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Improvement of Geometrical Accuracy of Micro Holes Machined Through Micro Abrasive Jet Machining

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Abstract

Assembling of various parts and subassembly needs the closer attention on the geometrical accuracy of the part apart from the dimensional tolerances. Micro holes machined through micro abrasive jet machining are tapered, resulting in poor cylindricity. Cylindricity of the machined micro holes can be improved by reducing the taper angle of the hole. This paper presents a novel approach for machining holes on brittle material-quartz, using the in-house developed micro abrasive jet machine, wherein the nozzle is given a feed rate equal to the average rate of change of the workpiece thickness. The experiments are conducted to study the effect of this novel approach to the shape of the machined hole by measuring the entrance diameter and exit diameter and hence calculated the taper angle. The obtained experimental results reveals that the taper angle of the machined hole is reduced by approximately 58 % using this novel approach and hence achieved the improvement in cylindricity of the machined holes.

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Keywords: workpiece, machining, feed rate, material removal, cylindricity, taper angle

Nomenclature

ϕ_1	entrance diameter of the machined hole, (mm)
ϕ_2	exit diameter of the machined hole, (mm)
ϕ_N	nozzle diameter, (mm)
V_f	feed rate of the nozzle, (mm/min)
r	average rate of change of the workpiece thickness, (mm/min)
S	nozzle stand-off distance at t=0, (mm)
S'	nozzle stand-off distance at time t=dt, (mm)
t	machining time, (s)
T	workpiece thickness, (mm)
dT	small amount of change in the thickness, (mm)
dt	time was taken to machine the workpiece up to thickness dt, (s)
α	taper angle, (˚)

1. Introduction

Micro-Abrasive Jet Machining (Micro-AJM) is a non-conventional machining process in which a high-energy jet composed of abrasive particles and compressed air is focused on the work surface through the nozzle. The compressed air possessing potential energy acts as a carrier media and imparts substantial kinetic energy to the abrasive particles that further gets amplified by the nozzle. These abrasive particles coming out of the nozzle with a very high velocity impacts the target surface and removes the material by mechanical erosion. Micro-AJM process is a highly productive and cost effective for machining hard and brittle materials such as glass, silicon and ceramics finding wide applications in semiconductors, electronic devices, MEMS, flat display panels, micro-fluidic devices etc [1]. The mechanism of material removal in solid particle erosion is not same for

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ductile and brittle material. The ductile material undergoes weight loss due to plastic deformation process in which material is removed by displacing the eroding particle; whereas, the brittle material is removed by the intersection of cracks radiating out from the point of impact of the eroding particles [2,3]. In abrasive jet machining, Nozzle Stand-off Distance (NSD) is one of the most important process parameters that affects the material removal rate as well as the size and shape of the features produced, particularly in our case cylindricity of the workpiece. It has been found that material removal rate increases up to a maximum value with the increase in NSD and then decreases with the further increase in NSD [4,5].

Many works have been reported on the size and shape of the surface produced by micro-abrasive jet machining. Park et al. observed that the cross section profile of the hole and straight groove machined on glass [6]. Balasubramaniam et al. reveals that The abrasive air jet is divergent in nature i.e. the radius of the jet changes along the center line of the jet, as consequences of which the machined feature gets oversized. The divergence effect becomes more pronounced with the increase of NSD [7]. Zhang et al. introduced a new method-Micro Abrasive Intermittent Jet Machining (MAIJM) and studied the effect of various process parameters on the shape of the machined hole. The study revealed an increasing diameter of the machined hole with an increase in the NSD [8]. Venkatesh et al. also reported that the abrasive jet machined surface is reverse bell mouthed in shape with an edge radius at the entry side of the target surface. The entry side diameter and the edge radius increase with increasing NSD [9]. The size of the jet is in the order of several millimeters and therefore, erosion resistant masks need to be applied to the surface of the target to define the edges of desired micro features [10].

In the conventional micro-abrasive jet machining, the required holes are machined keeping the nozzle and the workpiece in stationary position. The distance between the nozzle and the workpiece known as nozzle stand-off distance (NSD) is set at a value at the beginning of the experiment, but as the material starts eroding from the entry surface of the workpiece the NSD changes. So ultimately, even though NSD is set to a certain value at the beginning of the experiment, it changes during the machining at a certain rate. Literatures revealed that NSD has a considerable effect on the shape of the hole produced i.e. entrance and exit diameter of the machined hole. The current work presents a novel approach for machining the holes using micro-AJM, in which, to maintain the NSD to a set value during the machining, the nozzle is given a certain feed rate and the workpiece is held stationary.

The effect of this novel approach to the shape of the machined hole is presented in terms of entrance diameter, exit diameter, and the calculated taper angle. The most important part of the work is the rate at which the nozzle is to be fed down to maintain the constant NSD. The detailed explanation on the feed rate is provided in section 2. To feed the nozzle, a nozzle feed system is designed, fabricated and integrated with current micro-AJM setup, which is discussed in detail at section 3.

2. Methods

Figure 1 shows the schematic diagram of nozzle-workpiece system in micro-AJM. The set value of NSD at the beginning of the experiment changes during machining, as the new surface from different workpiece depth becomes the entry surface and the nozzle is held stationary. Therefore, in contrast to the conventional approach, nozzle is moved down towards the workpiece to maintain the set value of NSD in the current approach.

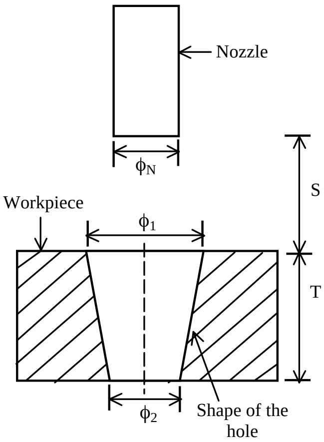

Fig. 1. Schematic diagram of nozzle-workpiece system in micro-AJM

Figure 2 shows the schematic diagram showing the effect of variation in workpiece thickness on NSD.

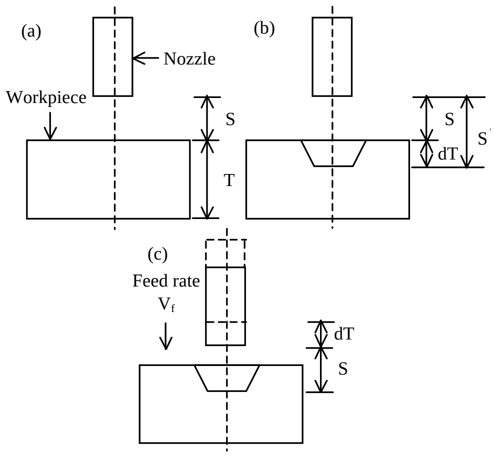

Fig. 2. Schematic diagram showing the effect of variation in the workpiece thickness on NSD

Figure 2 (a) shows the condition at the beginning of the machining i.e. at time $t=0$, when NSD is set to S. After some time of machining, at time $t=dt$, the workpiece thickness is reduced by amount dT, which results in the increase of NSD by an approximately equal amount dT in the same amount of time dt. So the value of NSD is changed from the set value of S to a new value of $S^{'}$, as shown in Fig. 2 (b). So NSD at time $t=dt$ is given as

$$S^{'} = S + dt \quad (1)$$