Drilling of Glass Sheets by Abrasive Jet Machining

A. El-Domiaty, H. M. Abd El-Hafez, and M. A. Shaker

Abstract—Drilling of glass sheets with different thicknesses have been carried out by Abrasive Jet Machining process (AJM) in order to determine its machinability under different controlling parameters of the AJM process. The present study has been introduced a mathematical model and the obtained results have been compared with that obtained from other models published earlier [1-6]. The experimental results of the present work are used to discuss the validity of the proposed model as well as the other models.

Keywords—Abrasive Jet Machining, Erosion rate, Glass, Mathematical model.

I. INTRODUCTION

THE Abrasive Jet Machining (AJM) is considered as an attractive and effective machining method for hard and brittle materials [7-11]. Abrasive jet machining is similar to sand blasting process but in abrasive jet machining finer abrasive powders and smaller nozzles are used. Focusing on the abrasive jet stream from the nozzle onto the workpiece, smaller holes or slots can be machined on hard and brittle materials. Machining mechanism and characteristics of abrasive jet machining are major topics of many research works in the recent years [6-14]. The parameters associated with abrasive jet machining are summarized and shown in Fig. 1.

The abrasive size and the impact angle effects were studied by Wensink and Elwenspoek [10]. Their results showed that smaller abrasive size and less impact angle improve the machinability.

The nozzle pressure effect has been reported in many [15]-[19]. They proved that after threshold pressure, the Material Removal Rate (MRR) and the penetration rates have increased with increasing the nozzle flow pressure. Similarly, the effect of impingement angle has been reported and concluded that the maximum MRR for brittle material is obtained when normal impingement was applied.

Effect of abrasive grit size and mixing ratio, which is the ratio of the weight of the abrasive powder to the weight of the air and abrasive grits, has been thoroughly investigated by many researchers [20-22]. The stand-off-distance which is the

A. El-Domiaty is with Faculty of Engineering, Sues Canal University, 42523 Port Said, Egypt (e-mail: alieldomiaty@gmail.com).

H. M. Abd Elhafez is with Faculty of Engineering, Sues Canal University, 42523 Port Said, Egypt (e-mail: abdelhafez1@gmail.com).

M. A. Shaker, Prof. Dr., is with Faculty of Engineering, Sues Canal University, 42523 Port Said, Egypt (e-mail: profmshaker@hotmail.com).

distance between the workpiece and the nozzle has also great effect on the material removal rate as well as the generated surface quality [14].
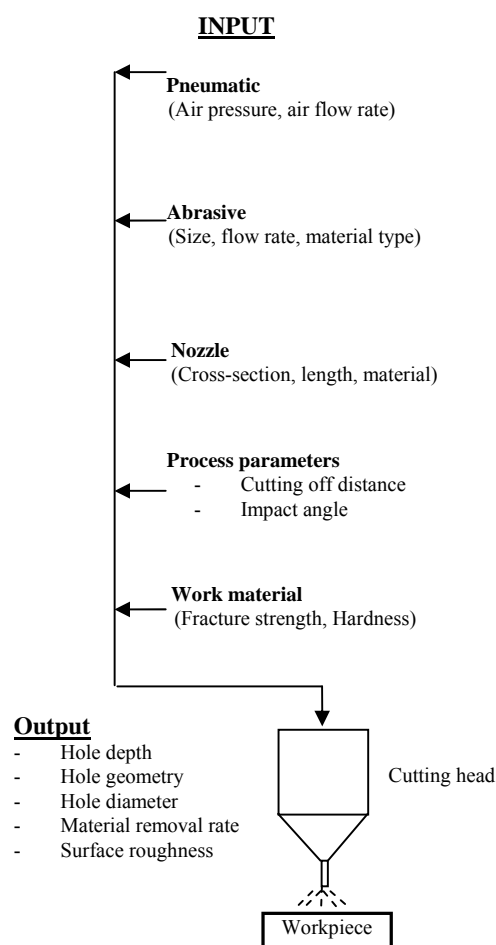
Micro-grooving of glass have been carried out by Park et al. [11]. The effects of workpiece properties as well as the process controlling parameters have been studied in many researches [13], [14], and [23]-[28]. Ghobeity *et al.* [29] had studied surface evolution models in abrasive jet micromachining and they found that the velocity decreased linearly from the centerline of the jet to the periphery, and that the probability of a particle arriving at the surface a given radial distance from the center of the impacting jet followed a Weibull distribution.

Well-established erosion models for brittle materials are

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:3, No:8, 2009

reviewed [13] and the conclusions of the review show that the erosion rate (w) is a function of the abrasive velocity (v), the abrasive diameter (size) (d), the abrasive density (ρ_a,) the workpiece toughness (Kc_t) and the workpiece hardness ($\tilde{H_t}$) The validity of the erosion model has been established for a wide range of materials and abrasive particles [30]-[32].

Optimization of the process parameters of abrasive jet machining and other nontraditional processes have been found in Ref. [6]. Neelesh et. al. [6] have used the material removal model, produced by Sarkar and Pondey [16], in their analysis. The Neelesh's model is used in the present work to compare its prediction with the prediction obtained from the proposed model.

II. EXPERIMENTAL WORK

Experiments were conducted to confirm the validity of the proposed model as well as the models found in the literature. The experimental work was carried on a test rig which was designed and manufactured in the workshops of the Faculty of Engineering, Port Said Egypt. The abrasive grits (sand) were mixed with air stream ahead of the nozzle and the abrasive flow rate was kept constant throughout the machining process. The jet nozzle was made of tool steel to carry high wear resistance. Several nozzles were manufactured with different bore diameters of 1 mm, 2 mm and 3 mm. Drilling of glass sheets was conducted by setting the test rig on the parameters listed in Table I.

TABLE I
ABRASIVE JET MACHINING EXPERIMENTAL PARAMETERS

AJM Parameter	Condition
Type of abrasive	Sand (SiO$_2$)
Abrasive size	0.15-1.25 mm
Jet pressure	0.5 MPa (5 bars)
Cut-off distance	10 mm
Nozzle diameter	1, 2, 3 mm
Abrasive flow rate	3 g/min
Machining time	20 sec

The properties of abrasive (sand) and the workpiece (glass) are as follows;

Abrasive density = 2.3 g/cm^3
Glass hardness (Hv) = 30 GPa
Glass fracture toughness = 2.5 MPa $\sqrt{m}$
Glass stress flow ($_{fw}$) = 5000 MPa

III. MODELING OF THE ABRASIVE JET MACHINING

In abrasive jet machining, the material removal takes place due to the impingement of the fine abrasive particles. These particles move with a high speed air stream. The abrasive particles are typically of 0.02 mm diameter and the air discharges at a pressure within a range of 2-8 bars.

When an abrasive particle impinges on the work surface at a high speed, the impact causes a tiny brittle fracture and the following air carries away the dislodged small workpiece

particle (wear particle). The impact of particles on the workpiece surface can cause severe erosion or material removal. The erosion process depends upon the number of abrasive particles striking the surface of the workpiece, their velocity and their direction relative to the surface of the workpiece. The mechanical properties of the workpiece are also major parameters controlling the erosion rate or the material removal rate.

Previous studies [3, 4, 33, 34] showed that the erosion rate (mass removed from the surface by unit mass of impinging particles) depends on the type of materials and the impact angles. These results are shown in Fig. 2. Ductile materials, such as mild steel, showed the greatest erosion rate at a shallow impact angle. On the other hand, more brittle materials such as glass and ceramics have rapid erosion rates when the particles were incident normal to the surface. The size of abrasive particles has also major effect on the erosion rate.

The results obtained by Sheldon and Finnie [34] showed that, on reducing the size of the silicon carbide particles from 127 μm to 9 μm, the erosion rate decreased and its maximum value occurred at an angle much lower, as shown in Fig. 3.
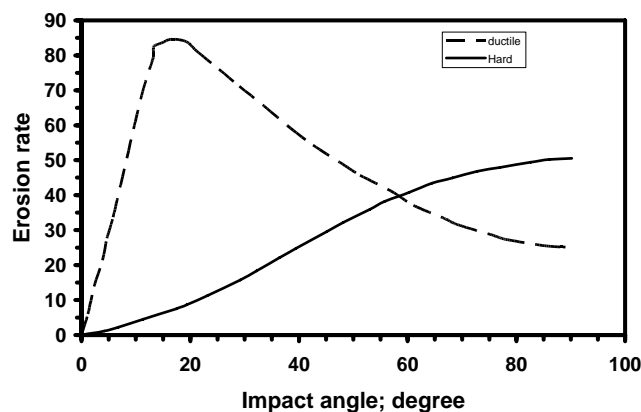

Fig. 1 Typical curves showing the variation of erosion with impact angle [33]

The principle factors affecting the erosion wear of brittle materials by solid particle impact are summarized in Table II.

The erosion rate V, which is defined as the eroded volume of target material to the volume of the impact particles, can be predicted by the aid of many relations, found in the literatures. Some of these relations and their references are given in Table III.

In order to introduce a mathematical model for the abrasive machining process, one of the equations given in Table III can be used as the building stone for that model since the mechanism of cutting is mainly erosion process.

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
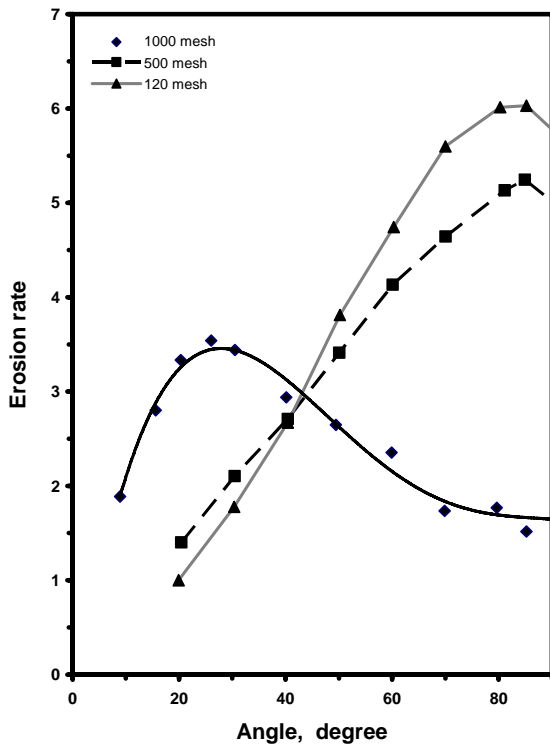Vol:3, No:8, 2009

Fig. 2 Variation of erosion rate with impact angle for soda-lime glass eroded by silicon carbide particles with three different sizes [34]

TABLE II
PRINCIPLE FACTORS AFFECTING THE EROSION WEAR OF BRITTLE MATERIALS BY SOLID PARTICLE IMPACT

Properties	Property	Symbol	Units
target material	Hardness	H_t	MPa
	Fracture toughness	K_{Ct}	MPa $\sqrt{m}$
impact particles	Hardness	H_p	GPa
	Fracture toughness	K_{Ct}	MPa $\sqrt{m}$
	Particle diameter	d	mm
	Specific gravity	ρ_a	g/cm^3
Process parameters	impact speed	v	m/s
	Impact angle	Θ	degree
	Temperature	T	°C

For convenience, equation (5) is used to estimate the volume removed from the target material per unit volume of the abrasive particle as the following;

$$V = \frac{C_1\, v^{2.8}\, d^{3.9}\, \sigma_a^{1.4}\, H_t^{0.48}}{K_{ct}^{1.9}}; \quad g_{material}/g_{abrasive} \qquad (7)$$

Multiplying the above equation by the flow rate of the mixture of abrasive particles and air (m$^.$), it is possible to obtain the material removal rate from the surface of the target material. The abrasive flow rate;

TABLE III
SOME RELATIONS AND THEIR REFERENCES

Pub. Year	Ref. #	Relation	Eq. #
1976	1	$V \alpha\, v^{2.5}\, d^4\, \sigma_a^{0.25}\, H_t^{-0..25}\, K_{ct}^{-1.5}$	(1)
1978	2	$V \alpha\, v^{3.166}\, d^{3.667}\, \sigma_a^{1.583}\, H_t^{-0..25}\, K_{ct}^{-1.333}$	(2)
1979	3	$V \alpha\, v^{2.444}\, d^{0.333}\, \sigma_a^{1.222}\, H_t^{-0..111}\, K_{ct}^{-1.333}$	(3)
1982	4	$V \alpha\, v^{2.333}\, d^{3.5}\, \sigma_a^{1.1667}\, H_t^{-1.41675}\, K_{ct}^{-1.0}$	(4)
1983	5	$V \alpha\, v^{2.8}\, d^{3.9}\, \sigma_a^{1.4}\, H_t^{0.48}\, K_{ct}^{-1.9}$	(5)
2006	6	$m_t\, \alpha\, \eta_a\, m_a\, v_a^{1.5}\, \sigma_{fw}^{-0.75}\, \rho_a^{-0.25}$	(6)

$$m_a = \frac{\pi D^2 v \rho_a}{4} \qquad g_{abrasive}/s \qquad (8)$$

The velocity of the abrasive particles, which are carried by air, can be determined by applying Bernoulli equation at two points. The first point is inside the nozzle and the second is outside the nozzle. With some assumptions and formula simplifications, the velocity can be obtained as fellow;

$$v = \sqrt{\frac{2P}{\rho_{air+abrasive}}} \qquad (9)$$

Assume that $\rho_{air+abrasive} = \rho_a$; neglecting ρ_{air}
Substituting (8) and (9) into (7) as follow;

$$m_t = m_a V \qquad g_{material}/s$$

$$m_t = \frac{C_1\, v^{2.8}\, d^{3.9}\, \rho_a^{1.4}\, H_t^{0.48}}{K_{ct}^{1.9}} m_a$$

$$m_t = \frac{C_1\, v^{2.8}\, d^{3.9}\, \rho_a^{1.4}\, H_t^{0.48}}{K_{ct}^{1.9}} \cdot \frac{\pi}{4} D^2 v \rho_a$$

$$m_t = \frac{C_2\, v^{3.8}\, d^{3.9}\, \rho_a^{2.4}\, H_t^{0.48}\, D^2}{K_{ct}^{1.9}}$$

$$m_t = \frac{C_3\, P^{1.9}\, d^{3.9}\, \rho_a^{0.5}\, H_t^{0.48}\, D^2}{K_{ct}^{1.9}} \quad g_{material}/s \qquad (10)$$

Moreover, equation (6) which was established by Jain et. al. [3] for brittle materials was chosen to be compared with the obtained equation (10) as follows;

$$MRR = m_t = \frac{K_3\, \eta_a\, P^{1.25}\, D^2\, \rho^{0.5}}{\sigma_{fw}^{0.75}}; \quad mm^3/s \qquad (11)$$

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:3, No:8, 2009

This equation was obtained at the abrasive particles size (d) range 0.01–0.15 mm. Substituting for m_a and v as in equations (8) and (9) into equation (11) gives;

$$m_t = \frac{K_2 \, \eta_a \left[D^2 \, \rho_a \, \{2P/\rho_a\}^{0.5} \right] \{2P/\rho_a\}^{0.75}}{\rho^{0.25} \sigma_{fw}^{0.75}} \qquad (12)$$

To convert (12) to grm/s; (12) must be multiplied into the density of the abrasive material. Then, (13) could be obtained as follows;

$$m_t = \frac{K_3 \, \eta_a \, P^{1.25} \, D^2 \, \rho^{0.5}}{\sigma_{fw}^{0.75}}; g_{material} / s \qquad (13)$$

IV. RESULTS AND DISCUSSION

A. Experimental Results

Fig. 4 shows the relationship between the cut-off distance and the required time to drill a glass plate with a 2 mm thickness. The results indicate that time decreased with increasing the cut-off distance up to 5 mm. The curve returns to higher time values above 5 mm distance. This is due to the abrasive stream has covered a wide area which decrease its effect on the spot. Moreover, the dimension of the required hole becomes not accurate as shown in Fig. 5. From these results, it can be concluded that the optimum cut-off distance is 5 mm under these conditions.
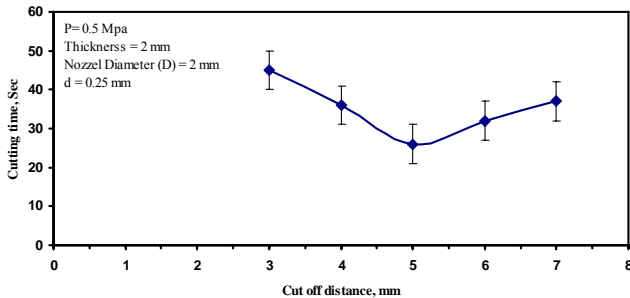

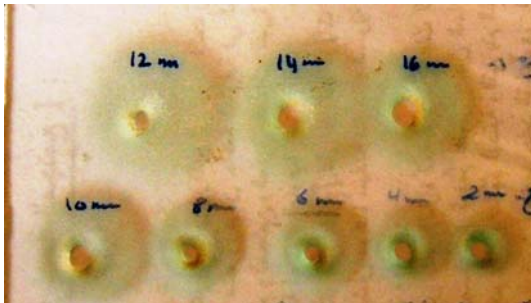Fig. 3 Effect of cutting time on the cut-off distance using SiO abrasive particles

Fig. 4 A glass specimen drilled with the given data in Table I, at different cut-off distances

The effect of nozzle diameter (D) on the material removal rate was studied at a pressure of 0.5 MPa and an abrasive size

(d) of 0.15 mm. The results were plotted in figure 6 with a standard deviation. The increase of the nozzle diameter increases the material removal rate due to the increase of the flow rate of the abrasive particles. Moreover, the increase of the abrasive size (d) increases the material removal rate as shown in Fig. 7. The results indicate that the mass of the abrasive particles is an important factor in this machining process.
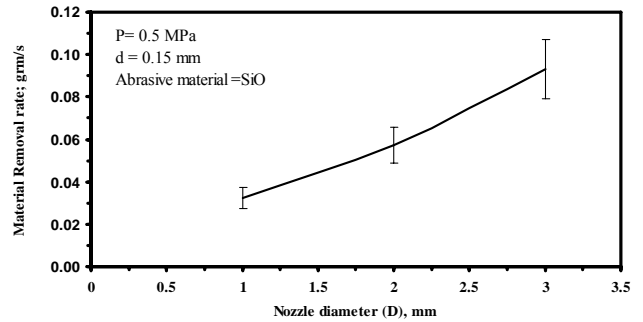

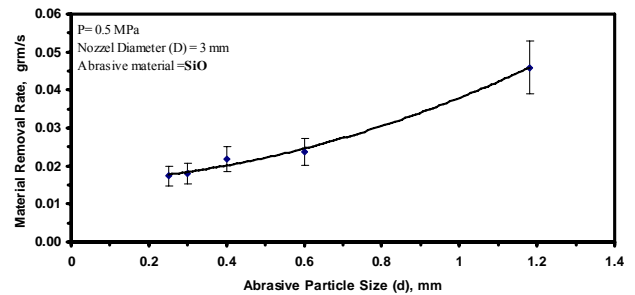Fig. 5 Effect of nozzle diameter (D) on the material removal rate of the glass

Fig. 6 Effect of abrasive particles size on material removal rate

B. Theoretical Results

From (10) it is possible to obtain some relationships between the material removal rate and both pressure and nozzle diameters at different particle sizes.

The pressure varied between 0.2 and 0.8 MPa; whereas, the particles diameters was in the range of 0.15-1.25 mm. These results are obtained at three different nozzle diameters of 1, 2 and 3 mm as shown in Figs. 5-7. The constant C_3 is assumed to be unity and its value will be determined experimentally after comparing the experimental and the theoretical data.

The effect of nozzle diameter (D) on the material removal rate (MRR), when different sizes of abrasive particles are used, is shown in Fig. 8. It shows that the nozzle diameter is an important factor affecting the MRR due to the resulted speed and flow rate of the abrasives. Therefore, large nozzle diameter causes material to be removed with higher values. The diameter of the abrasive material is also another key factor controlling the MRR. Lower sizes than 0.5 mm give very low values for MRR. Therefore, it is better to use larger abrasive sizes.

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
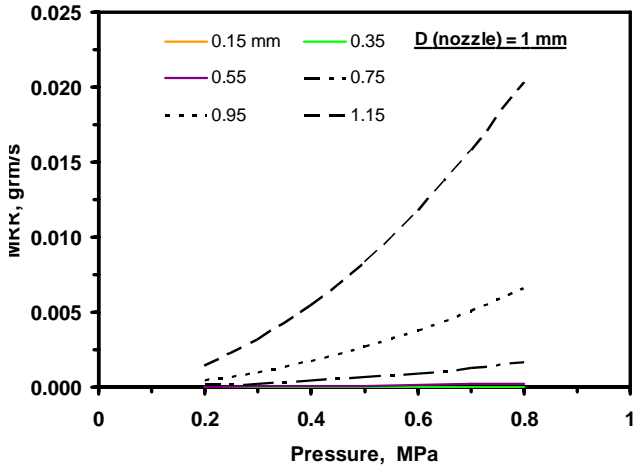Vol:3, No:8, 2009

Fig. 7 Effect of pressure on the material removal rate at different size of abrasive particles for nozzle diameter of 1 mm
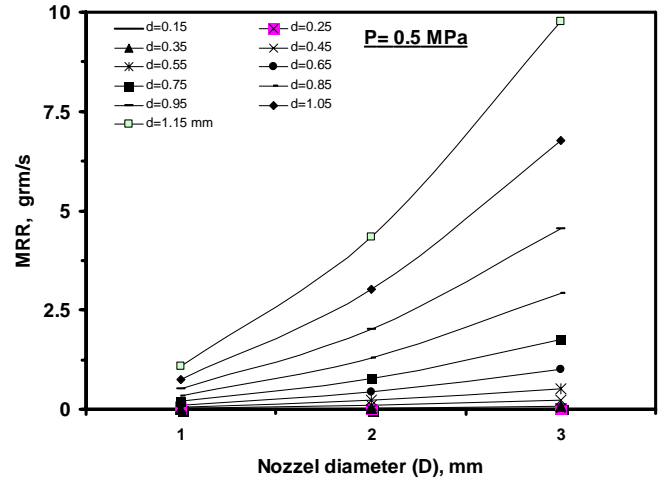

Fig. 11 Effect of nozzle diameter on the material removal rate at different size of abrasive particles carried out by model 1 (10)

Air pressure in the range of 0.2 up to 0.8 MPa is used in the present work and it shows that the increase of air pressure makes it possible to remove material at higher rates.

Comparison between the prediction obtained by (10) and (13) are shown in Fig. 9. The results, shown in Fig. 9, demonstrate that the values of MRR have no difference at low pressure and small nozzle diameters. The difference between the predictions of the two models become noticeable when larger nozzle diameter (D=3 mm) is used as shown by solid and dotted curves.

This type of difference between the predictions of the two models as well as the experimental findings is shown in Fig. 10. It can be clearly shown that both models predict values for material removal rate less than the experimental values for the nozzle diameter less than 2 mm. When the nozzle diameter of 3 mm is used, the experimental value for material removal rate (MMR) is less than the theoretical prediction from both models {(10) and (13)}.
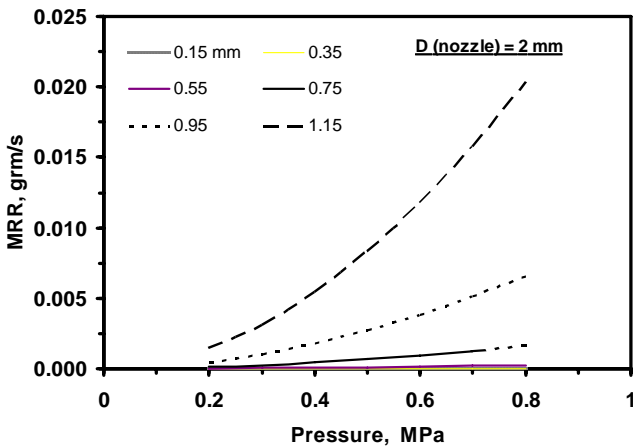

Fig. 9 Effect of pressure on the material removal rate at different size of abrasive particles for nozzle diameter of 2 mm
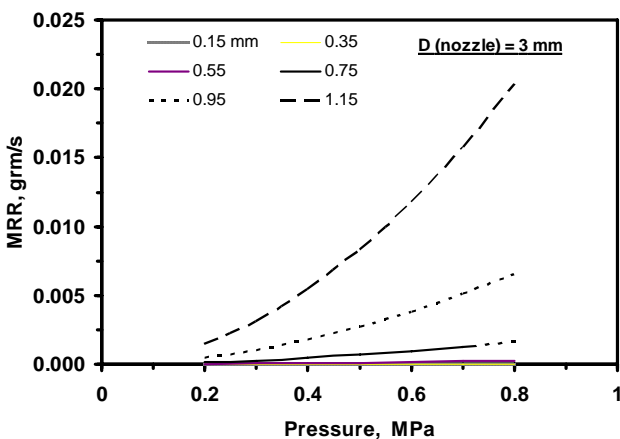

Fig. 10 Effect of pressure on the material removal rate at different size of abrasive particles for nozzle diameter of 3 mm
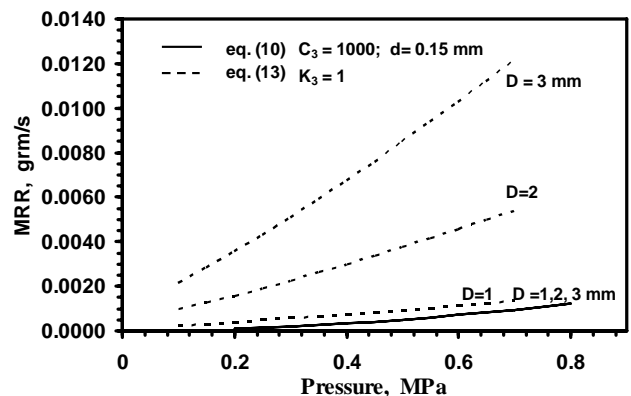

Fig. 12 Effect of pressure on material removal rate at different nozzle diameters for the two models {ρ_a= 2.3 g/cm³; P= 0.5 MPa; η= 0.7 and σ_{fw} = 5000 MPa for glass}

The difference between the experimental and the theoretical values is mainly due to many sources of errors. The first type

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:3, No:8, 2009

of errors is mainly associated with the measurement techniques and their accuracies. The second source of errors is associated with the simplifications and the assumptions of the theoretical model. One aspect in the theoretical model is the velocity of air and the abrasive, i.e. the mixture of air and abrasive which is assumed to be equal to air velocity only which is obtained by Bernoulli equation (9).
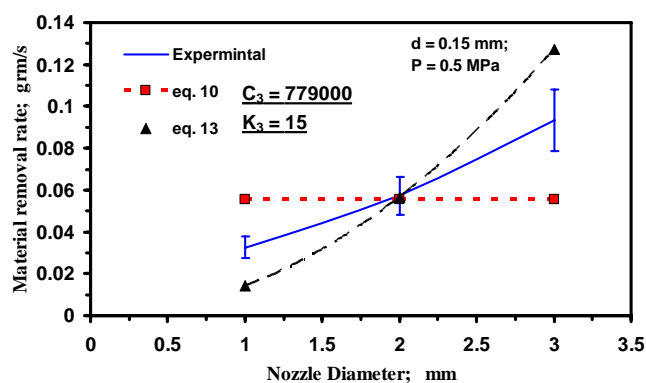

Fig. 13 Comparison between experimental and theoretical models at different nozzle diameter

The second aspect is the neglecting friction effect which reduces the velocity of the mixture (air + abrasive). This friction effect reduces the velocity and consequently, reduces the kinetic energy of the abrasive particles. Therefore, the lower prediction may be mainly due to these causes.

For bigger values of nozzle diameter (D=3 mm) the flow rate of the mixture (air + abrasive) is high and this higher value compensates for the adverse effect of friction

The model predictions and the experimental findings are within ±20% difference between each other. This might be considered as a reasonable result obtained by the available equipments and the assumed simplification of the proposed theoretical models.

V. CONCLUSION

Experimental and theoretical analyses are introduced. The experimental and theoretical results obtained for material removal rates are close to each other within an error of not more than 20 percent which can be accepted for a mathematical model based on an erosion model. More experimental work and also more refinement for the theoretical model are needed to reduce the difference between the results as well as to introduce the neglected controlling parameters of the cutting process such as the cutoff distance.

REFERENCES

[1] Evans, A.G., Gulden, M.E., Eggum, G.E. and Rosenblatt, M., Rockwe. Sci. Center Report No. SC023.9TR, 1976.
[2] Evans AG, Gulden ME, Rosenblatt ME., "Impact damage in brittle materials in the elastic–plastic response regime", Proc R Soc London, Ser A 1978; 361:343–65.
[3] Ruff AW, Wiederhorn SM., "Erosion by solid particle impact"; Treat Mater Sci. Tech, 1979.
[4] Marshall DB, Lawn BR, Evans AG., "Elastic/plastic indentation damage in ceramics: the lateral crack system", J Am Ceramic Soc, 1982;65(11).
[5] Wiederhorn SM, Hockey BJ., "Effect of material parameters on the erosion resistance of brittle materials", J Mater Sci 1983; 18:766–80.
[6] Neelesh K. Jain, V.K. Jain, K. Deb, "Optimization of process parameters of mechanical type advanced machining processes using genetic algorithms", International Journal of Machine Tools & Manufacture (2006).
[7] Belloy, E., Thurre, S., Walckiers, E., Sayah, A., Gijs, M.A.M., "The introduction of powder blasting for sensor and microsystem applications", Sensors and Actuators A: Physical 84 (3) (2000) 330–337.
[8] Schlautmann, S., Wensink, H., Schasfoort, R., Elwenspoek, M., Van den Berg, A., "Powder-blasting technology as an alternative tool for microfabrication of capillary electrophoresis chips with integrated conductivity sensors", Journal of Micromechanics and Microengineering 11 (4) (2001) 386–389.
[9] Slikkerveer, P.J., Bouten, P.C.P., de Haas, F.C.M., "High quality mechanical etching of brittle materials by powder blasting", Sensors and Actuators, A: Physical 85 (1-3) (2000) 296–303.
[10] Wensink, H., Elwenspoek, M.C., "Reduction of sidewall inclination and blast lag of powder blasted channels", Sensors and Actuators A: Physical 102 (1-2) (2002) 157–164.
[11] Park, D.S., Cho, M.-W., Lee, H., Cho, W.-S., "Micro-grooving of glass using micro-abrasive jet machining", Journal of Materials Processing Technology 146 (2) (2004) 234–240.
[12] Lei Zhanga, Tsunemoto Kuriyagawab, Yuya Yasutomib, Ji Zhao, "Investigation into micro abrasive intermittent jet machining", International Journal of Machine Tools & Manufacture 45 (2005) 873–879.
[13] Wakuda, M. a, Yamauchi, Y. b, Kanzaki, S., "Effect of workpiece properties on machinability in abrasive jet machining of ceramic materials", Journal of the International Societies for Precision Engineering and Nanotechnology 26 (2002) 193–198.
[14] Balasubramaniam, R., Krishnan, J., Ramakrishnan, N., "A study on the shape of the surface generated by abrasive jet machining", J. of materials processing Technology 121, 2002, pp. 102-106.
[15] Ingulli, C.N., "Abrasive jet machining", Tool manufacturing Eng., 59 (5), 1967.
[16] Sakar, P.K., Pandey, P.C., "Some investigations on abrasive jet machining", Journal of Inst. Eng., Indea (56), 1976.
[17] Verma,, A.P., Lat, G.K., "An experimental study of abrasive jet machining", International Journal of MTDR 24, 1984.
[18] Wolak, J., "Parameters affecting the velocity of particle in an abrasive jet", Transaction of ASME, Journal of Engineering Material Technology, 99H, 1977.
[19] Murthy, K.N., Roy, D.C., Mirshra, P.C., "Material removal of brittle materials in abrasive jet machining", 12th. AIMTDR conference, Delhi, 1986.
[20] Neema, M.L., Pandey, P.C., "Erosion of glass when acted upon by abrasive jet", Int. Conference on wear of materials, 1977.
[21] Balasubramaniam, R., Krishnan, J., Ramakrishnan, N., "An investigation on abrasive jet deburring", Journal of Material Processes and Technology (79), 1998.
[22] Balasubramaniam, R., Krishnan, J., Ramakrishnan, N., "An empirical study on the generation of edge radius in abrasive jet external deburring (AJED)", Journal of Material Processes and Technology (99), 2000
[23] Wakuda, M., Yamauchi, Y., Kanzaki, S., "Material response to particle impact during abrasive jet machining of alumina ceramics", Journal of Materials Processing Technology 132 (1-3) (2003) 177–183.
[24] Kuriyagawa, T., Sakuyama, T., Syoji, K., Onodera, H., "A new device of abrasive jet machining and application to abrasive jet printer", Key Engineering Materials 196 (2001) 103–110.
[25] Venkatesh V.C., "Parametric studies on abrasive jet machining" CIRP Ann 1984;33(1):109–12.
[26] Ramachandran N, Ramakrishnan N., "A review of abrasive jet machining" J Mater Proc Tech 1993;39:21–31.
[27] Finnie I., "Some reflections on the past and future of erosion", Wear 1995;186/187:1–10.
[28] Slikkerveer P.J., Bouten P.C.P., in't Veld FH, Scholten H., "Erosion and damage by sharp particles", Wear 1998; 217(2):237–50.
[29] A. Ghobeity, T. Krajac, T. Burzynski, M. Papini, J.K. Spelt, "Surface evolution models in abrasive jet micromachining", Wear 264 (2008) 185–198.

World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:3, No:8, 2009

[30] Gulden ME., "Solid particle erosion of Si3N4 materials", Wear, 1981;69:115–29.

[31] Roubort J.L., "Degradation of structural ceramics by erosion", J Nondestr Eval 1996; 15(3/4):107–12.

[32] Feng Z, Ball A., "The erosion of four materials using seven erodents: towards an understanding", Wear 1999; 233–235:674–84.

[33] I.M. Hutchings, "Transitions, Threshold effects and erosion maps", Key Eng. Materials 71, 1992, pp 75-92.

[34] Sheldon, G.L. and Finnie, I., Trans. ASME B (J. Eng. for Industry), 1966, 88 B, 387-392.

EL-Domiaty A. was born in Egypt, 1948. *Ph.D.* (1986) University of California, Los Angeles, Material Science and Engineering Department, USA.

   Academic Experience; April 1999 – Now Suez Canal University, Faculty of Engineering, Mechanical Design and Industrial Engineering Dept., Professor. April 4, 1995 – June 1998, Kuwait University, Faculty of Engineering & Petroleum, Mechanical and Industrial Engineering Dept., Associate Professor. August 1992 - April 4, 1995: Kuwait University, Faculty of Eng. & Petroleum, Mechanical Engineering Department, Assistant Professor. October 1986 - October 1987, School of Engineering, California State University Fresno, Lecture C. January 1986 - October 1986, School of Engineering, University of California, Los Angeles, Visiting Lecturer.

Practical Experience; Fatigue properties of high strength alloy steel by rotating bending test, (California, Los Angles, 1987). Stress analysis of oil pipe line (Egypt 1990). Stress analysis for pipe line flange (Kuwait 1995). Providing short courses for the industry: Mechanical Testing of Engineering Materials, (18-22) December, 1993. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait, University, Kuwait. Failure Analysis of Machine Components, (16-20) April, 1994. Office of Consultation and Career Development, College of Eng. and Petroleum, Kuwait University, Kuwait. Computer Aided Selection of Engineering Materials (15-19) April, 1995. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait University, Kuwait. Value Technology, (14-17) May 1995. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait University, Kuwait. Chilled Water System, Sizing, Selection and Maintenance, sponsored by ASHRAE, Kuwait. Value Technology, (17-20) March 1996. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait University, Kuwait. Computer Aided Selection of Metallic Materials According to Standard Specifications, (1-6) June 1996. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait University, Kuwait. Selection of Lubrication System & Lubricants (4-6) May 1996. Office of Consultation and Career Development, College of Engineering and Petroleum, Kuwait University, Kuwait.

Prof. El-Domiaty, *Memberships in Professional Societies*
   Egyptian Association of Professional Engineers
   Egyptian Society of Mechanical Engineers
   Egyptian Society for Foundry
   International Society of AWJ

"The susceptibility of 90 Cu-10 Ni in Sea Water Polluted by Sulfide Ions", J. of Material Engineering and Performance, Vol. 6, No. 4, August 1977, pp. 534-544.

"End Conditions Effect on Fracture Behavior of Circumferentially Through Wall Cracked Pipes", Accepted for presentation in the 25th Midwestern Mechanics Conference, South Pakota School of Mines and Technology, USA, Sept. 21 - 24, 1997.

"Modeling of Abrasive Water jet Cutting Process for Brittle Materials", Accepted for Presentation in the 25th Midwestern Mechanics Conference, South Dakota School of Mines and Technology, USA, Sept. 21 - 24, 1997.

Maximum depth of cut for ceramics using abrasive water jet technique, Wear, 218, 1998, pp 216 – 222.

"An Energy Model for Friction Stir Welding", Materials Science and Technology 2007 Conference and Exhibition, September 16-20, 2007, COBO Center Detroit, Michigan, USA

"Bending of Tube and Section Made of Strain-hardening Materials", Journal of Materials Processing Technology, Article in Press, 2007-xxx.