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Improving Surface Finishing of Tempered Glass by Using Modern Abrasive Jet Machining Using Tagauchi Method

Mr. ROHTASH KUMAR

Abstract: **Modern machining methods are also known as Non Traditional machining methods. These methods form a group of processes which improves the surface finishing by various techniques and processes. There is very less cutting of glass with the help of modern carbide tool having sharp cutting edge and better tool geometry. The major reasons of development and popularity of the modern machining methods are listed below.**

- **Need to improve surface flatness of newly developed metals and non-metals specially glass having some special properties like extremely high strength, high hardness and high toughness. This type of material specially tempered glass poisoning the above mentioned properties are difficult to be machined by the Conventional machining methods.**
- **Sometimes it is required to produce very big shaped and size object having complex geometries that cannot be easily produced by following conventional machining techniques.**

So Non Traditional machining methods also provide very good quality of surface finish, which may also be an encouragement of these methods and techniques. In modern time there are a large number of Non Traditional methods and techniques available. These methods can be classified as the basis of their base principle of working as given in the following section.

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Keywords: **Modern machining methods, Traditional machining methods. Carbide tool, Tempered glass, complex geometry.**

1. INTRODUCTION

1.1 Classification Of Non Traditional Machining Processes :

The classification of Non Traditional Machining processes is carried out depending on the nature of energy used for material removal. The broad classification is given as Follows

- Mechanical Process
- Electrochemical Process
- Electro Thermal Process
- Chemical Process

1.2 Need for Non Traditional Machining:

Conventional machining has sufficed the requirement of the industries over the decades. But new exotic work materials as well as innovative geometric design of products and components were putting lot of pressure on capabilities of conventional machining processes, to manufacture the components with desired tolerances economically. This led to the development and establishment of Non Traditional Machining (NTM) processes in the industry as efficient and economic alternatives to its conventional ones. With advancement in the NTM processes, currently they are often the first choice and not an alternative to conventional processes for certain requirement. The following examples are provided where NTM processes are preferred over the conventional machining process:

- Intricate shaped blind hole – e.g. square hole of 15 mmx15 mm with a depth of 30 mm
- Difficult to machine material – e.g. same example as above in Inconel, Ti-alloys or carbides.
- Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding
- Deep hole with small hole diameter – e.g. φ 1.5 mm hole with l/d = 20 Machining of composites.

1.3 Abrasive Jet Machining:

In abrasive jet machining, a focused stream of abrasive particles, carried by a high pressure air or gas is made to impinge on the work surface through a nozzle and work material is removed by erosion though high velocity abrasive particles.

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In abrasive jet machining abrasive particles are made to impinge on work material at high velocity. Jet of abrasive particles is carried by carried gas or air. The high velocity stream of abrasives is generated by converting pressure energy of carrier gas or air to its kinetic energy and hence high velocity jet. A nozzle directs abrasive Jet in a controlled manner onto the work material. The high velocity abrasive particles remove the material by micro cutting action as well as brittle fracture of the work material.

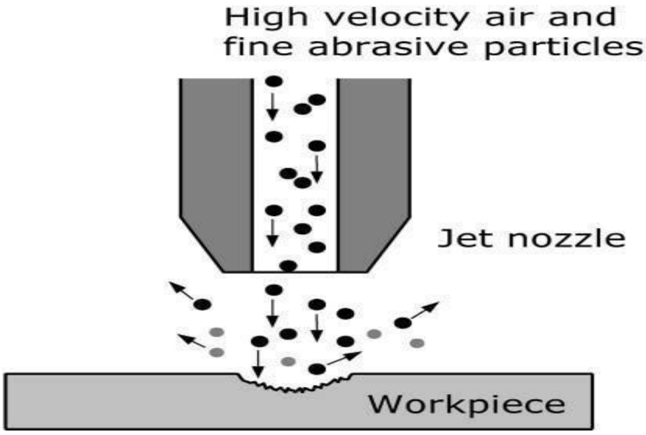

Fig.1.1 Principle of the AJM process [7]

It is a process of removal of material by impact erosion through the action of concentrated high velocity stream of grit abrasives entrained in high velocity gas stream. AJM is different from shot or sand blasting, as in AJM, finer abrasive grits are used and parameters can be controlled more effectively providing better control over product quality In AJM, generally, the abrasive particles of around 50 microns grit size would impinge on the work material at velocity of 200m/s from a nozzle of ID 0.5mm with a standoff distance of around 2mm. The kinetic energy of the abrasive particles would sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives. System of abrasive jet machining consists of:

- Gas propulsion system
- Abrasive feeder
- Machining Chamber
- AJM Nozzle
- Abrasives

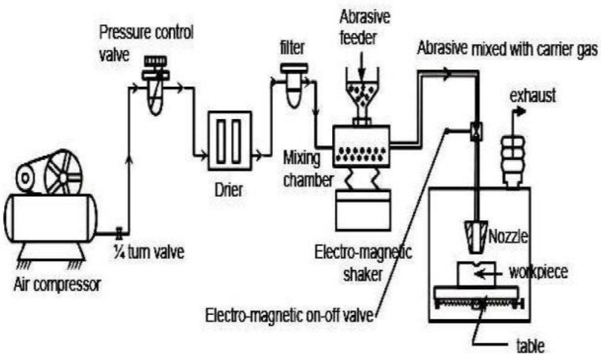

Fig.1.2 Schematic layout of AJM [25]

131. Gas Propulsion System:

Supplies clean and dry air, Nitrogen and Carbon dioxide to propel the abrasive particles. Gas may be supplied either from a compressor or a filled cylinder. In case of a compressor, air filter cum drier should be used to avoid water or oil contamination of abrasive powder. Gas should be non-toxic, cheap and easily available. It should not excessively spread when discharged from nozzle into atmosphere. In general propellant consumption rate is of order of 0.008 m^3/min at a nozzle pressure of 5 bar and abrasive flow rate varies from 2 to 4 gm/min for fine machining and 10 to 20 gm/min for cutting operation.

1.3.2Abrasive Feeder:

Required quantity of abrasive particles is supplied by abrasive feeder. The filleted propellant is fed into the mixing chamber where in abrasive particles are fed through a sieve. The sieve is made to vibrate at 50-60 Hz and mixing ratio is controlled by the amplitude of vibration of sieve. The particles are propelled by carrier gas to a mixing chamber. Air abrasive mixture moves further to nozzle. The nozzle imparts high velocity to mixture which is directed at work piece surface.

13.3 Machining Chamber:

It is well closed so that concentration of abrasive particles around the working chamber does not reach to the harmful limits. Machining chamber is equipped with vacuum dust collector. Special consideration should be given to dust collection system if the toxic materials (like beryllium) are being machined.

1.3.4 AJM Nozzle:

AJM nozzle is usually made of tungsten carbide or sapphire (usually life -300 hours for sapphire, 20 to 30 hours for WC) which has resistance to wear. The nozzle is made of either circular or rectangular cross section and head can be head can be straight, or at a right angle. It is so designed that loss of pressure due to the bends, friction etc is minimum possible. With increase in wear of a nozzle, the divergence of jet stream increases resulting in more stray cutting and high inaccuracy.

1.3.5 Abrasive:

Aluminum oxide (Al_2O_3) Silicon carbide (Sic) Glass beads, crushed glass and sodium bicarbonate are some of abrasives used in AJM. Selection of abrasives depends on MRR, type of work material, machining accuracy.

1.4 Process Parameters of AJM:

1.4.1 Abrasives:

- Material- Al_2O_3 Sic Glass beads Crushed glass Sodium bi carbonate Shape –irregular/regular
- Size-10 to 50 microns
- Mass flow- 2 to 20 gm/min

1.4.2 Carrier Gas:

- Composition –Air, CO_2, N_2
- Density- 1.3 kg/m3
- Velocity -500 to 700 m/s
- Pressure – 2 to 10 bar
- Flow rate- 5 to 30 microns

1.4.3 Abrasive jet:
- Velocity – 100 to 300 m/s
- Mixing ratio- Volume flow rate of abrasives / Volumes flow rate of gas Standoff distance-SOD- 0.5 to 15 mm.
- Impingement angle – 60 to 90 deg.

1.4.4 Nozzle:

- Material- WC/Sapphire
- Diameter – 0.2 to 0.8 mm
- Life- 300 hours for sapphire , 20 to 30 hours for WC

1.5 Process Capability:
- Material removal rate- 0.015 Cm3/min
- Narrow slots – 0.12 to 0.25 + 0.12mm
- Surface finish -0.25 micron to 1.25 micron
- Sharp radius up to 0.2 mm is possible
- Steel up to 1.5mm, Glass up to 6.3mm is possible to cut.
- Machining of thin sectioned hard and brittle materials is possible

1.6 Advantages and Disadvantages of Abrasive Jet Machining:

1.6. Advantages:

- High surface finish can be obtained depending upon the grain sizes
  It provides cool cutting action, so it can machine delicate and heat sensitive material
- Process is free from chatter and vibration as there is no contact between the tool and work piece.
- Capital cost is low and it is easy to operate and maintain AJM.
- Thin sections of hard brittle materials like germanium, mica, silicon, glass and ceramics can be machined.

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It has the capability of cutting holes of intricate shape in hard materials.

1.6.2 Disadvantages:

- Limited capacity due to low MRR for glass is 40 gm/minute
- Abrasives may get embedded in the work surface, especially while machining soft material like elastomers or soft plastics.
- The accuracy of cutting is hampered by tapering of hole due to unavoidable flaring of abrasive jet.
- Stray cutting is difficult to avoid.
- A dust collection system is a basic requirement to prevent atmospheric pollution and health hazards.
- Nozzle life is limited (300 hours)
- Abrasive powders cannot be reused as the sharp edges are worn and smaller particles can clog the nozzle.
- Short standoff distances when used for cutting, damages the nozzle.

1.7 Effect of process parameters on Material Removal Rate (MRR):

1.7. 1Effect of abrasive flow rate and grain size on MRR:

It is clear from the figure that at a particular pressure MRR increase with increase of abrasive flow rate and is influenced by size of abrasive particles. But after reaching optimum value, MRR decreases with further increase of abrasive flow rate. This is owing to the fact that Mass flow rate of gas decreases with increase of abrasive flow rate and hence mixing ratio increases causing a decrease in material removal rate because of decreasing energy available for erosion.

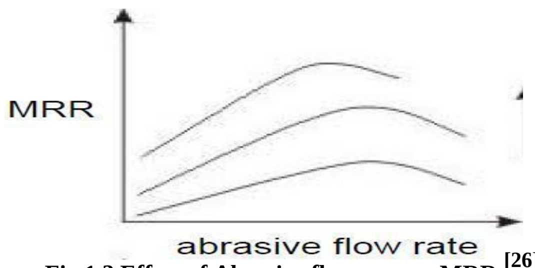

Fig 1.3 Effect of Abrasive flow rate on MRR [26]

1.7.2Effect of mixing ratio on MRR:

Increased mass flow rate of abrasive will result in a decreased velocity of fluid and will thereby decrease the available energy for erosion and ultimately the MRR. It is convenient to explain to this fact by term MIXING RATIO.

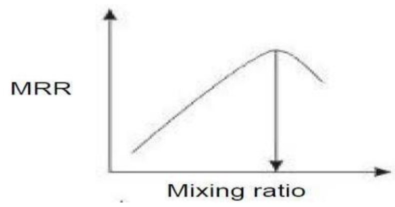

Fig.1.4 Effect of mixing ratio on MRR [26]

The effect of mixing ratio on the material removal rate is shown above. The material removal rate can be improved by increasing the abrasive flow rate provided the mixing ratio can be kept constant. The mixing ratio is unchanged only by simultaneous increase of both gas and abrasive flow rate.

1.7.3 Effect of Nozzle pressure on MRR:

The abrasive flow rate can be increased by increasing the flow rate of the carrier gas. This is only possible by increasing the internal gas pressure as shown in the figure 5. As the internal gas pressure increases abrasive mass flow rate increase and thus MRR increases. As a matter of fact, the material removal rate will increase with the increase in gas pressure Kinetic energy of the abrasive particles is responsible for the removal of material by erosion process.

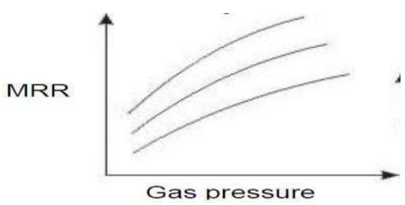

Fig.1.5 Effect of Nozzle pressure on MRR [26]

The abrasive must impinge on the work surface with minimum velocity for machining glass by SIC particle is found to be around 150m/s.

1.7.4 Effect of Standoff distance on MRR:

Standoff distance is defined as the distance between the face of the nozzle and the work surface of the work. SOD has been also found to have considerable effect on the work material and accuracy. A large SOD results in flaring of jet which leads to poor accuracy.

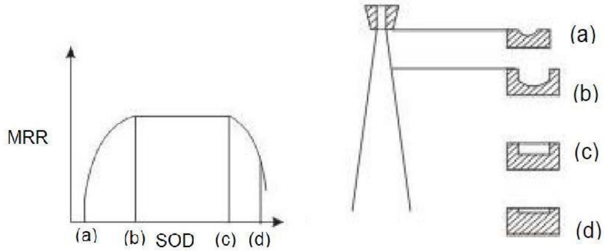

Fig.1.6 Effect of Standoff distance on MRR [26]

2. TAGUCHI METHODS

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, marketing and advertising. Taguchi methods are considered controversial among some traditional Western statisticians but others accept many of his concepts as being useful additions to the body of knowledge.

2.1 Objective of Taguchi's Method:

Taguchi's parameter design can be used to make a process robust against sources of variation and hence improve field performance. If we can design a process that has the robustness to noise factors that largely affects the variance of performance characteristics at a developing stage, it will very possible for the process to have robustness against other noise factors that could not be considered at the development stage. The aim of a parameter design experiment is, then, to identify settings of the design parameters that maximize the chosen performance measure and are insensitive to noise factors.

2.2 Orthogonal Array:

The goal of a Taguchi's experimental design is to identify optimal settings for all the design parameter, not to build the model fitting of process Taguchi has achieved substantial payoffs just by conducting many main-effect-only-experiments and checking the results by confirmation experiments. If it can be proved that the system could be described well by even only main effects, the optimal condition determined by only main effect analysis can be very efficient and simple method for optimization. Orthogonal array has been used to minimize the number of test runs while keeping the pair-wise balancing property in Taguchi's method for that purpose. These basic principles serve as a screening filter, which allows the examination of the effects of many process variables, identifying those factors, which have a major effect on process characteristics using a single trial with a few reactions. For example, optimization experiment would normally require each variable to be tested independently. Thus, a trial run investigating the effects and interactions of four reaction variables each at three concentration level, would require an experiment with 81 (i.e. 3^4) separate reactions. Using an orthogonal array, however, an estimate of the effect of each variable can be carried out using only nine experiments. Providing that three level are used for each variable tested, the number of experiments required (E) is calculated from the equation E=2k+1, where K is the number of factors to be tested. If the calculated number is not a multiple of three, then the required number of variables to be tested is the next multiple. Hence, as the number of experiments required becomes more marked; e.g. to test 9 factors would require 3^9 = 19683 experiments to analyze fully, whereas using Taguchi's methods this could be reduced to just 21

(2*9+1=19), 19 is not a multiple of three and then next integer divisible by three is 21. Example of Orthogonal Array for 4 factors and 3 levels

Table no. 3.1 Taguchi L9 OA (Orthogonal Array)

Expt. No.	A	B	C	D	response
1	1	1	1	1	-
2	1	2	2	2	-
3	1	3	3	3	-
4	2	1	2	3	-
5	2	2	3	1	-
6	2	3	1	2	-
7	3	1	3	2	-
8	3	2	1	3	-
9	3	3	2	1	-

Table 3.1 shows L9 OA (Orthogonal Array). This L9 table can apply for maximum 4Parameters and 3 levels.

2.3 Use of Orthogonal Arrays (OAs) and Signal-to-Noise(S/N) Ratio:

OAs is used to minimize the number of runs (or combinations) needed for the experiment. Many people are of the opinion that the application of OA is TM, but the application of OAs is only a part of TM. S/N ratios are used as a measure of the functionally of the system. S/N ratios capture the magnitude of real effects (signals) after making some adjustment to uncontrollable variation noise

Table 4.4 Taguchi L9 OA for Response (MRR)

Table 5.10 Taguchi L9 OA for MRR

Expt. No.	A	B	C	MRR (g/sec.)
1	1	1	1	0.0034
2	1	2	2	0.0049
3	1	3	3	0.0084
4	2	1	2	0.0086
5	2	2	3	0.0102
6	2	3	1	0.0096
7	3	1	3	0.0126
8	3	2	1	0.0113
9	3	3	2	0.0148

The L_9 orthogonal arrays table with 9 rows (corresponding to the number of experiments).

3. ANALYSIS OF THE S/N RATIO

Taguchi method stresses the importance of studying the response variation using the signal – to – noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better

Table 5.12 ANOVA results for metal removal rate

Source of variation	Degrees of freedom (DOF)	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage (%)
Model	6	1.01E-04	1.69E-05	96.65	0.0103	
A	2	8.08E-05	4.04E-05	231.52	0.0043	79.82%
B	2	1.24E-05	6.19E-06	35.49	0.0274	12.23%
C	2	8.00E-06	4.00E-06	22.94	0.0418	7.91%
Error	2	3.49E-07	1.74E-07			0.04%
Total	8	1.02E-04				

{*1.012E-004 means 1.012 times 10 to the -4th power (.0001). It should be 0.0001012

4. CONCLUSIONS

This study has discussed an application of the Taguchi method for investigating the effects of process parameters on the finished surface value in the abrasive jet machining (AJM) of tempered glass result in better finished surface. In the Modren AJM process, the parameters were selected taking into consideration of manufacturer and industrial requirements.

From the analysis of the results in the AJM process using the conceptual signal-to-noise (S/N) ratio approach, regression analysis, analysis of variance (ANOVA), and Taguchi's method, the following can be concluded from the present study:

- Statistically designed experiments based on Taguchi methods were performed using L9 orthogonal arrays to analyze the metal removal rate and improved finished surface as response Variable Conceptual S/N ratio and ANOVA approaches for data analysis drew similar conclusions.
- Statistical results (at a 95% confidence level) show that the pressure(A), angle (B), and abrasive grit size (C) affects the surface finishing by 79.82%, 12.23% and 7.91% in the abrasive jet machining of tempered glass respectively.
- The maximum metal removal rate is calculated as 0.00158 g/sec. by Taguchi's improving method.
- In this study, the analysis of the confirmation experiment for metal removal rate has shown that Taguchi parameter design can successfully verify the cutting parameters (A3B3C3), which are pressure=8 kg/cm^2 (A3) angle= 0^0 (B3) and abrasive = 320 mesh size (C3).
- Surface finishing of tempered increases with increase in pressure and abrasive size (microns) in abrasive jet machining of tempered glass. Surface roughness decrease in angle and abrasive mesh size in abrasive jet machining of tempered glass.

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