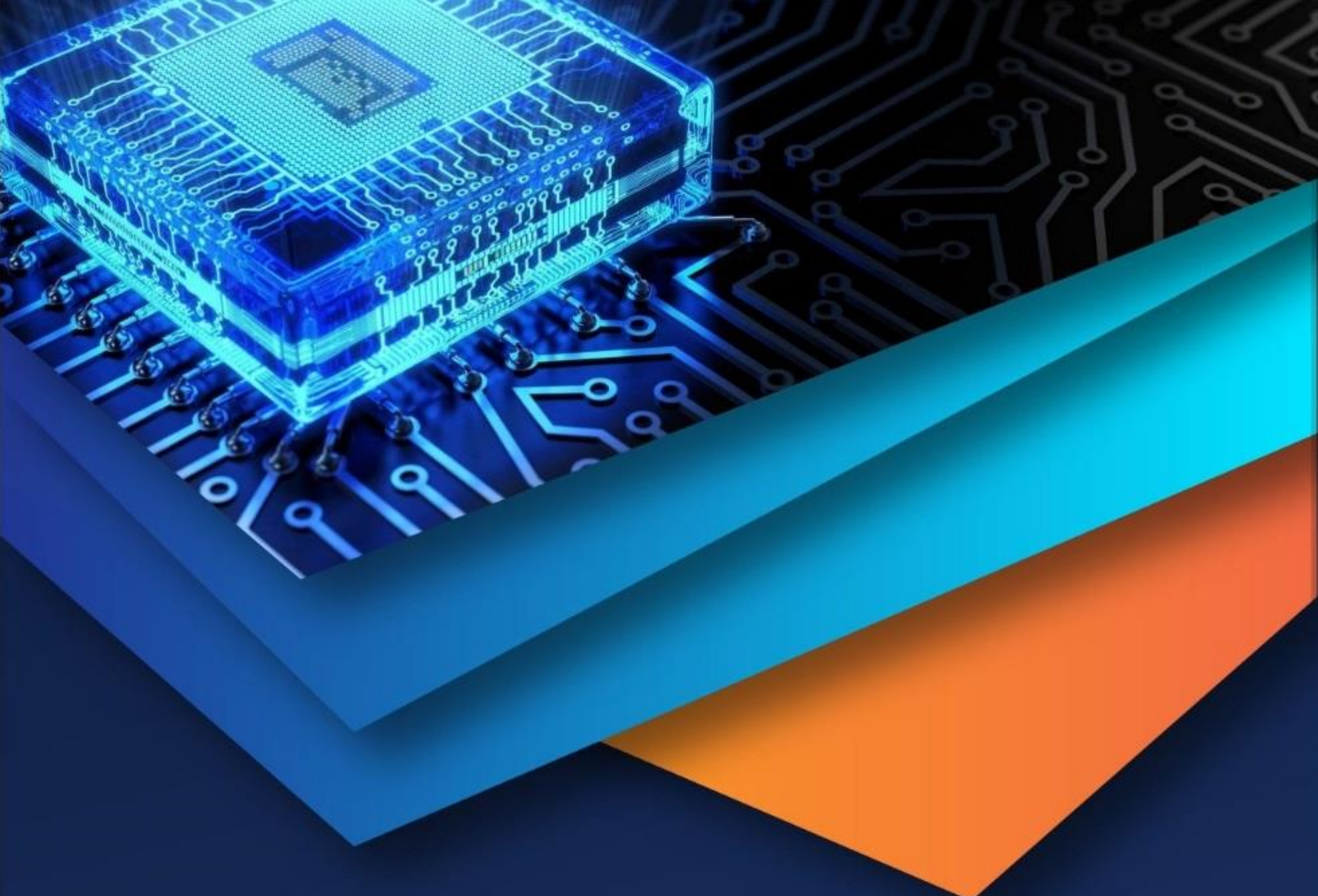

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