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STUDY ON MACHINING CHARACTERISTICS OF SILICON NITRIDES DURING CNC PULSED Nd:YAG LASER MACHINING

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ABSTRACT

A CNC pulsed Nd:YAG laser machining system has potential for precision machining operation on the small jobs. A laser power beam has great potential for machining very hard conductive as well as non-conductive materials such as high speed steel, ceramics, and diamonds etc. In this present paper includes the basic study of Nd:YAG laser machining system and development of a fixture, which can serve the purpose of holding the job firmly with sufficient pressure and without distortion during machining. This paper also deals with some parametric analysis on CNC pulsed Nd:YAG laser machining operation on Silicon Nitride ceramics.

Keywords: Nd:YAG laser machining of Silicon Nitride Ceramics, Surface roughness, Fixture Development.

1. INTRODUCTION

The major application areas like space research, automobile industry, nuclear rectors, aerospace, guided missiles electronic industry, and medical device industry etc., faces a requirement of more precision machining of engineering ceramics day by day. In order to fulfill these requirements the development of laser beam machining (LBM) process leads to become a versatile method of machining. The applications of LBM in modern machining industry are increasing at a faster rate because it has ability to machine a very hard conductive as well as non-conductive such as HSS, ceramic and diamond etc. And even soft materials like plastics and rubber can also be machined by using this process. Pulsed Nd:YAG laser machining becomes an excellent process because of high laser beam intensity, low mean beam power, good focusing characteristics due to very small pulse duration and narrow heat effected zone (HAZ). For brittle materials the process has become unavoidable as the process require minimum job supporting pressure and for tough and hard materials to get inclined cuts requires good holding and clamping. At the same time thermal stresses to be uniform during machining and there should be uniform work holding pressure. Due to these reasons the design and development of multi purpose fixture is important and necessary for holding the jobs during CNC Nd:YAG Laser machining operation. The fixture is designed so as to operate in limited space and fitted on the existing CNC X-Y table of the laser machining system and gives sufficient grip to the job while processing on CNC Nd:YAG laser machining system.

Silicon Nitride Ceramics have many applications such as cutting tools, self- lubricating bearings, insulations, turbines and engines etc. As the silicon nitrides are non-conducting and hard materials, the numbers of methods of machining is limited. The laser machining operation on silicon nitride can be performed but for improving the quality of the machining characteristics e.g.; high accuracy and better surface finish, the in-depth parametric analysis on pulsed Nd:YAG Laser machining of silicon nitrides has to be carried out.

2. CNC PULSED Nd :YAG LASER MACHINING SETUP DETAILS

The CNC Nd:YAG laser machining system consists of the various subsystems such as; Laser source and Beam delivery unit, Power supply unit, Radio frequency (RF) Q-switch driver unit, cooling unit and CNC controller for X,Y and Z axis movement.

The lasing medium in Nd:YAG lasers is Neodymium atoms are embedded in Yttrium Aluminium Garnet crystal host. The pump source is usually a Krypton arc lamp. When Nd:YAG crystal excited by Krypton arc lamp, for light to be amplified, the optical feedback is provided with 100% reflectivity rear mirror, and a front mirror of reflectivity 80%. The Q-switching is an excellent method to produce very short pulse width and very high peak power of light from a CW low power laser. The RF Q-switch driver unit supplies the RF signal to Q-switch for its operation. By using the beam delivery system the laser is focused on work spot. The main power supply unit controls the laser output by controlling the intensity of light emitted by Krypton arc lamp. The cooling unit cools the system to avoid thermal damage of laser cavity, lamp, Nd:YAG rod and Q-switch.

The CNC controller consists of X-Y-Z axis and controlling unit named Accupos. The motors are attached to each axis and connected to the Accupos. This Accupos unit can control the axis through the computer unit. The CNC Z-axis controller unit controls the Z-axis movement of lens. Over the table to hold the work piece, the developed fixture is placed. It takes care of the job posture. The CCD camera together with CCTV monitor is used for viewing the location of work piece and also for checking the proper focusing condition before laser machining parameter for achieving high quality machining characteristics of CNC Nd:YAG laser cutting operation. The photographic view of the CNC pulsed Nd:YAG Laser machining system is shown in Fig.1.

Fig. 1. Photographic view of the CNC pulsed Nd:YAG Laser Machining Setup

3. FIXTURE DEVELOPMENT FOR Nd:YAG LASER MACHINING

A multi clamp precision fixture has been developed to serve the purpose of proper job holding during machining. To hold the work piece of different thickness, strength, toughness, brittleness and thermal expansion coefficient, there should be proper fixture. It should assure that the job should not move while machining otherwise there is possibility of errors and inaccuracy. The job is much small and delicate there is need to take utmost care while processing. A T-slot adjustable work base is generated on the same fixture. The various components for fixtures are listed in Table 1.

The base plate is made up of duralumin material and size of 65 × 150mm and 25 thick. The reason behind choosing duralumin as fixture's base material is that it is easy to get close tolerances and also possess high thermal conductivity, light-weight and cost effectiveness. In the view of the space constraints in Nd:YAG laser machining worktable the dimensions of fixture for optimum serve of the holding purpose for different jobs have been finalized. The different set of holding clamps has been developed for accommodating jobs with various thickness and geometrical shape. For holding light and brittle materials less pressure is required and hence it is preferred to use 0.8mm thick spring steel clamps. And for hard materials like silicon nitrides etc. it is better to use 1.6mm thick spring steel clamps. For holding round objects it is better to use clamps with V-slot at it's end. If the job is small then it can be mounted on T-slotted base plate or it can be gripped between T-nuts depends upon the requirement. For better design and interchangeability of parts we adopted the majority of dimensions as preferred by Indian standards have been adopted. The photographic view of the developed fixture is exhibited in Fig.2.

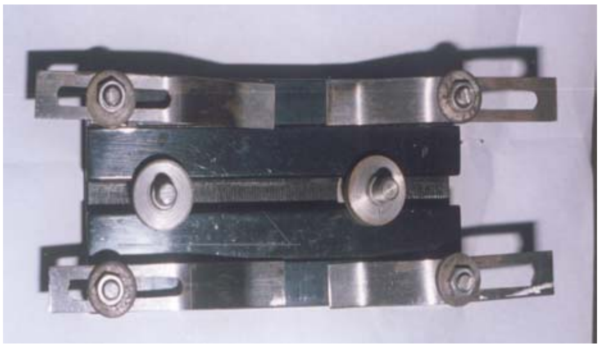

Fig. 2. Photographic view of the developed fixture

4. PARAMETRIC STUDIES ON SURFACE ROUGHNESS DURING LASER MACHINING OF SILICON NITRIDES

The process parameters taken into consideration with available machining setup are radio frequency of Q-switch, lamp current and cutting speed. The experiments have been carried out during saw cutting operation on Si_3N_4. The R_a value, which is the measure of surface roughness considered as the response. The machining process parametric setting for carrying out the experiments has been given in table 2.

After carrying out machining operation the surface roughness is measured by Surf-Com Surface Roughness measuring Instrument. Finally the experimental results are analyzed to study the effect of lamp current, frequency of Q-Switch and the cutting speed on surface roughness during cutting operation on silicon nitride ceramic materials.

4.1 Influence of Lamp Current on Surface Roughness

From the experimental results it is observed that the lower the lamp current, lower the energy level causing less evaporation of material. From the experimental results it is observed that while machining Si_3N_4 the surface roughness decreases as the lamp current increases up to nearly 25 amps, after that the surface roughness increases because, at the initial stage the energy per pulse is insufficient to melt and evaporate the material on the focused spot of the job. With the gradual increasing of lamp current the pulse energy attains threshold level i.e., minimum energy level to melt and evaporate the job material. Due to this, the cutting operation becomes smooth. With the further increase of the lamp current, the energy available per pulse causes excessive evaporation of the material from the metal removal zone as a result the surface roughness value increases. Fig 3 shows the effect of lamp current on surface roughness.

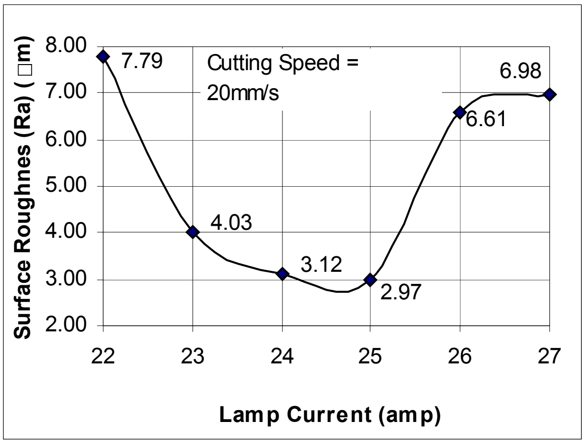

Fig. 3 Influence of Lamp Current on Surface Roughness for Si_3N_4

4.2 Influence of Radio Frequency of Q-Switch on Surface Roughness

The influence of Radio frequency of Q-Switch of surface roughness has been analysed and it is found that the lower the frequency of the Q-switch, higher the accumulated beam energy causing extensive evaporation of material. From the experimental results it is observed that, the surface roughness decreases with the increase of frequency of Q-switch up to 7 KHz, after that surface roughness shows increasing tendency, the further increase of the radio frequency of the Q-switch causes the less evaporation of the material by the laser beam. As a result the surface roughness increases. Fig. 4 shows the effect of radio frequency of Q-switch on surface roughness.

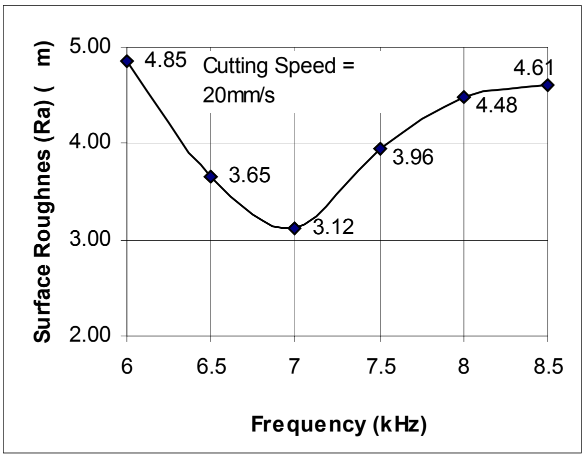

Fig. 4 Influence of Frequency of Q-switch on Surface Roughness for Si_3N_4

4.3 Influence of Cutting Speed on Surface Roughness

From experimental investigation it is observed that the low cutting speed causes the extra evaporation on the same cutting zone resulting increase in Surface Roughness. From the experimental results it is found that the surface roughness decreases up to the cutting speed of 20 mm/sec after that it shows gradual increase of surface roughness because with the further increase of cutting speed the molten material partially evaporates and remaining material are re-deposited as recast layer over the machined surface, which causes the increase in the surface roughness. So as to overcome this problem the increased gas flow can reduce the surface roughness up to certain limit. Fig. 5 shows the effect of cutting speed on surface roughness.

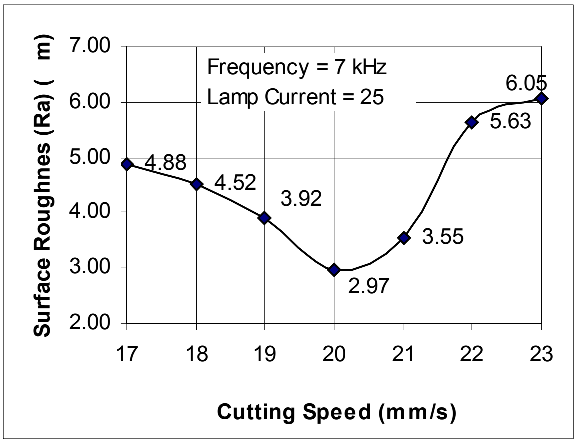

Fig. 5 Influence of Cutting Speed on Surface Roughness for Si_3N_4

5. CONCLUSIONS

The developed fixture for CNC Nd:YAG laser machining system is useful and effective for holding the job samples of varying shapes and sizes with high accuracy. The Surface roughness decreases with the increase of lamp current at lower range but increases rapidly at higher range of lamp current during laser cutting operations of Silicon Nitride ceramic. With the increase in the frequency of Q –Switch, the surface roughness initially decreases and then increases. With the increase of the cutting speed the surface roughness decreases smoothly upto certain level and then it shows increasing tendency. From the experimental results it is found that the cutting operation on Silicon Nitride can be performed successfully and for achieving better surface finish, the laser machining parametric settings are found as the Lamp current of 25 amp, the Frequency of Q-switch of 7 kHz and the cutting speed of 20.5 mm/sec. It is concluded that the present studies on machining characteristics of CNC Nd: YAG laser machining operation on engineering ceramics, is very much effective and useful for proper setting of laser machining parametric combination.

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REFERENCES

1] B.Doloi, A.S Kaur, B.Bhattacharya, "Analysis on Nd: YAG laser machining of engineering ceramics", Proceedings of DAE-BRNS symposium PBAMP-2002, pp 564-568.
2] K.Chen and Y.L Yao, "Process optimization in pulsed laser micro machining with application in medical devices manufacturing", Int. Journal of Adv. Manuf. Techno (2000) 16, pp243-249.
3] P.Di pietro, Y.L Yao , A.Jeramin , "Quality optimization for laser machining under transient condition", Journal of Material Processing technology 97 (2000), pp158-167.
4] C.Y. Jiang, W.S Lau, T.M Yu, L.Chiang, "On the maximum depth and profile of cut in pulsed Nd: YAG laser machining", Annals of the CIRP Vol 42/1/1993.
5] M.Geiger, "Laser fusion cutting of stainless steel with a pulsated Nd:YAG laser, welding in the world". Vol.31, No.3, pp.167-171, 1993.
6] Machine Tool Handbook, Central Tool Institute, Bangalore-Tata McGra-hill publishing co.ltd, New Delhi.

Table 1 :list of various components of fixture

Part No.	Component Name	Number of Components	Material	REMARKS
1.	Base Plate with T-Slot	1	Duralumin	To avoid reflection of light, the whole surface is chemically black coated
2.	Mounting bar	2	Duralumin	-Do-
3.	Elliptical slotted clamps	4	Spring Steel	Different sets (1set= 4 clamps) Suggested to hold different material of geometry and thickness
4.	Spring dwell pins (M4×8)	4	Spring steel	Standard type
5.	Washer (M6×1.5)	4	Mild steel	- Do-
6.	Hexagonal nut (M6)	4	Mild steel	-Do-
7.	Stud (M6)	4	Mild steel	-Do-
8.	Counter sink head screw with hexagonal socket (M4×25)	6	Mild steel	-Do-
9.	T-Bolt (M8×35)	2	Mild steel	-Do-
10.	T-Nut (M8×4.5)	4	Mild steel	

Table 2: Machining process parameters and their levels

Parameter	**Unit**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
Frequency of Q – switch	kHz	6.0	6.5	7.0	7.5	8.0	8.5
Lamp current	amp	22.0	23.0	24.0	25.0	25.0	27.0
Cutting speed	mm/s	17	18	19	20	21	22