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Machining Process Parameters of USM- A Review

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Abstract—

The selection of optimum process parameters is crucial for advanced machining processes, as these processes incur high initial investment, tooling cost, and operating and maintenance costs. In this paper, a review of machining process parameters for different materials is done in ultrasonic machining (USM). Machining of Different materials like ceramics, Glass Porcelain, Titanium, is done by different researchers using ultrasonic machining some materials like super alloys still need a research because of their wide applications in various industries. Various machining parameters like Static loading, types of abrasive, slurry concentration, tool geometry are studied by researchers. This is revealed from the various research works that the above said parameters plays a vital role in achieving optimum value of MRR and Surface finish in ultrasonic machining.

Keywords— ultrasonic machining, high initial investment, materials, machining parameter, MRR, Surface finish

I. Introduction

The machining of super alloys, ceramics, glass etc. to their final dimension by conventional methods is extremely tough, laborious, time consuming, and generally not possible. Advanced machining processes have emerged to beat these difficulties. Tight tolerance and dimension with acceptable surface are sometime only attainable at great cost. There are few machining methods available that ensure high efficiency and accuracy, but special machining methods to accomplish these are required to accomplish this. The ultrasonic machining is one of the viable processes for the precision machining of these materials because of its unique characteristics. Due to high investment and operating costs, there is an economic need to operate the ultrasonic machine as efficiently as possible in order to obtain the invested pay back. The success purely depends on the selection of machining process parameters. Proper selection of process parameters plays a significant role in ensuring the product quality, reducing the machining cost, increasing productivity.

Ultrasonic machining is a non-traditional machining process within which abrasives contained in slurry are driven against the work surface by a tool oscillating normal to the work surface at low amplitude (25-100 microns) and high frequency (15-30 kHz). It is preferably used to machine hard and brittle materials having hardness greater than 40 HRC with good accuracy and reasonable surface finish. Generally the tool is pressed downward with a feed force, F between the tool and work piece. The machining zone is flooded with hard abrasive particles within the water based slurry. The abrasive particles, as they indent on the work material, the material get removed if the work material is preferably brittle. Figure 1 shows the basic elements of an USM setup. During indentation, due to Hertzian contact stresses, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the work piece. The tool material should be such that indentation by the abrasive grits does not lead to brittle failure. Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and different ductile metallic alloys. In addition, abrasive should be made harder.

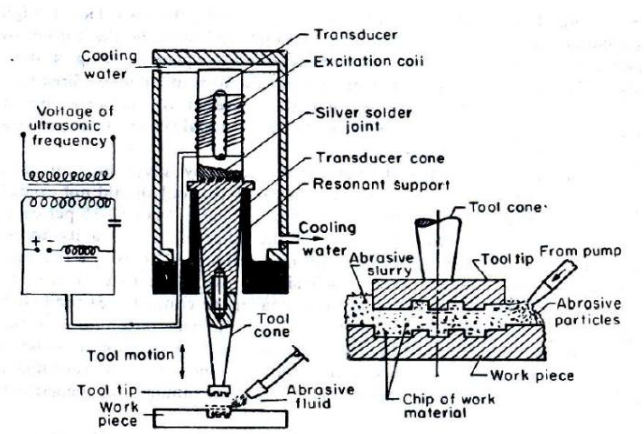

Figure 1: Schematic diagram of Material removal mechanism

II. REVIEW OF LITERATURE

M. Adithan and V. C. Venkatesh [1] presented the production accuracy for ultrasonically drilled holes affected by the continuous wear of the abrasive particles in the slurry and by tool wear. The effects of certain important parameters such as static load, machining time, type of abrasives, grit size were taken on dimensions of the workpiece and accuracy. It was concluded that the machining accuracy depends to a large extent on the abrasive grit size and to a lesser extent on the amplitude of vibration and the static load. Finer abrasives resulted in reduced oversize and increased accuracy of the holes of machined workpiece. M. Komaraiah et al [2] conducted experiments on different work materials –glass, porcelain, ferrite, alumina using various tools- titanium, stainless steel, nimonic 80A. The surface roughness of the different work pieces were analyzed with respect to hardness of the tool material and abrasive used. The results showed that surface roughness decreases with decrease in the grain size and harder tool material gives low surface roughness. R. Singh and Khamba [3] used Taguchi design to model the tool wear rate during ultrasonic machining of titanium and its alloys. The input parameters such as tool material, power rating, slurry type, grit size, slurry temperature, slurry concentration, were identified to give output in the form of tool wear rate. The interactions among input parameters were considered for developing the model. The results of the Taguchi model were used for preparing a mathematical model of tool wear rate by Buckingham's theorem.

V. Kumar [4] used design of experiment and regression approach for the statistical analysis of the ultrasonic machining of Glass. The response of the material removal rate of the glass was identified with the range of different parameters such as power rating, abrasive type, abrasive size, and slurry concentration. It was found that the grit size was most vital parameter and slurry concentration was the least significant parameter and having minimum contribution to the MRR It was conjointly ascertained that the carbide have additional impact on MRR as compared to the mixture of aluminium oxide + silicon carbide. The 60% power rating resulted in better MRR as compared to 20% and 40% slurry concentration. This might result to it additional power rating could lead to additional erosion of the work. The grit size of 280 resulted in more MRR as compared to the 400 and 600 grit size. V. Kumar and Khamba [5] applied the Taguchi multi-objective technique for determining the optimum combination of various input factors such as type of abrasive slurry, their size, slurry concentration, tool material, and power rating of ultrasonic machine for ductile chip formation in the machining of co based super alloy such as satellite work material. The optimum parameter values obtained were: Tool material; Titan 31, Abrasive slurry; B_4C, Slurry concentration; 30%, grit size; 220 and power rating; 125 W. J. Kumar and Khamba [6] evaluated the metal removal rate under the controllable experimental condition-power rating, tool/abrasive type, abrasive size, and slurry concentration. A macro model was developed by applying the Taguchi technique. The outcomes of the macro study was used for further development of the micro model by using Buckingham's theorem that was used for predicting metal removal rate in terms of tool hardness, power rating and slurry hardness factors. It was found that MRR in ultrasonic of titanium is directly related to the energy input rate for the particular process setting. A high level of input energy rate promotes the brittle fracture of the work surface.

R. S. Jadoun et al [7] investigated the effect of process parameters on the ratio of material removal rate to tool wear rate by the Taguchi model. The machining was carried out on the alumina based ceramic with silicon carbide abrasive. The Parameters considered were work piece material, tool material, grit size, power rating, and slurry concentration. The outcomes of the research were that cutting ratio decreases with increase in alumina content in the work piece and decrease in power ratio. The cutting ratio increases sharply as grit size increases from 220 to 320 grit size. Dam et al [8] investigated effect of ultrasonic machining on production rate, tool wear, and surface quality of ceramics. It was found that for tough material the low productivity, high tool wear and low surface roughness are obtained. For brittle material the relationship is reverse; high productivity, low tool wear rate and high surface roughness are obtained. It was also found that the lesser machining rate tends to give a lesser surface roughness. R. chakravorty et al. [9] used four methods such as weighted signal-to-noise (WSN) ratio method, Grey Relation Analysis, multi-response signal-to-noise (MRSN) ratio, (UT) utility theory methods for optimizing multiple response of ultrasonic machining and compared with the relative performance of these methods. The results showed that WSN or UT method gives better optimization performance for ultrasonic machining and WSN method is preferable to the UT method because it involves lesser computational complexity. M. A. Majeed et al [10] used acoustic emission monitoring while ultrasonic machining of $Al_2O_3/LaPO_4$. The metal removal rate and microstructure of work material were analyzed using different shapes of tool. Boron carbide as abrasive with grit size -280 mixed with water in ratio 1:3 was considered as machining setting. The results found that with the use of hollow tool as compared to the solid tool gives an appreciable enhancement in metal removal rate.

H. Lalchhuanvela et al [11] used central composite second order rotatable design for ultrasonic drilling of high alumina ceramic. Response surface methodology was employed for developing mathematical models of metal removal rate and surface roughness. The abrasive grit size, slurry concentration, power rating, tool feed rate, and slurry flow rate were considered as machining parameters. Material removal rate and surface roughness was evaluated by using the ANOVA. The results showed that higher level of slurry concentration, slurry flow rate, and higher abrasive grain high power rating gives higher MRR. The surface roughness decreased with decrease of slurry concentration, slurry flow rate, and higher abrasive grain. B.L. Ramu et al. [12] investigated tool penetration rate and tool wear rate under the significant parameters such as abrasive of boron carbide of 280 grit, slurry characteristics, and different tool material with static loading. Zirconia ceramic and cold impact alumina were taken as work piece in ultrasonic drilling. It used piezoelectric crystal type dynamometer for measuring the dynamic forces on work pieces and tool materials. It was found that higher hardness of Zro_2 results in lower material removal rate as compare to Al_2O_3.

Adithan and Krishnamurthy [13] investigated the surface integrity of glass workpieces by X-ray diffraction. The abrasive type, abrasive grit size, slurry concentration, amplitude of tool vibration, and frequency were consider as machining parameters. It was found that with increasing static loads, the out-of-roundness increased at the exit side and decreased at the entry of the ultrasonically drilled hole. Surface roughness of the hole increased with increasing static loads. R. S. Jadoun et al [14] investigated the effect of process parameters on the production accuracy (hole oversize, out-of-roundness and conicity) obtained through ultrasonic drilling of holes in alumina based ceramics using silicon carbide abrasive using the Taguchi model. The machining was carried out on the alumina based ceramic with silicon carbide abrasive. The parameters considered were work piece material, tool material, grit size, power rating, and slurry concentration. The optimal levels of various process parameters for minimum out-of-roundness were: work piece material; 70% Alumina, Tool; Tungsten carbide, Grit size; 500, Power rating; 40%, Slurry concentration; 30% and the optimal levels of various process parameters for minimum conicity were: work piece material 50% Alumina, Tool; Tungsten carbide, Grit size; 500, Power rating; 40%, Slurry concentration ; 25%.

Dvivedi and Kumar [15] used Taguchi method for experimentation and analysis of surface quality in ultrasonic machining of pure titanium and titanium alloy. It was found that the effect of slurry concentration and abrasive grit has played a significant role on the surface finish of titanium work piece. Surface roughness increased with an increase in abrasive slurry concentration. Kainth et al. [16] proposed a static and complicated model using the abrasive particle size distribution. An analysis was carried out considering the non uniformity of abrasive grains to assess the relation between the removal rate and static load/amplitude. Its calculations yielded approximately a linear relation between material removal rate and static load. Abrasive grains were assumed to be spherical, whereas actually the grains were of an irregular shape. The amplitude of vibration was remained constant with increase in static load. It was found that predicted linear relationship between MRR and static force F that was practically not true. Predicted linear increase in with grain size, while and optimum value exists. Theoretical machining rate was higher than practical values. M. A. Majeed et al [17] used acoustic emission monitoring for ultrasonic machining of Al2O3/LaPO4 composite with various percentage range of LaPO4 content. The machinability was analyzed with the different parameters such as abrasive of boron carbide with fixed grit size and 33% of slurry concentration. Low carbon steel was taken as tool material. The outcomes found that with the use of the more percentage of LaPO4 content material in composite, machinability additionally increases. Power spectra associated with monitoring acoustic emission clearly indicated good machinability along with 70: 30 composite.

J. Kumar and V. Kumar [18] investigated tool wear rate of pure titanium (ASTM Grade-1) under the effect of different process parameters such as tool material, abrasive material, slurry concentration, abrasive grit size and power rating. It was concluded that abrasive type and grit size found to be almost equally significant over the tool removal rate. Use of Silicon carbide as abrasive resulted in more tool wear rate as compared to alumina. R. Singh and Khamba [19] used L18 orthogonal array of Taguchi design to model the material removal rate during ultrasonic machining of titanium alloys. The metal removal rate was identified with the controllable parameters such as power rating slurry concentration, tool material, slurry material, slurry temperature and their size. These controllable parameters were optimized by the Taguchi approach. It was concluded that for greater metal removal rate ultrasonic power rating is the more significant factor with contribution of 28%, followed by types of tool, and slurry types. The optimum results were obtained with stainless steel tool. M. Adithan [20] investigated the behaviour of certain specific tool and work material combinations with respect to tool wear (longitudinal and lateral) under the influence of different parameters in ultrasonic drilling. The different combinations of workpiece and tool material used were 1. Tungsten carbide (WC) - Stainless steel 2. WC – WC 3. Glass - Stainless steel 4. Glass - WC. The results found that when softer materials such as glass or porcelain were machined only longitudinal wear occur. When hard materials such as tungsten carbide were machined both longitudinal and lateral wear occurs.

T.C. Lee and C.W. Chan [21] found the amplitude of the tool tip, the static load applied and the size of the abrasive effects on the material removal rate and the surface roughness. The micrographs were used to evaluate the significant effects of the given parameters on the metal removal rate and surface roughness. It was concluded that static load applied and the grit size of the abrasive resulted in an increase in the material removal rate and a roughening of the machined surface. Chander Nath et al. [22] studied the influence of the material removal mechanism on hole- integrity of structural ceramics like silicon carbide, alumina, Zirconia. Different types of tool were used with the constant parameters of the ultrasonic machine for study of metal removal rate, longitudinal and diametrical wear. It was found that the material within the lateral gap of the hole was removed by the angle penetration and the rolling actions of the abrasives. Both the entrance chipping and the wall integrity of USM holes were due to the radial and lateral cracks that propagate away from the tool periphery in the radial direction. At the top surface of the hole- cavity, the remaining portion of the cracks was appeared as entrance chipping.

M. Komaraiah and P. N. Reddy [23] conducted the experiments to study the influence of static loading, tool hardness in both the conventional and rotary USM modes keeping all other parameters constant. Mild steel, titanium, stainless steel, silver steel, Nimonic-80A, maraging steel and thoriated tungsten were taken as tool materials. It was found that the material removal rate increases with increase in the hardness of the tool material. The diametric wear resistance increases with increase in the hardness of the tool material. The roughness of the machined surface decreases with the employment of a harder tool material. The brittleness ratio of the workpiece material influences the roughness of the machined surface. The lower the brittleness ratio, lower the surface roughness. P.L. Guzzo et al. [24] studied different brittle and hard materials (Alumina, ferrite, Lif, Quartz, soda-lime glass, zirconia) to reveal the influence of structural and mechanical properties of workpiece materials on the rate of material removal and the topography of machined surfaces. The roughness profiles were measured with a Rank Taylor Robson profilometer. Scanning electron microscopy (SEM) was employed to characterize the micromechanisms related to material removal under ultrasonic abrasion condition. It was observed that the rate of material removal was abruptly decreased with the machining depth for workpiece materials in which hardness was at the same order of magnitude than the hardness of abrasive grits.

Soundararajan and Radhakrishnan [25]showed that direct hammering of the abrasive particles on the workpiece by the tool, resulting in material removal and particle crushing, may contributes up to 80 % of the stock removal in brittle solids such as glass. Cavitation effects from the abrasive slurry and chemical action associated with the fluid employed have been reported as minor material removal mechanisms. Material removal rate, surface finish and machining accuracy are influenced by various operational parameters such as amplitude and frequency of ultrasonic oscillations, static load applied on the sonotrode, tool design, hardness and size of abrasive particles. H. Hocheng et al. [26] carried out experiments on Zirconia ceramic for finding metal removal rate, hole clearance, surface roughness, tool wear rate of the workpiece. The results found that the metal removal rate increases with the increase of amplitude of the ultrasonic machine. At constant amplitude, the clearance decreases with applied load. Better surface roughness can be obtained by the 50% range of amplitude. An increase in applied load leads to decrease in hole clearance. And the larger the static load is favorable for a finer surface. M. Ramulu [27] investigated the effect of slurry hardness on metal removal rate of silicon carbide ceramics with the significant parameters such as work material properties, tool properties, amplitude of vibration and static load. It was concluded that use of boron carbide abrasive resulted in material removal rates which were approximately 75% higher than the silicon carbide abrasive for the 400 grit size and 320% higher for 220 grit size while machining silicon carbide ceramics.

D. Jianxin and L. Taichiu [28] investigated the properties and microstructure from the workpiece materials about the MRR and surface roughness in ultrasonic machining associated with alumina-based ceramic composites (Al_2O_3/TiC, Al_2O_3/TiB_2, Al_2O_3/ (Ti, W). It was found that the composites with high fracture toughness showed lower MRR while the particle reinforced ceramic composites showed the higher MRR and surface roughness. The whisker orientation played an important role on the MRR. As the direction angle ranged from 0° to 90°, a decrease in MRR was observed. The angle equal to 90° resulted smallest MRR, and the angle equal to 0° resulted higher MRR. B. Ghahramani and Z. Y. Wang [29] investigated method mechanism and dynamics of ultrasonic machining. The photoelastic technique was employed to simulate the tool within the ultrasonic machining process by impacting a grit particle in contact with the workpiece. The objective of this check was associated with the stresses developed within the subsurface of an Al_2O_3 workpiece (material) hammered by one abrasive particle attributable to the force of the vibratory tool and to investigate the characteristics concerned within the material removal method throughout ultrasonic machining. Experimental simulations were done to analyze the mechanisms of material removal involving the dynamic impacts of the abrasives from the high-frequency vibrations and also the impact mechanism of abrasives forced by the hammering action of the vibratory tool. Simulation testing of the material removal mechanisms concerned within the USM method may be an appropriate technique for getting essential data with relation to material morphology and also the stress characteristics at the subsurface.

III. CONCLUSIONS AND FUTURE SCOPE

USM process is purely depends on the work material properties mainly hardness and fracture toughness, tool properties (hardness, impact strength and finish), abrasive properties (hardness, coarseness and viscosity) and process settings (power input, static load, amplitude and frequency of vibration). The success in terms of MRR and Surface roughness purely depends on the selection of machining process parameters. Proper selection of process parameters plays a significant role in ensuring the product quality, reducing the machining cost, increasing productivity. The machining of materials such as Glass, super alloys, ceramics, Tungsten carbide etc. to their final dimension by conventional methods is extremely tough and generally not possible. To overcome such kind of problems USM can be utilized. Some others materials i.e.titanium, titanium alloys and other tougher and harder materials such as nickel alloys, polycrystalline diamond compact etc for their wide application in the various kind of industry.

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