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Fabrication of micro-hole array on brittle materials by abrasive jet machining

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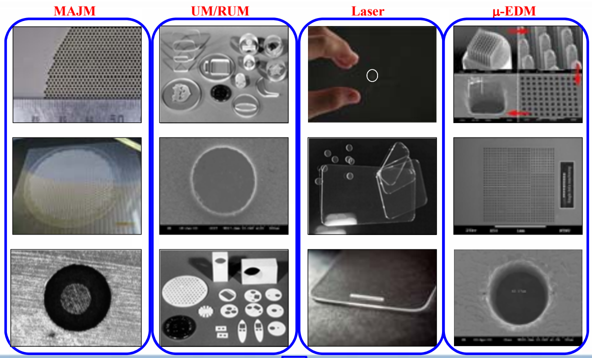
Micro holes on Hard and/or Brittle Materials



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Techniques for producing micro-holes on brittle materials

	Wet Chemical Etching	Dry Chemical Etching	EDM	Lasers drilling	Ultrasonic machining	MAJM
Advantages	1. Cheap 2. Almost no damage due to purely chemical nature 3. Highly selective	1. Avoid dangerous acids and solvents 2. Use a small amount of chemicals 3. High resolution and cleanliness 4. Less undercuts 5. Easy to automate	1. Can machining hard and brittle materials to very tight tolerances. 2. Non-direct contact. 3. Surface finish is good 4. Very small holes can be easily drilled	1. Non-contact technique 2. High aspect ratios possible. 3. Holes at shallow angles. 4. Drilling of difficult to process materials 5. High speed and accuracy.	1. Produces less heat 2. Various hole cut shape due to the vibrator motion of the tool 3. Threading of hard materials 4. Produces fine finishes and structured results.	***1. Low cost*** ***2. High production efficiency.*** 3. This process is very suitable for machining brittle, heat resistant and fragile materials. 4. Can effectively produce complex shapes of holes.
Disadvantages	1. Poor anisotropy 2. Poor process control (temperature sensitivity) 3. Poor particle control 4. High chemical disposal costs ***5. Environmental pollution***	1. Some gases are quite toxic and corrosive 2. Re-deposition of non-volatile compounds ***3. Expensive equipment***	1. The slow rate of material removal ***2. Conductive materials only*** 3. Reproducing sharp corners on the work piece is difficult due to electrode wear. 4. Over cut	1. Expensive equipment. ***2. Heat affected zone.*** 3. Particularly in holes with a large aspect.	1. High tool wear 2. Skilled labor in operated on the machine 3. Unnecessary large grain size cause defect 4. Repair should be necessary 5. Difficult to machine deep holes ***6. Limitations in productivity***	***1. When the depth of the hole is large, the taper becomes almost inevitable.*** 2. Dust collection room is the basic requirement. 3. Abrasive particles are embedded in the working surface.

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Basic principles of MAJM

- **Process parameters to define MAJM are:**
  1. Blasting ： pressure, time and velocity
  2. Abrasives material ： properties, size and density
  3. Nozzle scanning times：velocity and number of times
  4. Stand-off distance.
- Such parameters should be appropriately determined to improve machining accuracy and efficiency.

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MAJM Process

- The total process flow of micro-grooving using MAJM process is the following three steps:

Masking process → **Abrasive jet machining process** → **Mask removing and cleaning process**

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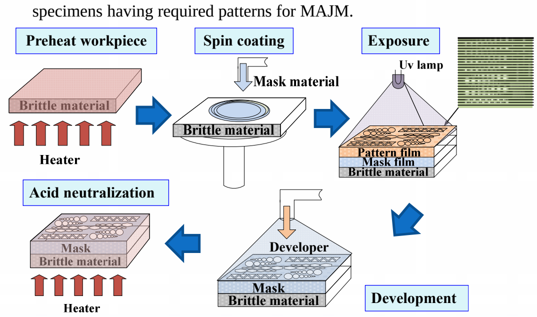
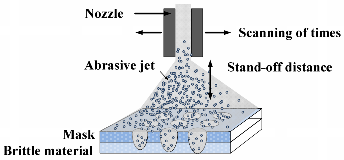
Masking process

1. **Masking process:** The masking process is used to prepare the specimens having required patterns for MAJM.



AJM Process

2. **Abrasive jet machining process:**
MAJM is performed on the machine. Here, the regions, where masks are removed in the developing process, are selectively machined.



3. **Mask removing and cleaning process:**
After the machining process is finished, any remaining mask adhered to the workpiece surface is removed, and the workpiece is cleaned using ultrasonic cleaning equipment.

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Experimental works

- Experimental parameters were designed different pressure, time and stand-off distance for machining soda lime glass (T=0.4mm), and then observe the machining profile, taper angle and efficiency.

Process parameters for MAJM	
Nozzle diameter	8mm
Abrasive	Al_2O_3 #320 (26-31μm) and #400 (18-22μm)
Air pressure	0.05, 0.1, 0.15….0.5 MPa
Stand-off-distance	10, 20, 30…..70mm
Mask pattern	Angle 30, 60, 75, 90, 120º
Scanning times	160, 200, 240
Machining time	20, 40, 60, 80s

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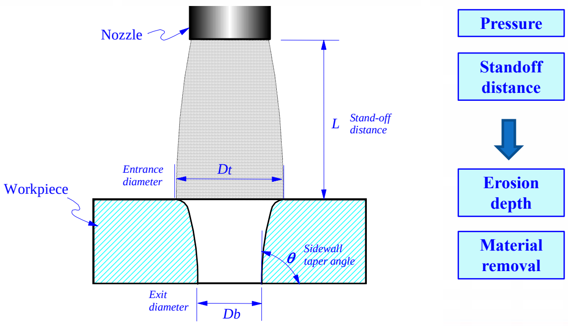
Schematic representation of the MAJM
(without using mask)



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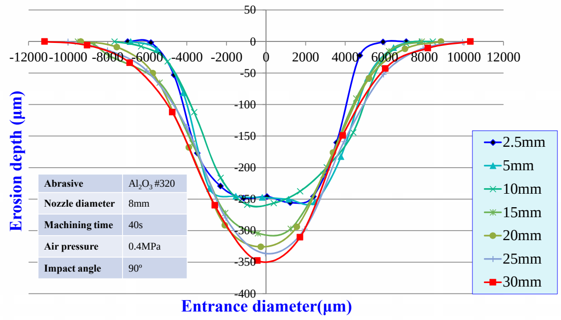
MAJM Tests Without Using a Mask



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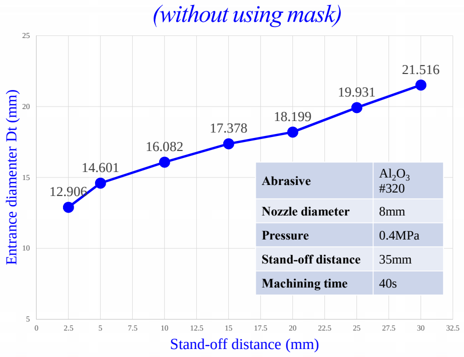
Entrance diameter increases with stand-off distance
(without using mask)



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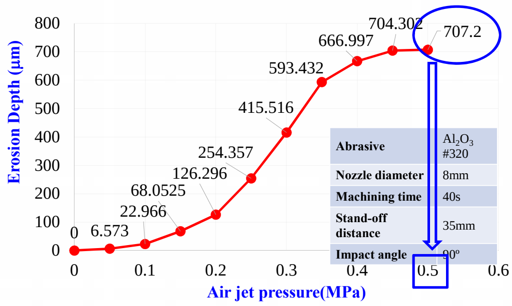
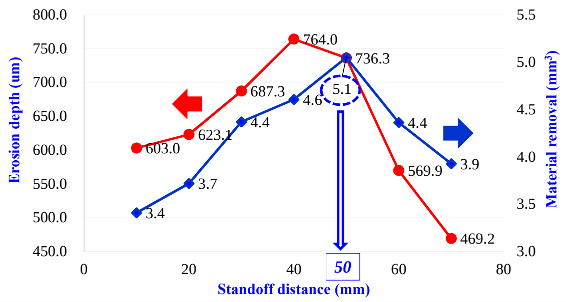
Air pressure vs. Penetration depth



Material removal /Penetration depth vs. Stand-off distance



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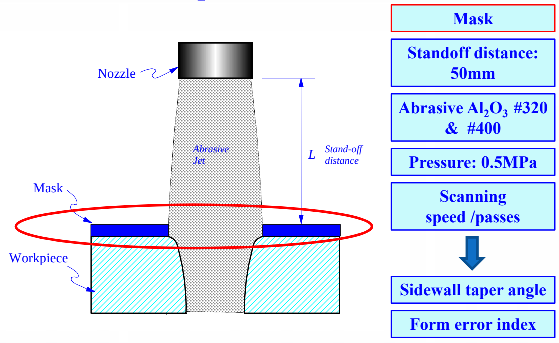
Schematic representation of the MAJM



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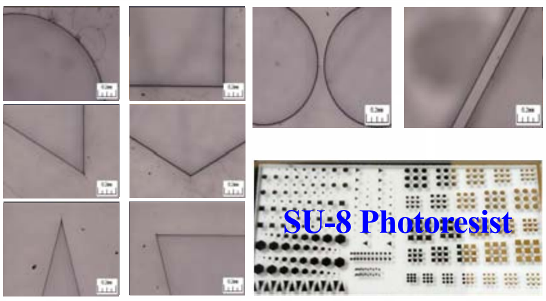
Optical Mask



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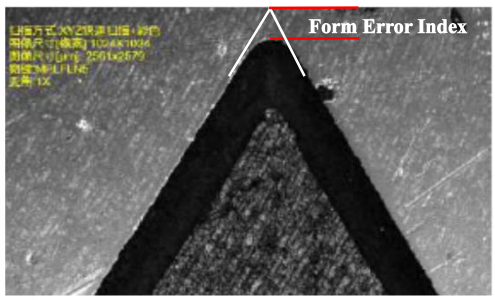
Form Error Index



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Influence of Various Machining Parameters

- *Scanning Speed*
- *Scanning Passes*
- *Abrasive Size*
- *Pattern Geometry (Shape, Spacing)*

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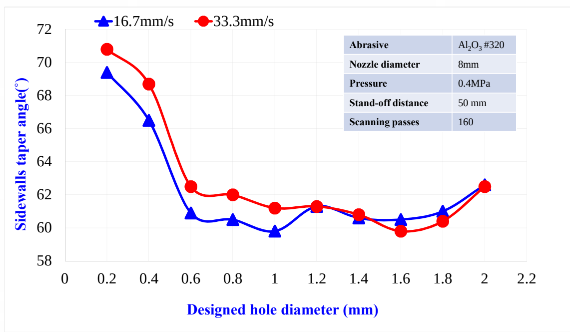
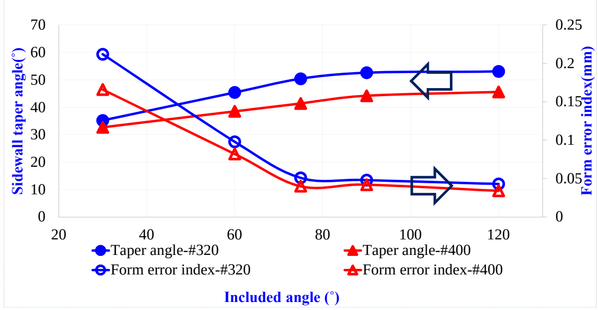
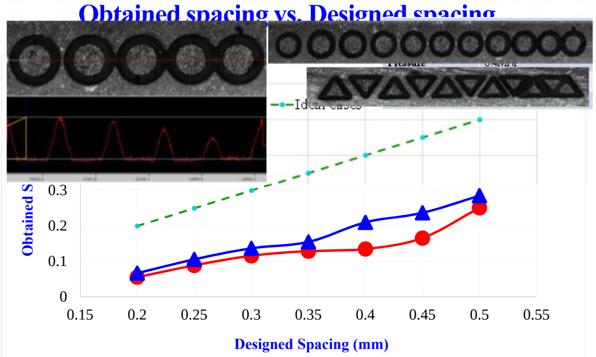
Sidewall taper angle vs. hole diameter at various scanning speeds



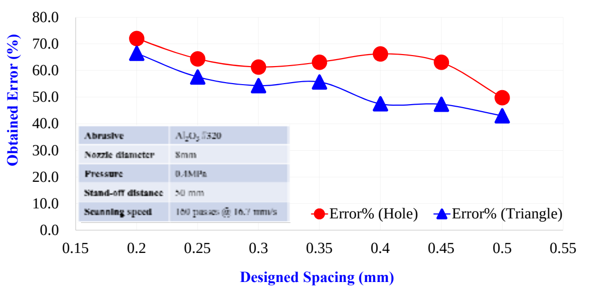
Sidewall taper angle & Form error index vs. Included angle at various abrasive sizes



Obtained spacing vs. Designed spacing

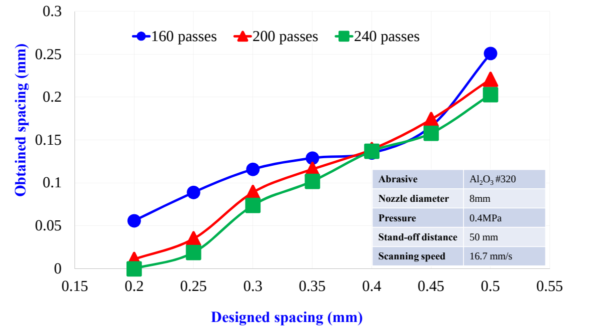


Obtained spacing error% vs. Designed spacing

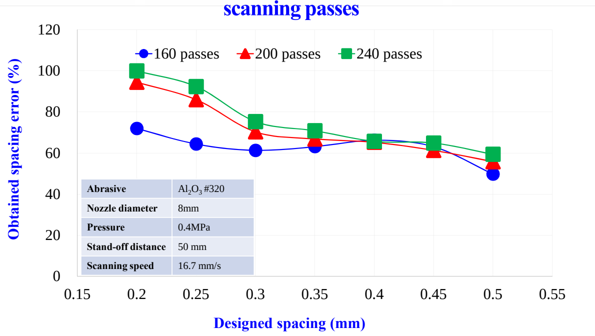


*(designed-obtained)/designed *100%*

Obtained spacing vs. Designed spacing at various scanning passes

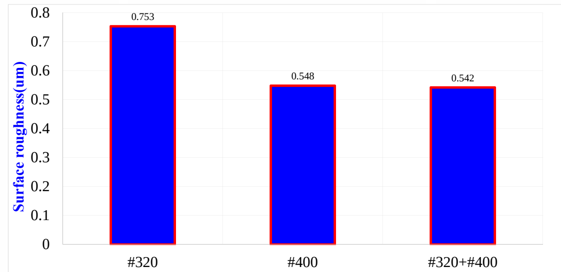


Obtained spacing error(%) vs. Designed spacing at various scanning passes



Abrasive	Al_2O_3 #320 / #400
Nozzle diameter	8mm
Pressure	0.5MPa
Stand-off distance	50 mm
Scanning speed	16.7 mm/s

Hybrid machining



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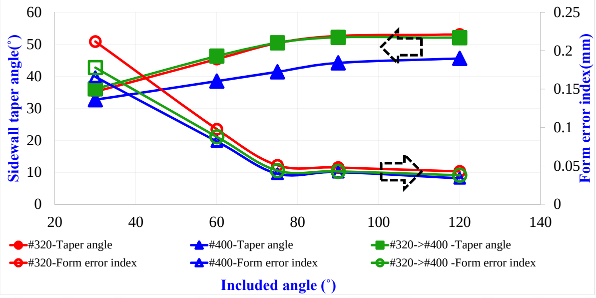
Abrasive	Al_2O_3 #320 + #400
Nozzle diameter	8mm
Pressure	0.5MPa
Stand-off distance	50 mm
Scanning speed	16.7 mm/s
Scanning passes	120/120

Hybrid Machining



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Conclusions

- Under the same machining conditions, big holes have deeper erosion depth than small hole and sidewall is more bias to form a "V" shape profile than those obtained in small holes. Thus, small holes have higher sidewall taper angle than big holes.
- As the included angle gets smaller, it's getting more and more difficult for abrasive particles to crush into the tip area. As a result, the form error gets higher as the included angle gets smaller.
- Since finer abrasives have better chances to "cut" into the tip area, the smaller the abrasive gets the higher form accuracy it can achieve.

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Conclusions

- In comparison to fine abrasive, coarse abrasive have deeper erosion depth and sidewall profile is more bias to a "V" shape than those generated by fine abrasive. Thus, fine abrasive generates higher sidewall taper angle than those generated by coarse abrasive.
- The hybrid process can effectively improve the form accuracy/surface roughness of the obtained patterned holes especially when the included angle is small.

Thank you for your attention.