Erosion in Abrasive Jet Nozzles: A Comprehensive Study

D. V. Sreekanth, M. Sreenivasa Rao

Abstract**—**Abrasive jet machining is one of the promising non-traditional machining processes which uses mechanical energy (pressure and velocity) for machining various materials. The process parameters that influence the metal removal rate are kerfs, surface finish, depth of cut, air pressure, and distance between nozzle and work piece, nozzle diameter, abrasive type, abrasive shape, and mass flow rate of abrasive particles. The abrasive particles coming out with high pressure not only hits work surface but also passes through the nozzle resulting in erosion. This paper focuses mainly on the effect of different parameters on the erosion of nozzle in Abrasive jet machining. Three different types of nozzles made of sapphire, tungsten carbide, and high carbon high chromium steel (HCHCS) are used for machining glass and the erosion of these nozzles are calculated. The results are shown in tabular form and graphical representation.

Keywords**—**AJM, nozzle, sapphire, tungsten carbide, chrome steel.

I. Introduction

SAPPHIRES are precious stones that are naturally available and generally embedded in jewels. They are also manufactured as large crystals for industrial use and decorative purposes. Nozzles in abrasive jet machining has small diameter hole with high length to diameter ratio. Because of the remarkable hardness of sapphires they withstand higher wear and tear. The life of the nozzle made out of sapphire is more when compared with any metal made nozzles. The work pieces made using these nozzles have higher surface finish at close tolerances. Due to its super natural properties, it is one of the preferred nozzle materials.

Tungsten Carbide (WC) is one of the promising metals which contain equal part of tungsten and carbon atoms. It has highest melting point (2870 °C) and its boiling point is 6000 °C. WC is extremely hard and used in various industrial applications like cutting tools, trekking poles, surgical instruments, jewelers, roller ball pens etc. [11].

Tungsten Carbide (WC) is one of the promising metals which contain equal part of tungsten and carbon atoms. It has highest melting point (2870 °C) and its boiling point is 6000 °C. WC is extremely hard and used in various industrial applications like cutting tools, trekking poles, surgical instruments, jewelers, roller ball pens etc. [11].

Abrasive jet machining is one of the advanced machining techniques which work with the help of abrasive media. The erosion takes place in abrasive jet machining due to the impact of high velocity abrasive particles on work surface [1], [8]. The optimal metal removal depends on pressure, nozzle diameter, stand of distance [SOD] etc.

The material removal rate [MRR] mainly depends on the pressure, flow rate and size of abrasives. It is highlighted by many reviewers that by increase in pressure the MRR increases followed by decrease in Ra value [2]. The increase in grain size of abrasives produces greater metal removal rates. At higher pressure the MRR increases followed by Abrasive flow ratio [AFR] up to an optimal level and then decreases with increase in AFR. It is also analyzed that by increasing in AFR the Mixture Flow Ratio [MFR] of air decreases causing decrease in MRR [10].

The abrasive practices play a vital role in the machining by AJM. There are different types of abrasive particles available with different grit sizes. They are silicon carbide, aluminum oxide, boron carbide, borosilicate carbide, diamond dust etc. [3], [9]. But in our experimentation we have used silicon carbide as abrasive and the work piece is glass.

Fig. 1 Setup of AJM at SMEC

Fig. 2 Hole formation on glass sheet

II. Methodology

In abrasive jet machining one of the vital parts of the equipment is nozzle. The life of the nozzle is an important

D.V.Sreekanth, Professor, is with the Mechanical Engineering Department, St. Martin's Engineering College, Secunderabad, India (phone: 9703050004; e-mail: dvsrikanth@smec.ac.in).

M. Sreenivasa Rao, Professor and BOS chairman, is with the Department of Mechanical Engineering, JNTUCE, JNTUH, Kukatpally, Hyderabad, India (e-mail: raoms63@rediffmail.com).

parameter in the machining process.

As per the process requirement the nozzle material should be of harder material (WC, sapphire etc.) to withstand high velocity air passing through the nozzle hole along with abrasives [4].

The nozzle directs abrasive jet in a controlled manner onto work material. The nozzle is made of circular cross section having a convergent head with or without a conical section at discharge end. The nozzle is designed to ensure minimum loss of pressure due to friction, bends etc. The divergent jet stream increases the wear of nozzle and results in inaccuracy of cut and also introduces stray cutting.

It is very important to study the various parameters which affect the life of the nozzle and to choose right parameters for prolonged life to avoid frequent change of nozzles.

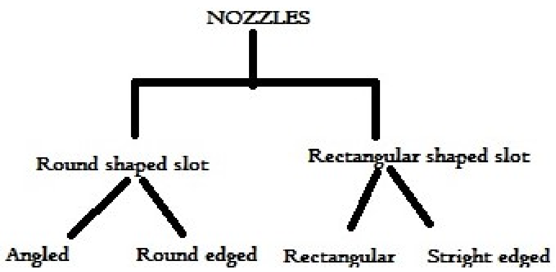

Fig. 3 Classification of Nozzles in AJM

Process parameters influencing the Nozzle Erosion are:

- Type of abrasives used
- Nozzle material
- Work piece being machined
- Operating pressure
- Diameter of nozzle
- Stand Off Distance (SOD)
- Grain size of abrasives
- Flow rate or feed of abrasive particles
- Velocity of abrasive grains

If the pressure of the gas increases then there is an increase in the metal removal rate. The kinetic energy present in the abrasive particles is responsible for the metal removal by erosion process. The nozzle controls the direction of abrasive jets on the work piece surface. The high velocity particles of abrasives remove the material by a technique of micro cutting and brittle fracture on the work piece.

While performing the machining operation, the coarse grains impinge on the surface and deflect back towards the nozzle tip, which also increases the erosion. It can be identified that the increase in flow rate of air the mass flow rate of abrasive particles increases and thus the metal removal rate increases, and the loss of nozzle material also increases [5].

By maintaining the optimal stand of distance between nozzle and work piece, the wear of the nozzle can be decreased.

The size of abrasive particles normally ranges from 10 to 60 microns and the mass flow rate of abrasives is selected as 5 gm/min [6], for experimental analysis. The increase in size of the abrasives more than the specified size causes the clogging of nozzle, which disturbs the machining operation. Accordingly, a cause-effect diagram (fish bone diagram) has been prepared. The fishbone diagram gives the effect of parameters on the nozzle erosion.

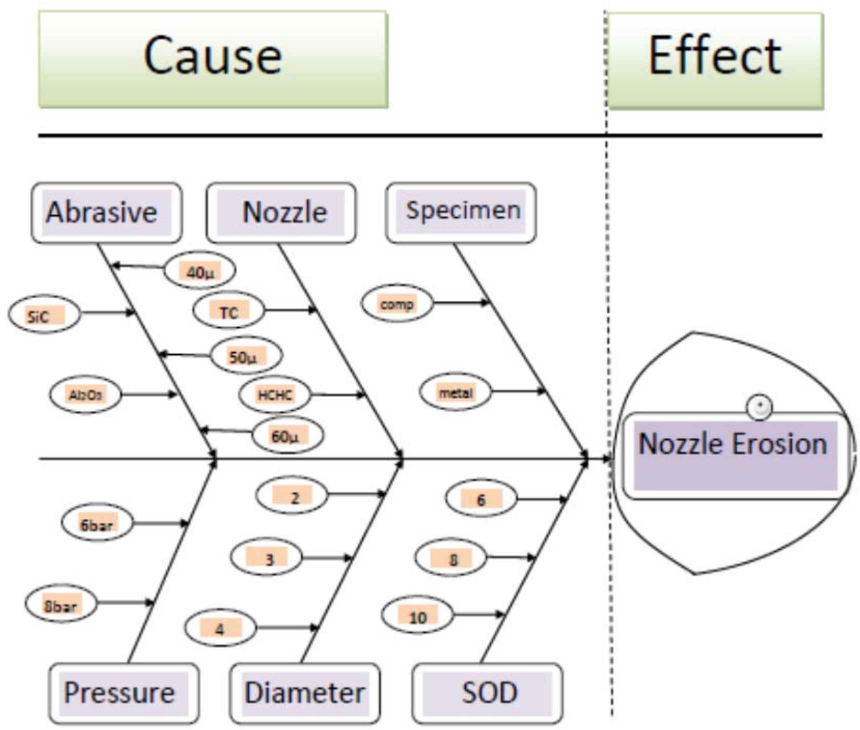

Fig. 4 Ishikawa or fishbone diagram of various causes and effect (Nozzle erosion)

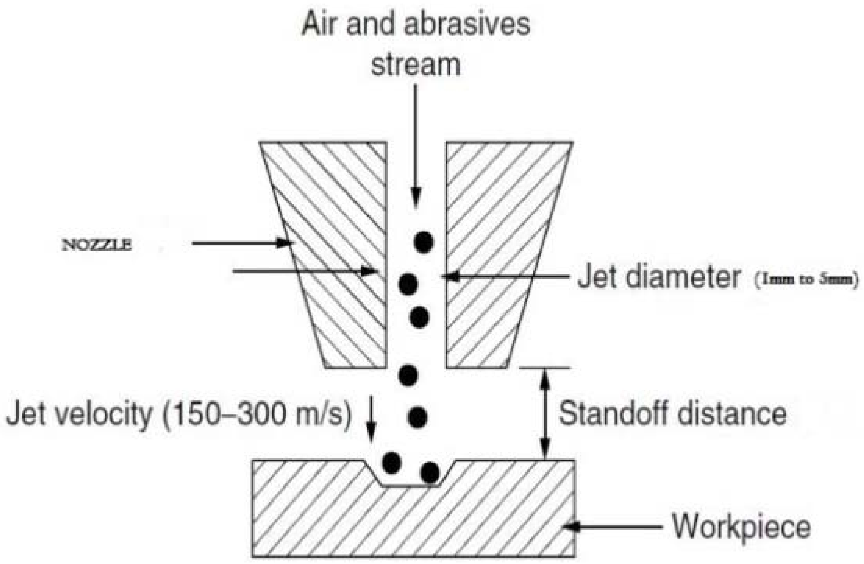

Fig. 5 Working of nozzle

III. Experimentation

Experiments are conducted on three different types of nozzles made of sapphire coated, WC and high carbon and high chromium steel on the Test Rig established at St. Martin's Engineering College, Secunderabad.

The abrasive particles coming through the nozzle affects the nozzle material causing erosion. The nozzle erosion tends to decrease in weight of nozzle [7].

Fig. 6 Nozzles made of different materials

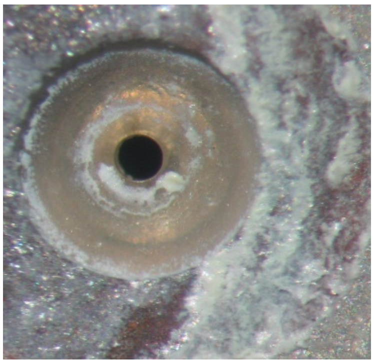

Fig. 7 Nozzles made of Sapphire coating

Fig. 8 Nozzles made of WC and HCHC steel

For finding the quantity of erosion of the nozzles, initial weight of the nozzle is measured and machining is performed on the glass specimen. After completion of the first machining the weight of the nozzle is measured. This weighing process is repeated up to four machining. The differences in weights are tabulated.

IV. Tabulation of Experimental Values

Tables I-VI are for three different sets of nozzles made up of a) sapphire b) WC and c) HCHC steel. The parameters tested are: a) diameters and b) Pressures. The results of nozzle erosions are analyzed and reported.

V. Results & Discussions

After the tabulation it has been observed that

(a) From Figs. 9-12, it is inferred that for all nozzle materials, the erosion increases as the pressure increases.

(b) From Figs. 9, 11, and 12, for all nozzle materials, as the nozzle diameter increases the erosion decreases.

(c) Fig. 14 shows that the erosion for sapphire nozzle is lower and TC is in the middle and HCHC is higher. So the erosion directly depends on the hardness of the nozzle material.

TABLE
EROSION OF SAPPHIRE NOZZLE (PRESSURE 6 BAR)

Diameter of the nozzle (mm)	Initial weight in (gms)	After first	after second machining (gms)	after third machining	after fourth machining	Total erosion (gms)
2	208.15	208.1	208.07	208.04	208.02	0.13
3	216.22	216.2	216.15	216.12	216.09	0.12
4	220.54	220.5	220.48	220.47	220.44	0.1

TABLE II
NOZZLE EROSION OF WC (PRESSURE 6 BAR)

Diameter of nozzle (mm)	Initial weight in (gms)	Weight after first machining (gms)	Weight after second machining (gms)	Weight after third machining (gms)	Weight after fourth machining (gms)	Total erosion (gms)
2	227.1	227.04	227	226.92	226.87	0.23
3	226.22	226.16	226.1	226.09	226.05	0.19
4	174.61	174.54	174.5	174.45	174.43	0.18

TABLE III
NOZZLE EROSION OF HC-HC STEEL (PRESSURE 6 BAR)

Diameter of nozzle	Initial weight in(gms)	Weight after first machining	Weight after second machining	Weight after third machining	Weight after fourth machining	Total erosion (gms)
2	202.02	201.95	201.87	201.77	201.66	0.36
3	205.66	205.58	205.48	205.39	205.33	0.33
4	203.2	203.11	203.12	203.04	202.99	0.21

TABLE IV
EROSION OF SAPPHIRE NOZZLE (PRESSURE 8 BAR)

Diameter of Nozzle	Initial weight in (gms)	Weight after first machining	Weight after second machining	Weight after third machining	Weight after fourth machining	Total erosion In (gms)
2	208.02	207.98	207.93	207.89	207.86	0.16
3	216.08	216.05	216.02	215.98	215.93	0.15
4	220.44	220.41	220.38	220.36	220.33	0.11

TABLE V
NOZZLE EROSION OF WC (PR 8 BAR)

Diameter of nozzle	Initial weight in (gms)	Weight after first machining	Weight after second machining	Weight after third machining	Weight after fourth machining	Total erosion In gms
2	201.66	201.58	201.49	201.36	201.26	0.4
3	205.33	205.24	205.14	205.05	204.98	0.35
4	202.99	202.92	202.86	202.81	202.75	0.24

TABLE VI
NOZZLE EROSION OF HC-HC STEEL (PR 8 BAR)

Diameter of nozzle	Initial weight in(gms)	Weight after first machining	Weight after second machining	Weight after third machining	Weight after fourth machining	Total erosion In gms
2	226.87	226.76	226.72	226.67	226.61	0.26
3	226.04	225.97	225.92	225.89	225.84	0.2
4	174.43	174.37	174.32	174.26	174.22	0.21

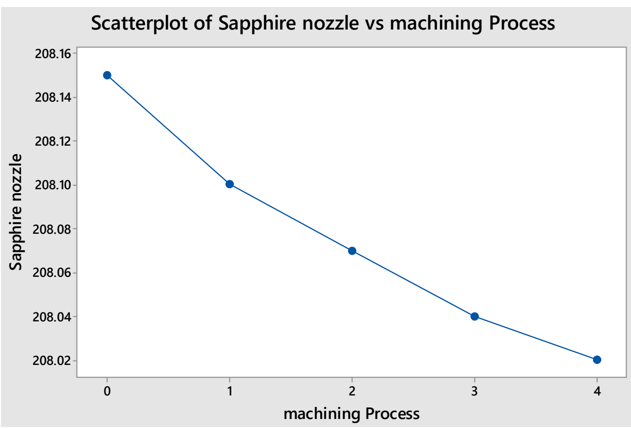

Fig 9 Weight loss of Sapphire nozzle of 2 mm dia under pr at 6 bar

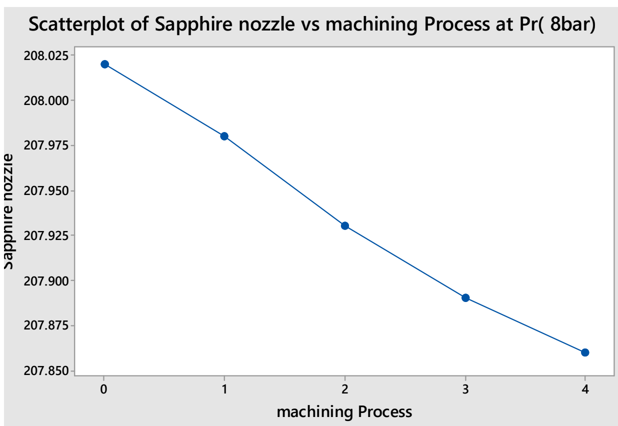

Fig 10 Weight loss of Sapphire nozzle of 2 mm dia under pr at 8 bar

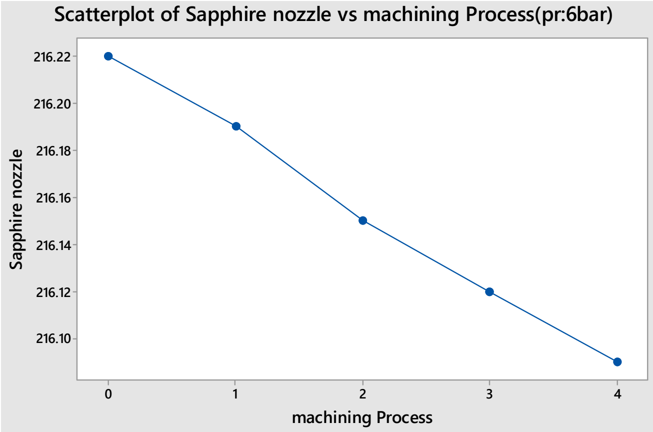

Fig 11 Weight loss of Sapphire nozzle of 3 mm dia under pressure 6 bar

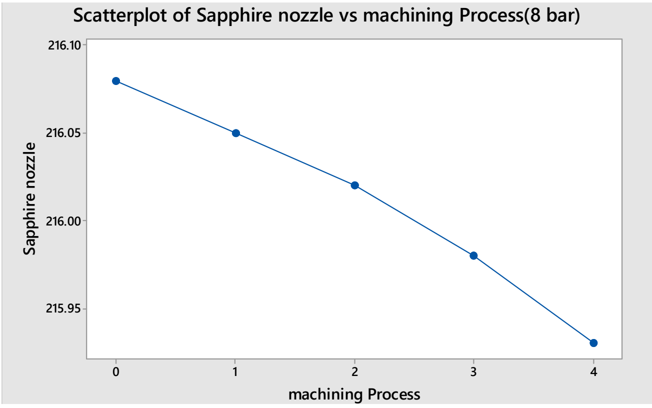

Fig. 12 Weight loss of Sapphire nozzle of 3 mm dia under pressure 8 bar

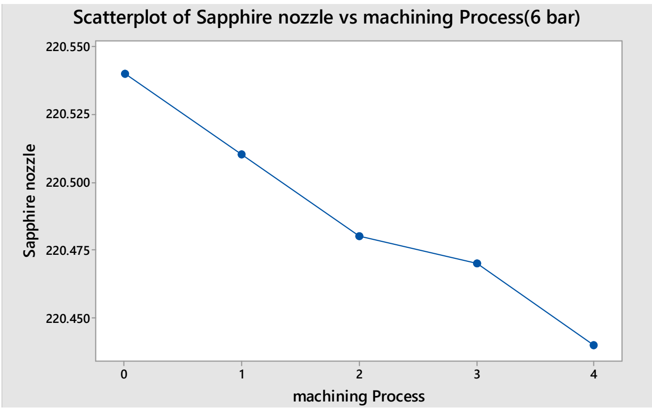

Fig. 13 Weight loss of Sapphire nozzle of 4 mm dia under pressure 6 bar

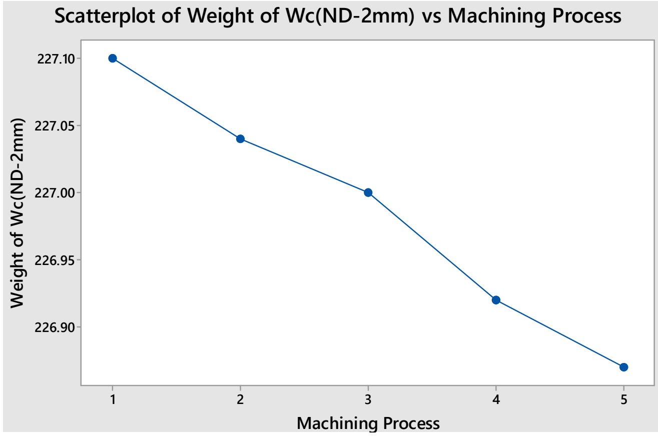

Fig. 14 Weight loss of WC nozzle of 2 mm dia under pressure 6 bar

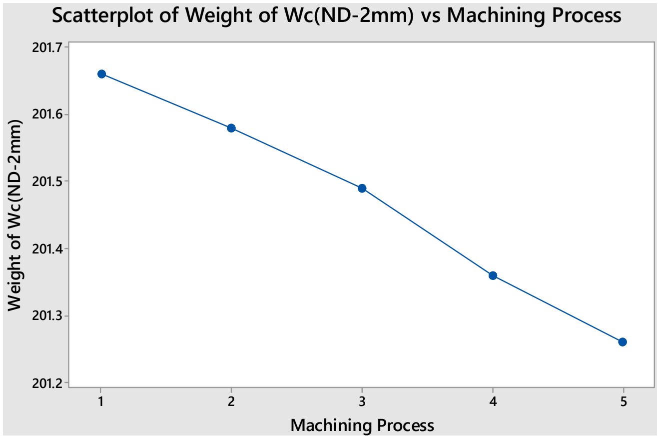

Fig. 15 Weight loss of WC nozzle of 2 mm dia under pressure 8 bar

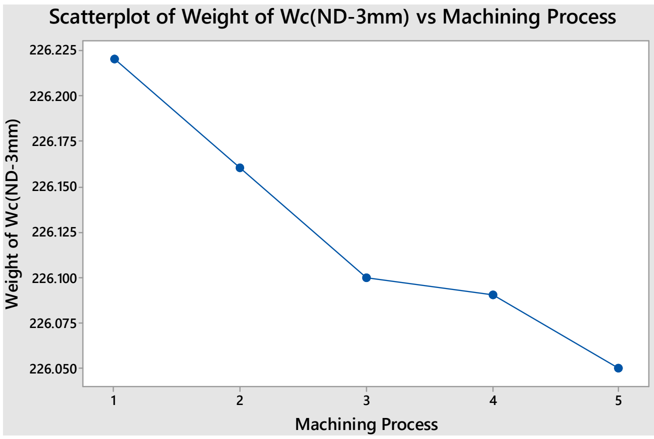

Fig. 16 Weight loss of WC nozzle of 3 mm dia under pressure 6 bar

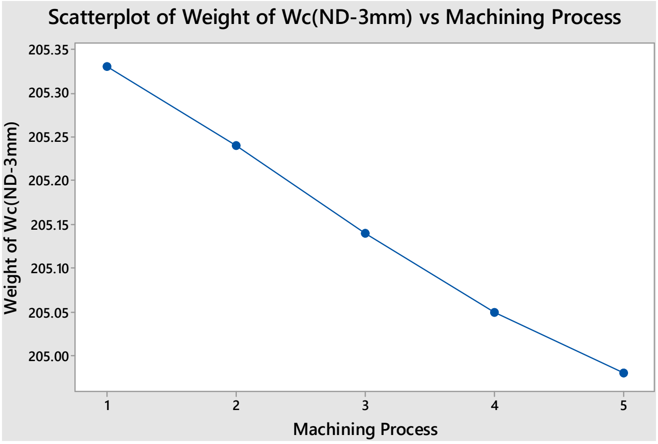

Fig. 17 Weight loss of WC nozzle of 3 mm dia under pressure 8 bar

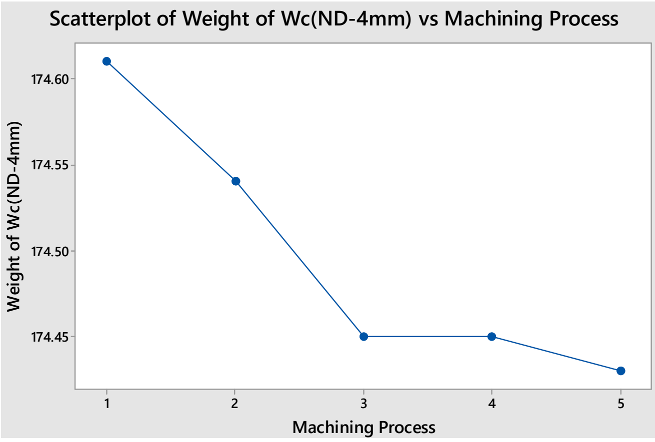

Fig. 18 Weight loss of WC nozzle of 4 mm dia under pressure 6 bar

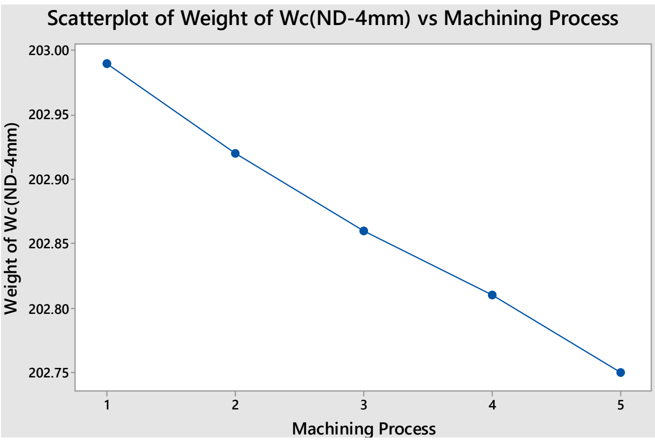

Fig. 19 Weight loss of WC nozzle of 4 mm dia under pressure 8 bar

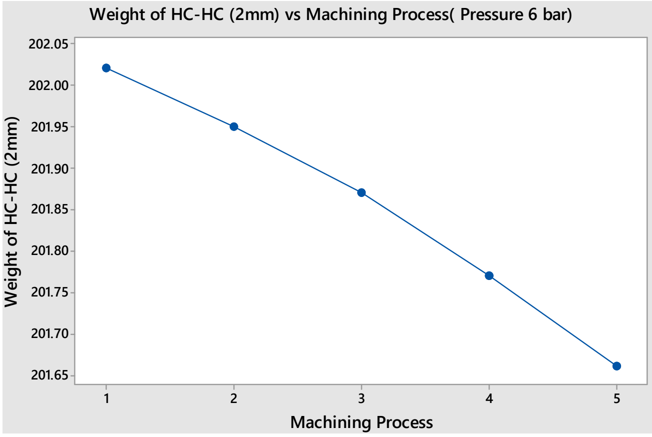

Fig. 20 Weight loss of HC-HC nozzle of 2 mm dia under pressure 6 bar

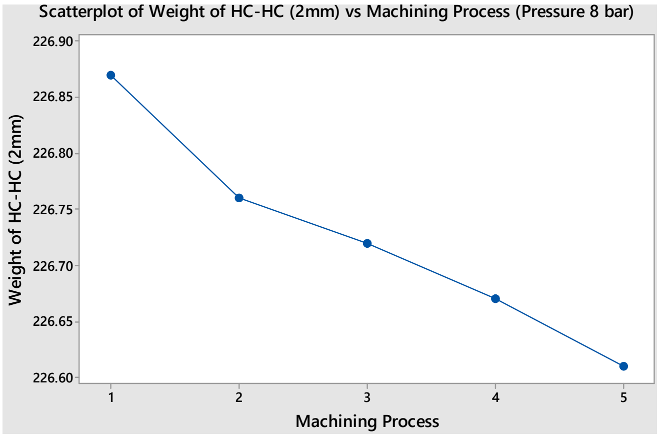

Fig. 21 Weight loss of HC-HC nozzle of 2 mm dia under pressure 8 bar

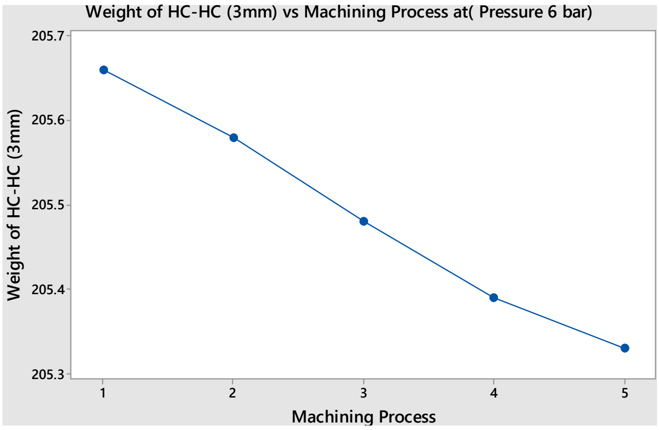

Fig. 22 Weight loss of HC-HC nozzle of 3 mm dia under pressure 6 bar

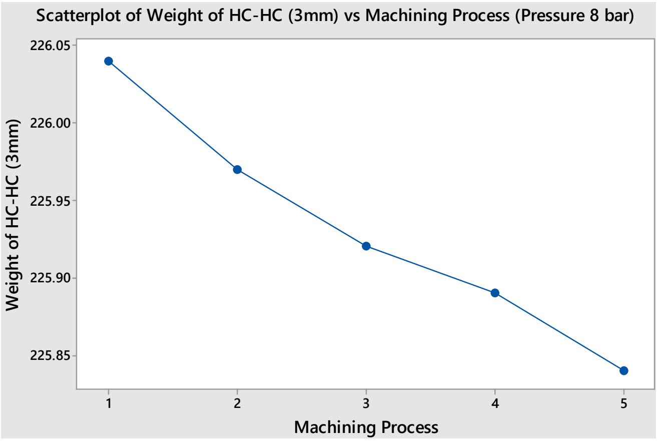

Fig. 23 Weight loss of HC-HC nozzle of 3 mm dia under pressure 8 bar

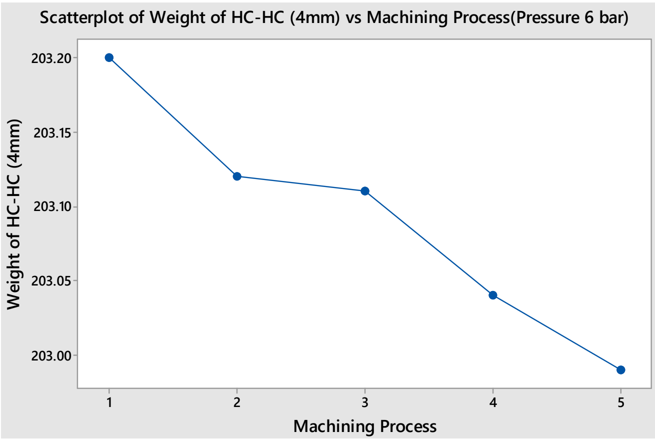

Fig. 24 Weight loss of HC-HC nozzle of 4 mm dia under pressure 6 bar

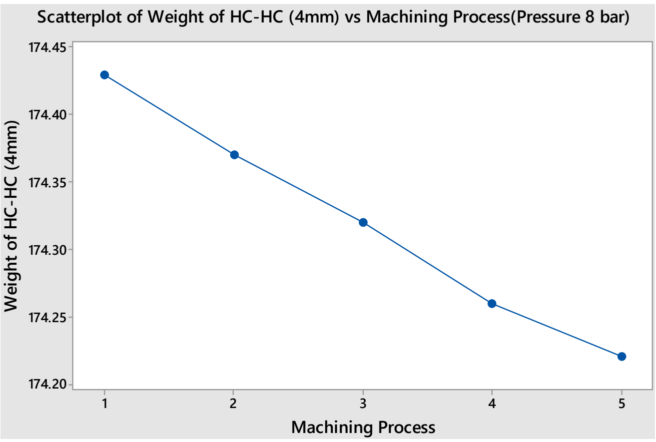

Fig. 25 Weight loss of HC-HC nozzle of 4 mm dia under pressure 8 bar

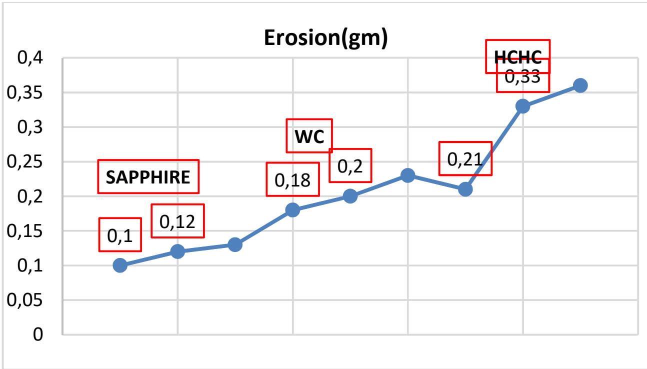

Fig. 26 Erosion graph of different nozzles

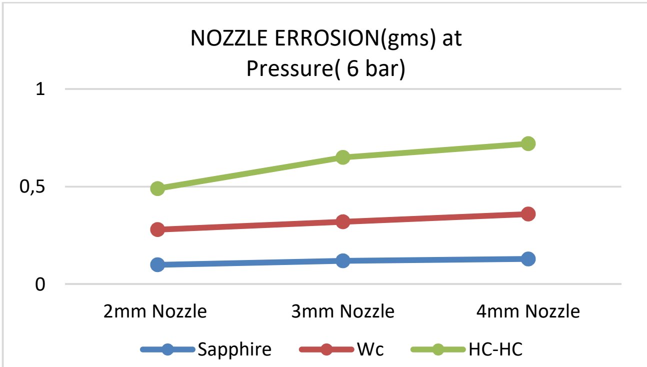

Fig. 27 Nozzle erosion vs pressure (6 bar)

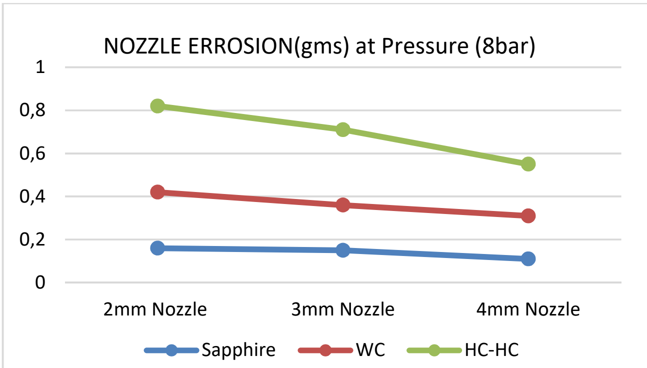

Fig. 28 Nozzle erosion vs pressure (8 bar)

Based on the observations of erosion, it is concluded that the sapphire coated nozzle is better when compared with other two nozzles. This analysis supports the theoretical statement made by [1]. The size of nozzle that can be effectively used in all three materials is 3 mm nozzle, where optimum erosion can be attained at that point at different pressures as shown in Figs. 27 and 28 respectively.

VI. Conclusions

This paper deals with experimental works for nozzle erosion for (a) sapphire coated nozzle, (b) WC and (c) HCHCS in AJM machining process. Experiments are conducted at two different pressures; 6 bar and 8 bar and 3 different nozzle diameters; 2 mm, 3 mm, and 4 mm, keeping all the other parameters such as SOD, material of job etc., constant.

From the results it may be concluded that

(a) For all the tested nozzle materials the erosion increases as the operating pressure increases within the operating range.
(b) For all the tested nozzle materials the erosion decreases as the diameter of the nozzle increases.
(c) The erosion increase is proportional to the hardness of the materials. If the nozzle material hardness is high the erosion is less, and if the nozzle material hardness is low, the erosion is more.

ACKNOWLEDGMENT

Author thanks Head and other faculty of the department of Mechanical Engineering JNTUH for extending their support to perform this analysis. The authors also thank management, Principal and other Professors of St. Martin's Engineering College for their support towards conducting the experiments successfully.

REFERENCES

[1] A P Verma and G K Lal. 'An Experimental Study of Abrasive Jet Machining'. International Journal of Machine Tool Design and Research, vol 24,-110 I, 1984.
[2] I Finnie. 'Erosion of Surface by Solid Particles'. Welr, vol 3, 1960.
[3] P K Sarkar and P C Pandey. 'Some Investigations on the Abrasive Jet Machining', Journal of the Institution of Engineers (India), vol 56, ME 6, 1976.
[4] R Balasubramaniam, J Krishnan, N. Ramakrishnan An experimental study on the abrasive jet deburring of cross-drilled holes, Journal of Materials …, 1999 – Elsevier.
[5] Balasubramaniam, J Krishnan, N. Ramakrishnan Preparation of edge radius in AJEM - Journal of Materials …, 2000 – Elsevier.
[6] Morrison, C.T., Scattergood, R.O., Routbort, J.L. (1986). Erosion of 304 stainless steel. Wear 111, 1-13 lsdr33 Elsevier.
[7] Bhaskar Chandra Kandpal1* Naveen Kumar2 Rahul Kumar3 Rahul Sharma4 Sagar Deswal5 Machining Of Glass And Ceramic With Alumina And Silicon Carbide In Abrasive Jet Machining, International Journal of Advanced Engineering Technology, IJAET/Vol.II/ Issue IV/October-December, 2011/251-256.
[8] Bhaskar Chandra1, Jagtar Singh2 A Study of effect of Process Parameters of Abrasive jet machining--International Journal of Engineering Science and Technology (IJEST) Vol. 3 No. 1 Jan 2011.
[9] V.C. Venkatesh, T.N. Goh, K.H. Wong, M.J. Lim -An empirical study of parameters in Abrasive Jet Machining 1989,Int Journal of Machine Tools and Mfg
[10] D.S. Robinson Smart, 2011. Experimental Investigation of Effect of Abrasive Jet Nozzle Position and Angle on Coating Removal Rate. International Journal of Manufacturing Systems, 1: 57-64.