PARAMETRIC STUDIES OF ABRASIVE WATER JET CUTTING ON SURFACE ROUGHNESS OF SILICON NITRIDE MATERIALS

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Abstract

Abrasive Waterjet Cutting [AWJC] is a rapidly developing technology that is used in industry for a number of applications including plate profile cutting and machining of a range of materials [1]. It has various distinct advantages over the other non-traditional cutting technologies, such as no thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces. Dense Si_3N_4, is one of the very hard ceramic materials, used for both room and high temperature structural application, was machined by Abrasive water jet machining technique using Silicon carbide grits (80 B.S.) in place of commercially used garnet sand. Water pressure, abrasive flow rate, traverse speed and standoff distance were varied between 5000-6000 bar at 250 bar interval, 10gm/min-20gm/min at an 2.5gm/min interval, Traverse speed and Standoff distance varied between 1mm/min - 7mm/min at an interval of 1.5mm/min and 4mm-16mm at an interval of 3mm respectively.

Keywords: Si_3N_4, Abrasive Water jet, Surface Roughness

1 Introduction

Structural materials can be classified into three types Metals, Ceramics & Polymers. Machining of those materials has its own advantages and limitations[1]. Metals are easy to machine with different conventional processes, polymers are easy to fabricate but cannot sustain in higher temperature (>300^0C). Ceramics like Al_2O_3 or Si_3N_4 [2] are formed in high temperature, can also sustain in higher temperature but very difficult to machine with conventional processes. In this experiment abrasive water jet, a non-conventional machining process has been introduced for machining of hard & brittle ceramic materials like Silicon Nitride (Si_3N_4)[3].

In 1979 Dr. Mohamed Hashish invents the process of adding abrasives to a standard waterjet. After testing a variety of options, he settled on garnet, a substance commonly used on sandpaper. The ultra high pressure (UHP) abrasive waterjet can cut virtually any hard material like composites. Eventually these non-traditional machining processes are very costly. Abrasive water jet machining process is also considered to be a costly process. Accordingly fabrication of $Si_3N_4$is also not very economic. So it is very important to identify the influence of the different machining parameters to reduce the loss of the resources like Si_3N_4 materials, abrasives and power etc.

2 Fabrication and Properties of Si_3N_4

Wet mixing of **Si_3N_4 powder** (UBE chemicals, Japan, Grade E-10), **Y_2O_3** (Indian rare earths, Alleppey, India), **SiO_2**and**AlN** (H.C.Starck, Germany) has been carried outby **Attrition mixing** [4]processfor **homogeneous mixing** in **Isopropanol medium.** At the time of attrition, few grams of Alumina balls of 3mm diameter, preferred to keep in that slurry for better mixing**.** It can be kept at 70-80^0C for 2-3 hrs to dry completely. After drying the powder is needed to sieve to separate the Alumina balls from the powder composition. A Uniaxial pressing desired to make billets of exact 50mm × 25mm × 25mm size after drying. Then the samples are taken to the cold Isostatic pressing (CIP) at 150 MPa for better compaction and better strength of the samples. Before CIP, the green samples are needed to keep within a soft vacuum packet so that the sample can be kept as formed as uni-axial pressed at the time of CIP within the oil medium. After CIP sample taken for **Sintering at 1750^{0}C** (Furnace Used- Astro Furnace, Thermal Technologies, USA) the total soaking time was 2hr at the highest temperature in Nitrogen atmosphere.

Table 1 Physical and Mechanical properties of Si_3N_4 samples

Average Density (gm/cc)	Average 4-point Flexural strength (MPa)	Average Hardness (GPa)
3.23	689.3	14.4

3 Experimental Procedure

Before experimentation a trial and error method was used to achieve nearer best input parameters. On the basis of which the levels were considered for experimentation, see Table 2.

Table2 Process parameters and their levels considered for experimentation

Symbols	Abbreviation	L_1	L_2	L_3	L_4	L_5
A	WP	5000	5250	5500	5750	6000
B	AFR	10	12.5	15	17.5	20
C	TS	1	2.5	4	5.5	7
D	SOD	4	7	10	13	16

Where,

A = Water Pressure, in Bar, B= Abrasive flow rate in gm/min, C= Traverse speed (Axis movement) in mm/min, D= Standoff distance in mm.

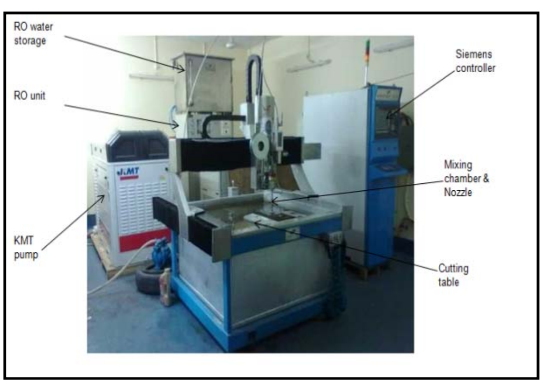

Fig.1 Abrasive Water Jet Machine installed at C.G.C.R.I., Kolkata

Table3 Specification of the components of AWJM

Sl. No.	Components	Specification
1	Cutting table	1m x 1m
2	Nozzle	Tip diameter 0.76mm
3	Controller	Siemens 802D Senumerik
4	Pump	KMT streamline pro-I-60S. 60HP.
5	Abrasive feeder	Abraline III, KMT
6	RO unit	Tharmax 500LPH

The samples were mounted in wooden blocks for machining by AWJM (Nanojet 1212, assembled by Anjanitechnoplast, India). A 60 HP pump was used to generate the required pressure (Maximum 6200bar, Streamline Pro, KMT, Germany), machining process was numerically controlled by Siemens controller (802D SL Sinumeric, Siemens, Germany), 80 B.S. black SiC particle was used as abrasive materials in place of commercially used garnet sand. In the experiment Water pressure, abrasive flow rate, traverse speed and standoff distance were varied between 5000-6000bar at 250bar interval, 10gm/min-20gm/min at an 2.5gm/min interval, 1mm-7mm at an interval of 1.5mm and 4mm-16mm at an interval of 3mm respectively according to the design. The tungsten carbide focusing tube of internal diameter was 0.76mm, which was used for continuous 10 operations each to minimize the effect of incremental nozzle diameter by SiC particle abrasives. The sequence of machining operation was programmed by a CAM software (Meta CAM-3D, USA). The Surface roughness (R_a) was measured by a non-contact type profiler (Bruker, USA).

4 Results & Discussions

Surface roughness is one of the most important criteria, which help us determine how rough a workpiece material is machined. In all the investigations it was found that the machined surface is smoother near the jet entrance and gradually becomes rougher towards the jet exit. This is due to the fact that as the particles moves down they loose their kinetic energy and their cutting ability deteriorates. By analyzing the experimental data of all the selected materials, it has been found that the optimum selection of the four basic parameters, i.e., water pressure, abrasive mass flow rate, nozzle traverse speed and nozzle standoff distance are very important on controlling the process outputs such as surface roughness. The effect of each of these parameters is studied while keeping the other parameters considered in this study as constant. The following discussion uses the experimental data at the center of the cut for each specimen and the surface roughness is assessed based on the center-line average Ra.

4.1 Effect of Water Pressure on surface roughness

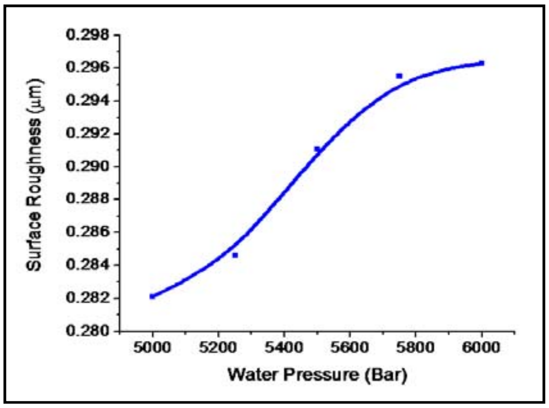

Fig2 (a) Surface Roughness Vs Water Pressure

The influence of water pressure on the surface roughness is shown in fig.2 (a). Jet pressure plays an important role in surface finish. As the jet pressure increases, surface becomes rougher. With increase in jet pressure, brittle abrasives break down into smaller ones which again corrode the inner surface of the material. As a result of reduction of size of the abrasives the surface becomes rougher. Though, due to increase in jet pressure, the kinetic energy of the particles increases which ought to results in smoother machined surface.

4.2 Effect of Abrasive Flow Rate on surface roughness

It needs a large number of impacts per unit area under a certain pressure to overcome the bonding strength of any material. With the increase in abrasive flow rate, surface roughness decreases. This is because of more number of impacts and cutting edges available per unit area with a higher abrasive flow rate. Abrasive flow rate determines the number of impacting abrasive particles as well as total kinetic energy available. Therefore, higher abrasive flow rate, higher should be the cutting ability of the jet. But for higher abrasive flow rate, abrasives collide among themselves and loose their kinetic energy. It is evident that the surface is smoother near the jet entrance and gradually the surface roughness decreases towards the jet exit. The effect of abrasive flow rate on surface roughness is shown in fig.2 (b)

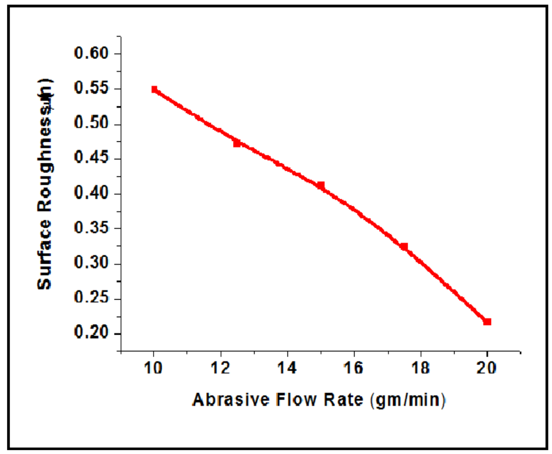

Fig 2 (b) Surface Roughness Vs Abrasive Flow Rate

4.3 Effect of Traverse Speed on Surface roughness

Traverse speed didn't show a strong influence on surface roughness. For decreasing of the machining costs every user try to choose the feed rate of the cutting head as high as possible, but increasing the traverse speed always causes increasing of inaccuracy and surface roughness. But with increase in work feed rate the surface roughness increased. This is due to the fact that as the nozzle moves faster, less number of particles are available that pass through a unit area. Therefore, less number of impacts and cutting edges are available for non uniform cut on the surface. Finally the generartion of a rougher surface.The relationship between the traverse speed and the surface roughness is shown in fig. 2(c).On the other hand as the nozzle traverse speed is high so the abrasive water mixture is getting very less time to penetrate with maximum pressure. This could cause serrations shown in fig 3.Which indicates the rough surface?

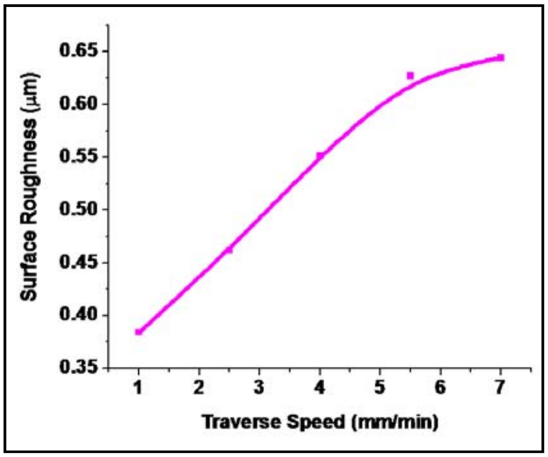

Fig 2 (c) Surface Roughness VsTraverse Speed

4.4Effect of Standoff Distance on Surface roughness

Surface roughness increase with increase in standoff distance. This is shown in fig. 2(d).

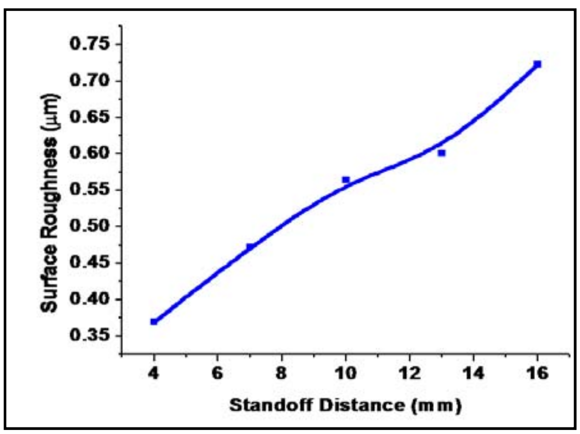

Fig 2 (d) Surface Roughness VsStandoff Distance

Generally, higher standoff distance allows the jet to expand before impingement which may increase vulnerability to external slog from the surrounding environment. Therefore, increase in the standoff distance results an increased jet diameter as cutting is initiated and in turn, reduces the kinetic energy of the jet at impingement. So surface roughness increase with increase in standoff distance. It is desirable to have a lower standoff distance which may produce a smoother surface due to increased kinetic energy. The machined surface is smoother near the top of the surface and becomes rougher at greater depths from the top surface.

The present study includes the parametric influences on surface finish during abrasive water jet cutting of silicon nitride ceramics. The process parameters are varied according to the statistical design during experimentation. The experimental results are observed and discussed in the present work.

From the parametric studies on surface roughness (R_a) of cut edge, it is observed that the better surface finish (R_a) 0.2921μm is obtained at 5000 bar Water pressure, 20gm/min abrasive flow rate, 1mm/min traverse speed and 4mm standoff distance. 3D topography of cut surface of Silicon Nitride work piece is shown in figure 3.From that fig it is clearly visible that the serrations are much higher towards the opposite surface of the water and abrasive mass flow because of the loss of the kinetic energy.

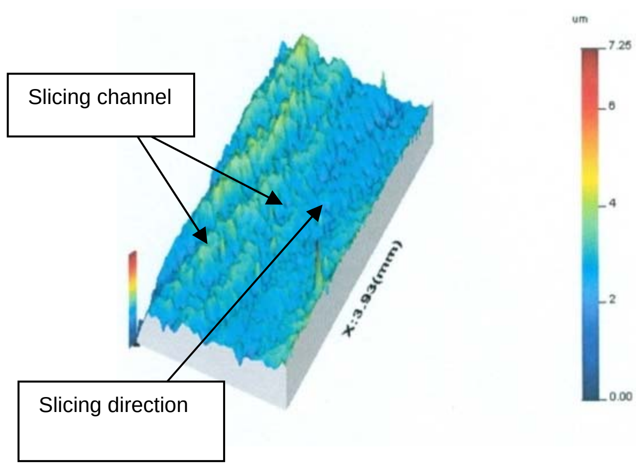

Fig 3:3D topography of Si_3N_4 samples

5 Conclusions

Experimental investigations have been carried for the surface roughness in abrasive waterjet cutting of ceramics. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on surface roughness have been investigated.

As a result of this study, it is observed that these operational parameters have direct effect on surface roughness. An increase in water pressure is associated with anincrease in surface roughness. Machining with 5000 bar pressure is basically a high pressure operation. These results indicate that the use of high water pressure is preferred to obtain good surface finish. Surface roughness constantly decreases as mass flow rate increases. It is recommended to use more mass flow rate to decrease surface roughness. Among the process parameters considered in this study water pressure and abrasive mass flow rate have not the similar effect on surface roughness. As nozzle traverse speed increase, surface roughness increases. This means that low traverse speed should be used to have more surface smoothness but is at the cost of sacrificing productivity. This experimental study has resulted surface smoothness increase as standoff distance decreases. Therefore to achieve an overall cutting performance, low standoff distance should be selected.

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