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Parameter Affecting Ultrasonic Machining

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***Abstract*- The ultrasonic machining is the technique generally used in the machining of the brittle workpiece material by the repeated impact of the abrasive particle on the workpiece material. Unlike the other non-traditional machining process such as the electric discharge machining, chemical machining, electrochemical machining it will not thermally damage the workpiece nor it chemically damages the workpiece and also it will not appear to introduce the significant amount of the stress.The material removal rate and the surface finish of the USM have been influencing by many parameters which include the property of the workpiece material, size of the abrasive particle amplitude and frequency of the vibration tool, slurry concentration, tool material,and the static load. In this article, a review has been reported on the parameter such as the abrasive grain size, slurry concentration, amplitude and frequency of the tool vibration and the static load on the machining parameter of the ultrasonic machining such as the majorly discuss is the material removal rate and the surface finish these parameters are definitely would influence the selection of the different non-traditional machining process and also it will influence the selection of the various parameter that is desirable for their product in the industries.**

INTRODUCTION

Ultrasonic machining is the non-conventional machining process and generally, it is preferred for hard and brittle material preferably having the hardness above 40 HRClike semiconductor, glass, quartz, ceramic, silicon, germanium, ferrite,etc. It is Generally Associate with Low material removal rate,however, its application is not limited by the electrical or chemical characteristics of the workpiece materials. It is used for both conductive and non-conducting materials, The holes as small as 76 μm in diameter can be machined using this machining process, wherein this machining process the depth to diameter ratio limited to 3:1.

The history of ultrasonic machining (USM) starts with the initiation of by R. W. Wood andL. Loomis in 1927 and the first patent was awarded to L. Balamuthin 1945[4]. The USM is now been used has ultrasonic drilling, ultrasonic cutting, ultrasonic dimensional machining, ultrasonic abrasive machining,and slurry drilling. Whereas in past days it was called the ultrasonic impact grinding or USM [4].

The ultrasonic machining can be used for anyoperations that require conventional metal removal techniquesif certain unwanted effects can be eliminated or at least reduced. The Ultrasonic machining is based on the principle that when a tool vibrating at a very high frequency is brought closer to the workpiece with abrasive particle between them, the vibrating energy of the tool can propel the abrasive particle to strike the workpiece with great velocity. The impact of the abrasive particles furthers the hard work surface resulting in the removal of material from the workpiece. When comparing to that of another non-traditional machining process the ultrasonic machining process is unique because of its suitability for the brittle material such as glass, ceramics, carbides, precious stones, hardened steels,etc., are difficult to machine byconventional methods. USM is that process where it is not involved with the thermal, nor chemical or it creates no change in the microstructure, chemical or physical properties of the workpiece and it also offers virtually stress-free machined surfaces. These features enable hard and brittle materials to be economically and efficiently machined, which otherwise would have been difficult to shape by conventional methods.

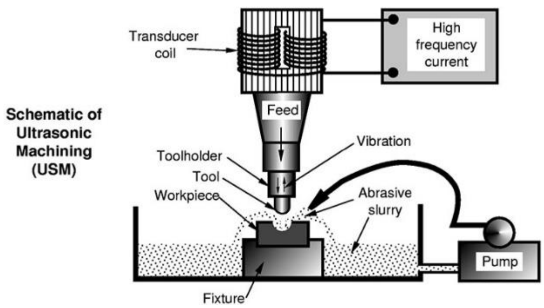

Figure 1: Schematic of Ultrasonic Machining process.

The USM process first carried out with the conversion of the low-frequency electrical power to anoutput of high-frequency electrical signal, which is then moved to a transducer. The transducer converts the high-frequency electrical signal to a high-frequency frequency mechanical motion, which in turn is amplified by the means of the waveguide that is nothing but the horn, and then transmitted to the tooltip. The tool, which is having the same shape as the cavity to be machined, vibrate or

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oscillates at a very high frequency in the abrasive slurry pumped between the tool-work interference.

Then the vibration of the tool transmits a high velocity to the abrasive particles, and as a result, the abrasive particle strikes the workpiece with the great force. This impact fracture the hard and brittle worksurface resulting in the removal of the material in the form of small wear particles. The individual abrasive grains that come into contact with the vibrating tool acquire high velocity and are moved towards the work surface. High-velocity bombardment of the work surface by the abrasive particles gives rise to the formation of the amplitude of tiny highly stressed regions, leading to a fracture of the work surface, resulting in material removal. The magnitude of the induced stress into the work surface is proportional to the kinetic energy of the particles hitting the work surface. Thus, a brittle material can be more easily machined than a ductile material[5]. The abrasive slurry flowing at the cutting zone carries away the fractured particles. The tool is pressed against the workpiece by applying a slight force, while the abrasive slurry is being pumped in at low pressure till the operation is completed.

In the non-traditional machining techniques such as electric discharge machining and laser beam technique has been employed in the industries and the advantages of the using the USM is the ability of this machining process to machine the brittle materials more often the non metallic materials, and many machining techniques has the limitation of the heat-induced techniques which are not preferable for some operation because it causes the change in the microstructure of the workpiece and also it also induced the thermal stress on the workpiece, so the USM process is preferred because in this process there is no use of the chemical nor any thermal interaction with the workpiece, and also as this method can be used for both non-conducting as well as conducting materials.

LITERATURE REVIEW:

Slurry concentration and size of abrasive particle

In the work by Kennedy&Grieve[1] shows that the grit size hardness and the concentration of the abrasives have certain relationships with the machine rate.

With the help of a graph between the machine rate and the concentration of the slurry, it is shown that the cutting rate is proportional to the low concentration of the slurry and thusbecomes independent when the concentration reaches 30-60 percentage by volume.

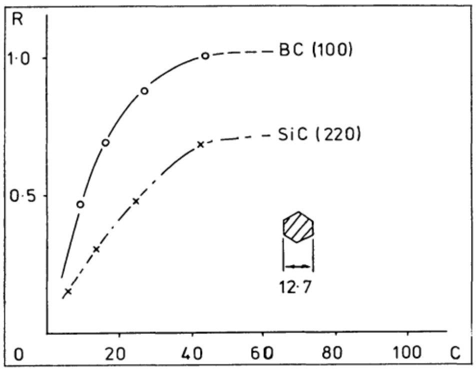

Figure 2: Machine rate(R) as a function of Concentration(C), where the material used is Soda glass

Kennedy &Grieve[1] states that the machining rate depends upon the microhardness of the abrasive particle.In above figure shows the rate of machining with respect to the concentration of slurry when using the Soda glass has an abrasive particle, Where we can see thatthe machining rate of boron is taken as unity then the silicon carbide has the rate of 0.8-0.85. It is being noted that the material removal rate is depended on the grit size and also there is an increase in machine rate with the increase in grit size, but they noted that there is a decrease in machine rate when the above optimum size of grit size is used and decrease is dependent on the amplitude of the tool.

The slurry distribution has influence in the material removal rate, It is stated that when machining takes place inside the bath of slurry the availability of the abrasive grain is reduced between the tool and workpiece result in low machining rate, so this can be reduced by using of Internal feed system as shown on figure(2)where it is noted that the material removal rate has increased with the use of this system which improves the grit concentration between the tool and the workpiece.

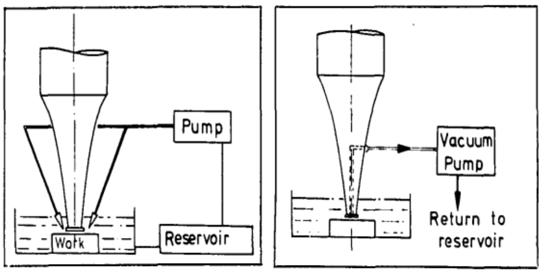

Figure 3:Slurry system left-jet flow, right-suction flow

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As shown in the figure(3) the suction type slurry flow system is used most preferred type in industries where it has improved machining rate.

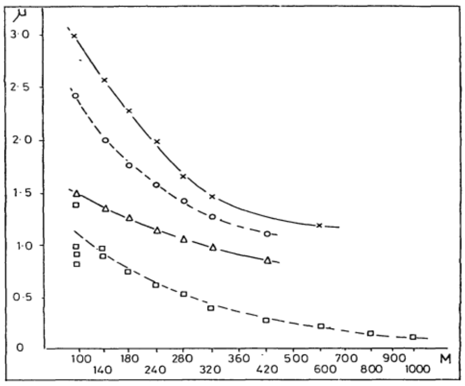

Figure 4: Surface finish as the function of the grain size of Boron carbide when machined with various materials. Key: X-Glass, 0- silicon- semiconductor, Δ-ceramic, □- hard alloy steel

The above figure(4) shows that change in the grit size would affect the surface quality than another parameter, Kennedy & Grieve[1] state that an increase in the grit size would decrease the surface finish of the workpiece.
Komaraiah et al.,[2] are conducted experiment on the conventional and rotary ultrasonic machining and they study about the surface roughness in ultrasonic machining,

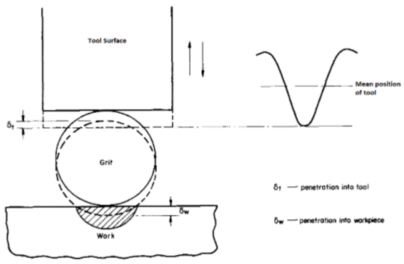

Figure 5: Schematic representation of impact in Ultrasonic Machining.

They conducted an experiment on various material and using that they plotted the graph between the surface roughness and the Grain size(grit number) and this is shown in the figure(6) below.

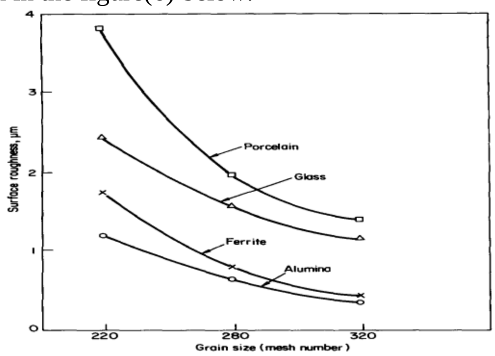

Figure 6: Effect of the grain size on the surface roughness. The tool used is stainless steel of 5mm diameter and a static load of 1.25kgf.

In the figure(6), the order of increase in surface roughness is seen where it takes the order of carbide, alumina, ferrite, glass,and porcelain.So this property can change the fracture property and material property of the material. Komaraiah et al., [2] conducted the experiment by using the Sic has the abrasive particle which has the mesh number of 280 with the help of the Italy surf and finds out the following results as shown in figure(7).

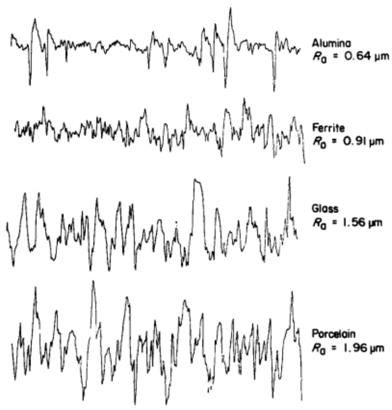

Figure 7: Surface roughness on the workpieces, Tool used is stainless steel and the abrasive material is Sic.

$$\delta w = (d - x)/(1 + q)$$

Where δw- Depth of indentation.
d- Average size of the Grain.
x- Distance between the tool and workpiece.
q- Ratio of work hardness and tool hardness.
Wherefromthe above equation shows that the increase in δw will increases with an increase in the abrasive grain, so larger the abrasive grain more the material removed and so lesser the surface finish of the material, Thus the higher surface Roughness due to the larger the Grain size. George [3] in his work has come with the equational method for describing the different parameter, wherein his work describing many parameters, In which he mentions the abrasive particle size has one of the parameters,

$$N = \frac{\pi r A Y x}{2v^2 \rho_a v d^3 (x+1)}$$

In the above equation where N represents the effective number of particles under the tooltip. Where d is the abrasive particle size, ρa is the density of the abrasive. So the abrasive particle will affect the number of particles in the tooltip, This is explained by Miller[3] has the effect of the steric hindrance which causes the accumulation of the particles in the tooltip, has N is directly proportional to the √(3d).

$$(TN) = \frac{\pi r A Y x}{2v \rho_a v d^3 (x+1)}$$

So in the above equation 'T' represents the number of particles per cc of slurry where 'd' represents the abrasive particle size, so 'T' is proportional to $(\sqrt{(3d)})^{-3}$.

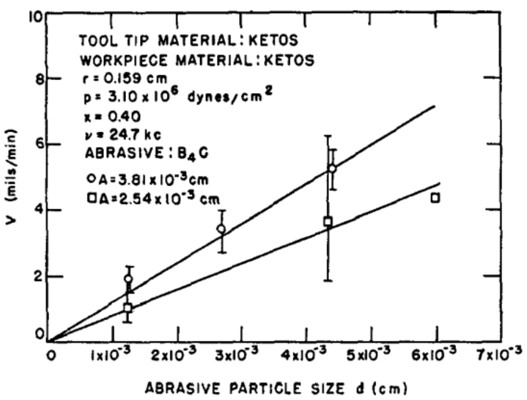

Figure 8: Machining rate vs the abrasive particle size.

So Miller[3] explains the machine rate with the abrasive particle size with the Figure(8).Which states the increase in the abrasive particle size results in an increase in the machining rate.Thoe et al., [4] in there review paper explains the slurry feed as that the slurry is fed to the ultrasonic machining by the pumping action or through the jet flow as shown in the figure(3), and they stated that the slurry not only carries the abrasive particle but also perform the action of coolant for the horn, tool,and workpiece, and supplies the fresh abrasive to the cutting zone and removes debris from the cutting area. The slurry also provides a good acoustic bond between the tool, abrasive and workpiece, allowing efficient energy transfer.
Thoe et al., [4] has explained the abrasive particle diameter to be equal to that of the amplitude in order to obtain the optimized the cutting rate, so above the optimum value, the

MRR decreases results in a reduction in the size of the abrasive grain reaching the tool interface and insufficient slurry circulation. They stated on the material removal rate as that the abrasive particle should be harder than the workpiece and also states that the larger abrasive grit size and a higher concentration of slurry yield higher MRR. On increasing the abrasive grit size of slurry concentration, an Optimum MRR is reached. Any further increase in both of these results

Table 1: Various parameter of the abrasive particle with 320 mesh abrasive[4].

Sl number	Workpiece Materials	Hardness Hv	Surface roughness Rs(μm)	Recommended Abrasive	MRR(mm^3/min) 5mm diameter tool	MRR(mm^3/min) 10mm diameter tool
1	Graphite	65	1-2	Sic/B_4C	164	224
2	Silicon oxide	500	0.85	Sic/B_4C	39	50
3	Aluminium oxide	1000	0.9	Sic/B_4C	7.6	9.3
4	Zirconia	1100	0.75	B_4C	0.65	3.1
5	sialon	1500	0.4	B_4C	1.2	1.8
6	Sodium carbide	2400	0.3	B_4C	0.6	3.5

in the reduction of the MRR. The optimum concentration of the slurry is 30% is recommended[4].where the low concentration will reduce the chances of blockages in the nozzle.Kazantsev[5] noted that forced delivery of the slurry increases the output of USM and also five times without the increase in the grit size increase. And it is noted that the suction pump also provides higher MRR with upto 2-3 times more than the pump type USM[7].

The tool used in the abrasive material should have the lower limit of about 5 times the grit size[4], The tool wear generally occur due to abrasive particle nature harder the abrasives, like boron carbide, cause higher tool wear than softer abrasive like silicon carbide for a tool of the same cross-sectional area[4].The tool hardness also affects the penetration of the abrasive grain into the tool result in higher workpiece MRR.

Thoe et al.,[4] has also explained that the surface finish or accuracy are affected by the abrasive grain size and adds that the decrease in the abrasive grain size result in the lower material removal rate which is shown in the figure(9) and also the decrease in the abrasive grain size results in the machine hole accuracy and explains that the low abrasive size increases better surface finish at the bottom face than on the walls of the cavity and states that when feed rates and the depth of cut decreases which result in the better surface finish, for the workpiece is a hard ceramic, a slightly better surface finish can be obtained than with a material of lower hardness than higher harness material.

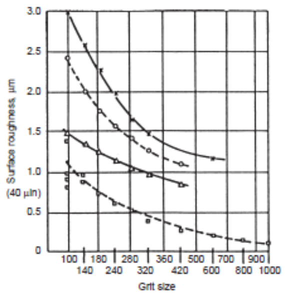

Figure 9: Effect of the surface roughness vs grit size for boron carbide-for the Workpiece material (X-glass, O-silicon semi-conductor, Δ-ceramic, □-hard alloy[4].

Boron carbide is considered as the fastest cutting abrasive and it is also the commonly used cutting abrasive[6]. Whereas aluminum oxide and silicon carbide are also used as abrasive extensively, because of the costly nature of the boron carbide where it costs 29 times higher than that of aluminum and silicon carbide[6]. The abrasive particle concentration varies from 30-60% by volume of the slurry concentration. The concentration will vary for the tool area.

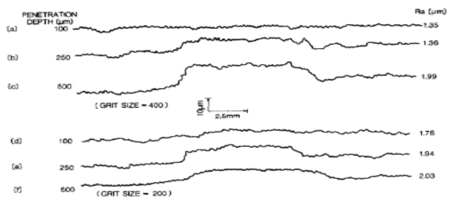

Figure 10: Section of the surface profile of HSS[7].

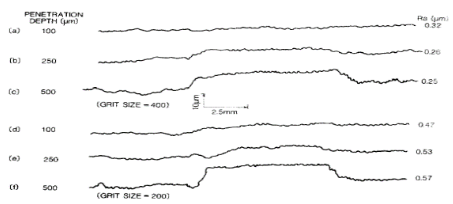

Figure 11:Section of the surface profile of the glass[10].

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The concentration will be low for higher tool area, to avoid circulating difficulties. He[6] states that the grit size is the important parameter which determines the surface finish and material removal rate of the material, and he added that experimentally it is proved that the grit size of 200-400 is used for roughing operation whereas 800-1000 is used for finishing the operation.

Khairy[7] has conducted many experiments and in which he uses the glass and high-speed steel has the work material SiC has the abrasive of 400 grit size, In his experiment he concludes that the material removal rate of HSS is in the range from 3.1% to 0.96% of the grit size of 200 and 400 respectively, and also claims that the rougher the grain size, higher the material removal rate rougher the machined surface. In his experiment for the grit size of 200 and 400,he observed that the surface profile at the beginning of the workpiece and at the middle and the end of the machining time for both grit sizes were found out in order to know more about the influence of the working mechanisms. Which is shown in figure(10 & 11), in both the figure it is observed that the as the increase in the penetration depth of the workpiece there will be an increase in the material removal rate for both the material like glass and HSS and for both the grit size of 200 and 400. And it is been observed that the penetration at the upper surface will be less as well as the material removal rate.

Jatinder kumar[8] in his comprehensive review paper on the ultrasonic machining explains that the in addition to the conventional abrasive Boron carbide, aluminum oxide, silicon carbide, for more precision machining and for very hard workpiece materials, cubic boron nitride or diamond powder is also used as the abrasive particle and their property is shown in the figure below

Table 2 Abrasive Used in USM and their property[8].

Abrasive	Knoop hardness	Relative cutting power
Diamond	6500-7000	1.0
Cubic Boron Nitride	4700	0.95
Boron Carbide	2800	0.50-0.60
Silicon carbide	2480-2500	0.25-0.45
Alumina	1850-1920	0.14-0.18

He[8] further stated that slurry should be of low viscosity so that it efficiently flows when drilling deep hole or forming complex cavities an also provide good wettability and high thermal conductivity and specific heat for efficient cooling. It is stated that the most commonly used concentration has 50%[8] by weight. The abrasive is stored in the tank and then supply to the USM machine and by pumping action to the tool work interference at the rate of 3.5L/min[8].

Das et al.[9] has conducted the experiment on the ultrasonic machining where they use the alumina (AL_2O_3) has the workpiece material, where the tool is used is of stainless steel of 20 mm long ad the experiment is carried out with different abrasive diameter where the boron carbide is used as abrasive.

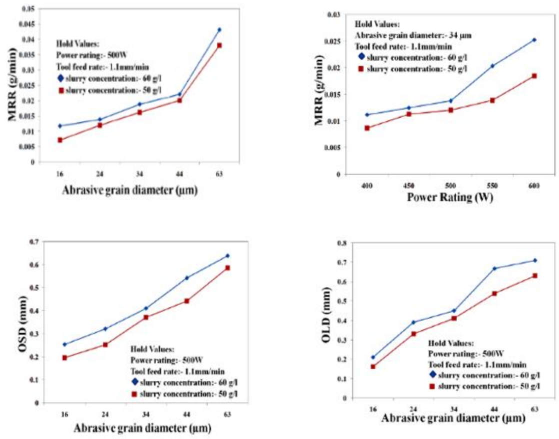

Figure 12: Variation of the different parameter on two different slurry concentration.

The above figure(12) represent the experimental result of how the MRR changes with the grain diameter change as the diameter of the abrasive particle increases there will be more MRR, due to weight of the coarse grain size is high the kinetic energy will be high so due to which MRR will be more. He[9] states that the MRR also depends on the slurry concentration. If the slurry concentration is high then the MRR increases. Similarly in the figure(12) shows the effect of the abrasive particle on the OLD (overcut of the large diameter) and the (OSD)overcut of the small diameter, from the graph it is shown that the fine-grain diameter gives low value of the overcut that is both (OLD and OSD) where coarse grain give the higher value of the overcut. A number of the researchers have tried to develop the theories to find out the characteristic of the ultrasonic machining.

The model proposed byShaw[10] is the well-accepted model, despite its limitation it explains the material removal reasonably well.In his model, he considers the impact of the abrasive particle into the workpiece and he assumed that all the abrasive particle are identical in shape and spherical in nature, and also all the impacts are identical in shape. From the above figure(13) D-represents the diameter of the indentation, h-represents the depth of the indentation and d-represents the diameter of the

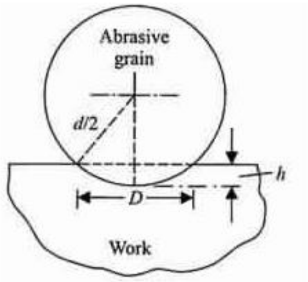

Figure 13: Scheme of the idealized grain indentation.

abrasive grain.Shaw[10] with some of the numerical methods find out the relation between the material removal rate and many other parameters that defines the USM process, and that equation is given below.

$$Q\alpha \frac{dF^{3/4}A^{3/4}C^{1/4}}{H_W^{3/4}(1+\lambda)^{3/4}}$$

Where Shaw[10] assume that the rate of work material removal is proportional to the volume of the work material per impact, The equation mentioned below shows, the parameter affects the MRR in the USM. So from that parameter the slurry concentration and also the abrasive grain diameter affect the MRR, from the equation we know that the MRR should be rise proportionally with the mean grain diameter (d), where when d become too large and also nearer to the value of the amplitude A, then the crushing tendency increases and result in the fall in the MRR. This is shown in the below graphs.

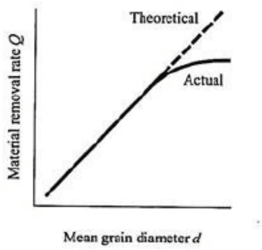

Figure 14: Variation of the MRR with the grain diameter.

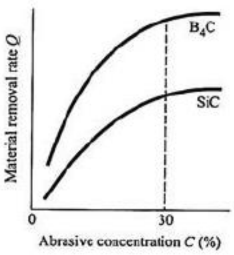

Figure 15: Variation of the MRR with the slurry concentration.

So the concentration of the slurry means the number of the grain-producing the impact per cycle, and so the MRR depends on the concentration, and it is proportional to $C^{1/4}$. so for the B_4C and SiCabrasive, the variation of the MRR and the concentration graph is shown above figure, so it is seen that the concentration of the slurry crosses above 30% there is a reduction of the MRR rate.

Das et al., [11] have performed the USM operation on the flat zirconia as the workpiece which is 58.5*58.5*5.1 thick, where they used the boron carbide powder of different grit size and mixes with water at the room temperature has the abrasive particle. Where the tool of the vibrating frequency of 20 kHz and the amplitude of 12-50μm is applied, Das et al. [11] used the response surface modeling to develop the empirical model and they have been uses establish the mathematical relationship between the response and the various machining parameters. The parameter influences on the various response criteriaare as follows:

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$$Y_u = \beta_o + \sum_{i=1}^{n} \beta_1 X_{iu} + \sum_{i=1}^{n} \beta_2 X_{iu}^2 + \sum_{i=1}^{n} \beta_{ij} X_{iu} X_{iu} + e_u$$

Where Y_u is the corresponding response and the $X_u$represents the coded values of the i^th^machining process parameters, the terms used as β_0, β_i, β_{ii}, $\beta_{ij}$are the regression coefficients and the residual, where the abrasive grit size(X1), slurry concentration(X2), power rating(X3), and the tool feed rate(X4) are considered as the process parameters.

Table 3 Design of Experimental values of the process parameters and observed response.

Exp.no	Process parameters with uncoded value				Response	
	Grit size (µm)	Slurry Conc (g/l)	Power rating (W)	Feed rate (mm/min)	MRR (g/min)	Ra (µm)
1	34	40	400	0.84	0.1401	0.71
2	24	45	350	1.2	0.1231	0.55
3	16	40	400	1.08	0.1241	0.63
4	44	35	350	0.96	0.1587	0.89
5	24	35	350	0.96	0.121	0.53
6	24	45	450	0.96	0.1213	0.52
7	24	35	450	0.96	0.1203	0.56
8	34	40	400	1.08	0.1372	0.63

Where the below table(3) shows the experimental results of the response obtained by the various parameter which is obtain by the above equation. The table(3) show beside shows the various number of the experiment carries out considering the different girt size abrasive particles and different slurry concentrations to find the Material removal rate and surface roughness.

DebkalpaGoswami and Shankar Chakraborty[20] in there review paper explains the paper of the Das et al..[11] andrepresent the experimental values into the graphs which are shown in figure(16 & 17).

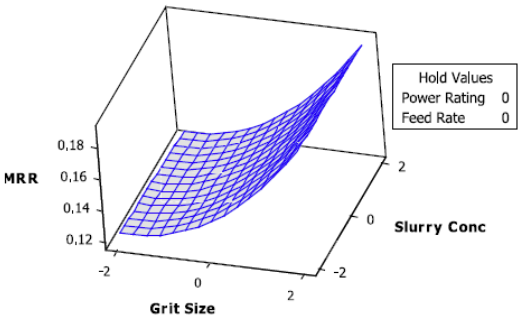

Figure 16 Response surfaces for MRR

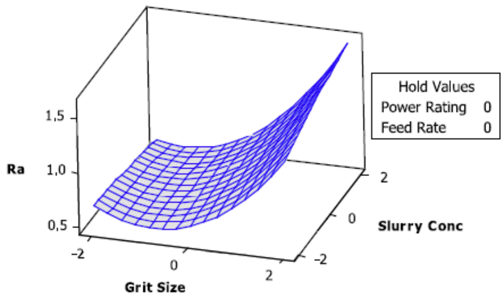

Figure 17: Response surfaces for surface roughness.

STATIC LOAD

According to THOEet al., [12] a static load is applied to an abrasive slurry which consisting of a mixture of abrasive material examples are boron carbide which are suspended in oil and water and the tool is made to pumped around the cutting zone. Resulting in material removal by microchipping.Which is caused when the vibration of the tool causes the abrasive materials held in the slurry between the workpiece and the tool to impact on the workpiece surface. USM set up was made using either a piezoelectric transducer or magnetostrictive with screwed tooling or wit brazed.According to him the theoretical static force required for the formation of cracks for sliding indentation is greater than in brittle materials.

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He has shown that in practice with other parameters constant an increase in static load from zero,gives an liner relationship

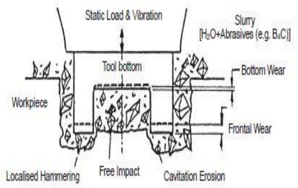

Figure 18: USM mechanism

between MRR and static load. Above a optimum value owing to reduction in size of the abrasive grains reaching the tool interface and insufficient circulation in slurry the MRR also decreases. From Fig(19) the optimum static load for maximum MRR has been seen that it is dependent on tool size and shape. He also suggested that the use of a value smaller than the optimum value helps in increasing the tool life and reducing the abrasive wear.

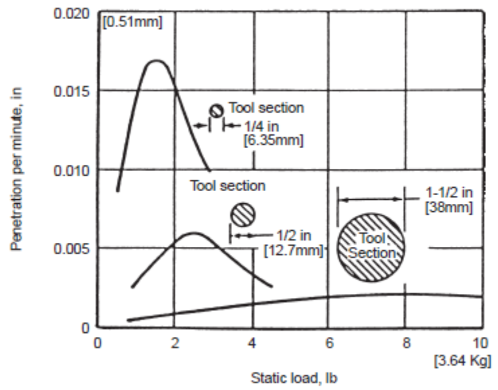

Figure 19: Penetration v/s Static load graph

According to Komaraiahet al.,[13] at different loads experiments were conducted, and the out-of-roundness were obtained Fig(20). The increase in static load results in reduction of out-of roundness of the drilled holes. This is because, at higher static load the vibration of the tool are reduced. And due to crushing action, the size of the abrasive particles is reduced. With decrease in grain size there is a natural improvement in the geometry of the already drilled hole. The main reason behind increasing the static load is that it is recommended for the finishing cuts.

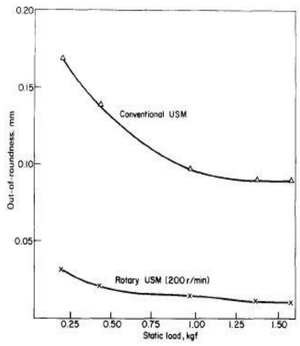

Figure 20: Effect of static load on out-of-roundness in the rotary and conventional USM

According to GS Kainathet al.,[14] He showed that by direct impact of the tool, the bulk of the material is removed . He assumed that the volume of material "V" dislodged per impact is directly proportional to the rate of material removal "v". The tool frequency "f" and the number of impact per cycle "N". Assuming the mean grain diameter "d" and the grains to be identical. He expressed the MRR as

$$v\alpha[dh]^{3/2}Nf,$$

Where "h" is the depth of indentation. It is found be equating the mean static force to the mean of the tool on grains. Assuming particles in working gap is inversely proportional to square of diameter of each particles f0r a tool of fixed area. He gave the above expression for h.

$$\left[\frac{8F_s y_o d}{\pi KHC(1+q)}\right]^{1/2},$$

He measured contact force and concluded that rate of machining varies linearly with static load up to a certain optimum load.

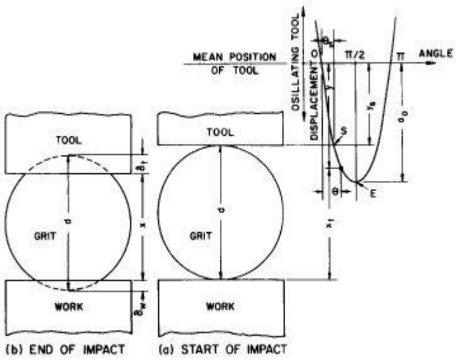

Figure 21: Figure shows the abrasive particle before and after impact.

Machining rate is calculated by varying static load. The resulting graph is shown in Fig(22). The curves indicates that with increase in static load the machining rate also increases. However in practice the machining rate first increases with static load .But it falls further,when static load reaches an optimum value.

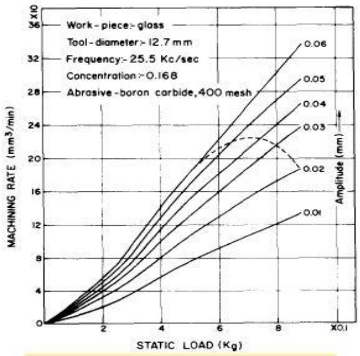

Figure 22:Variation of machining rate v/s static load

According to Ya et al., [15] Fig (23). Shows in the tool end face the vibratingcondition of each abrasive particle. At the beginning the indentation depth of abrasive particle vibrates up and reaches a highest point in sine curve under application of static load.

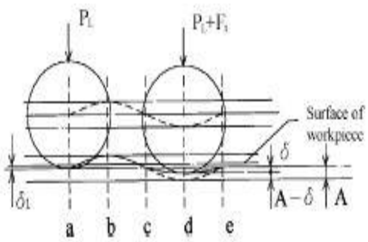

Figure 23: Movement of abrasive particles.

It imparts surface of the workpiece when it is vibrating downwards to the lowest point and reaches the maximum indentation depth. During this, maximum shock force is produced. During contact between workpiece and abrasive particle due to rotational motion of tool the particle scratches a groove on the surface.

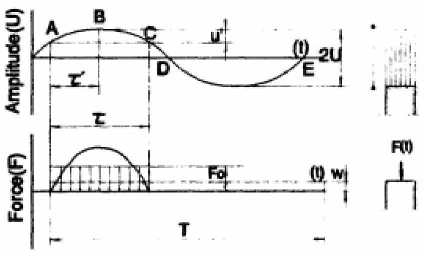

Figure 24: tool tip vibrating state and the diagram of the forces

According to LEE [16]. Fig(24) shows the shocking force bound is bound with the vibrating condition of tool tip. Here F is the average shocking force, T is the vibrating cycle, U is the amplitude of the tool tip, W is the static load and t is the shocking time.

According to law of conservation of momentum:

$$W.T = \int_{ta}^{tc} F(t)dt$$

The average shocking force $F_o$is

$$F_o = \frac{1}{\tau}\int_{ta}^{tc} F(t)dt$$

So that

$$F_o = \frac{W.T}{\tau}$$

At 1.5 kg the tool has peaked off due to the effect of static load applied on the tool. Thus for a greater MMR the heavy static load may not contribute. With increase in static load the amplitude of the tool vibration decreases and the shocking time lengthening, concluded that the effect of static force is complicated. Moreover when the static load is heavy the tool vibrates improperly. Normally the value of static load lies in between 1kg and 1.5 kg.

According to work ofJain[17], Fig(25) shows with increase in average static load the machining speed also increases, however beyond a certain value the machining speed decreases.

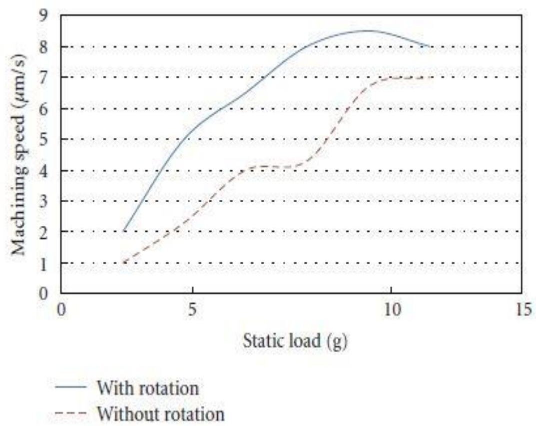

Figure 25: Machining speed versus static load for rotation and non-rotation USM.

Variation of observed MR as a function of static load

Fig [26] shows the variation of observed MR as a function of static load for two types of load. In both types of load with increase in static load machining rate also increases. In case of hollow tool the MR is more. This is because of necessary contact area between the tool and the abrasives. And correspondingly between workpiece and abrasives.

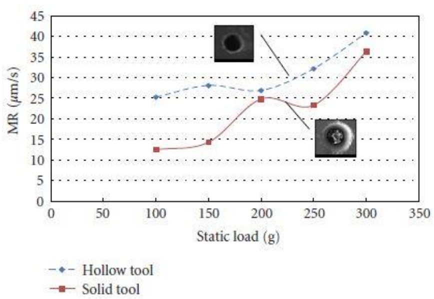

Figure 26: The variation of the metal removal with the static load.

By considering the work of the Yu et al., [18] have done the experiment to determine the machining characteristic by changing the machining parameter. In there experiment setup consist of the ultrasonic machining vibrator with the X,Y,Z stages and the electronic balance has the static load sensor.

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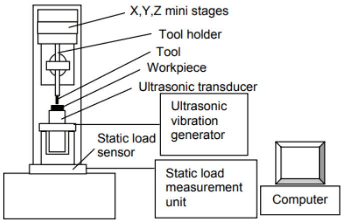

Figure 27: experimental setup.

The above experimental conditions and the materials used in the experiment is Tungsten and the diameter of the tool is 95μm rotation speed of the tool is 3000 rpm. And the workpiece material is Silicon. The abrasive particle material is Polycrystalline diamond. It is a extreme hard material under high temperature and high pressure. Here the 3% of Abrasive particle is taken for every 97% of water. Here the specific gravity of Abrasive particle is 3.47. And the Youngs modulus of Tungsten and Polycrystalline Diamond is 405GPA and 853GPA.

With this experiment the machining parameter is drawn with the change in the static load and results are noted in the form of the graphs as shown below.

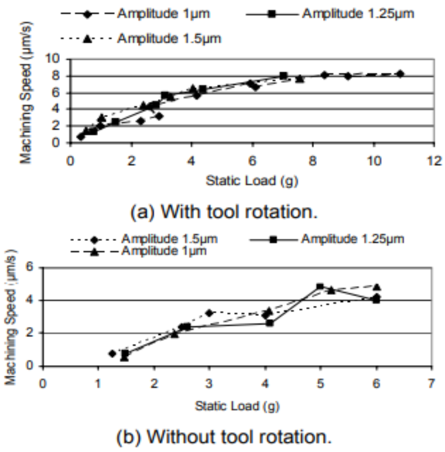

Figure 28: Experimental result obtained with respect to the rotary and non-rotary USM.

Where the figure(28) shows the machining speed with respect to the static load with the different in the amplitude, where the amplitude change is not significant but the increase in the static load would increase the machining speed for both the rotating and non-rotating USM, and it is also observed that the machining decreases with the increase in the static load above certain value.The machining speed increases with an increase of the average static load. However, the machining speed decreases with the increase of the average static load beyond a certain value. The debris accumulation in the working area leads to a part of the static load consumed in impacting the debris instead of removing the material from the workpiece, resulting in a lower machining efficiency. The rotation of tool improves the machining speed significantly as shown in Figures(29)(a) and (b). The tool rotation helps the debris removal and, therefore, increases the machining speed.

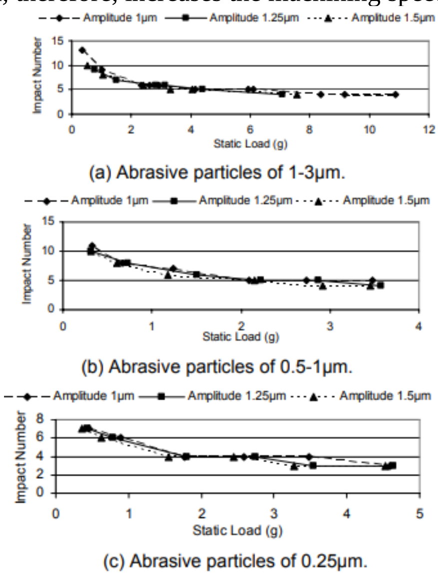

Figure 29: number of the impact with the static load.

It is seen from the figure(29) that the number of impacts will decrease with the increase in the static load.

AMPLITUDE AND FREQUENCY

Neppiras[19] explain in his paper about the power required to produce a constant amplitude will also increases with the square of the frequency, upper threshold will be there in the frequency above due to which the efficiency will fall rapidly. This upper frequency is well inside the audible range and it is therefore not feasible to use it for actual machine tools. In general, we should choose a frequency which is low and just above the audible limit, which is, just above 20 kc/s.

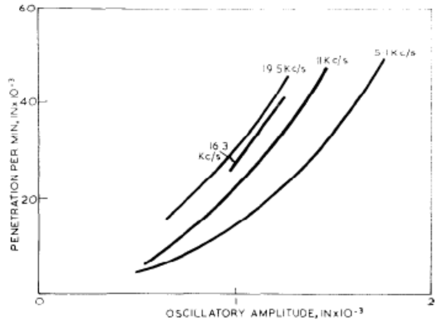

Figure 30: Cutting rate increases as the square of the amplitude at any given frequency of vibration

The Figure(30) shown above explains the dependence of cutting rate on the oscillatory amplitude and at a constant steady pressure.The characteristic is almost a square law, as might be expected. From the simple physics it is easy to show that the process cutting rates should increase as the square of both oscillatory frequency f , and amplitude A, and linearly with the steady pressure, *P*, and abrasive grit size, at least for cutting rates sufficiently low for the penetration per cycle to be small compared with *A*. But this condition will hold good for almost all practical machining operations.

Neppiras[19] explains that In the operation of lapping, the lapping tool or plate is vibrated at very low amplitude; surface finishes have been improved by a factor of up to three. Also says that, The Russians did thoroughly investigated the influence of amplitude of vibration and of feed rates on accuracy and surface finish. They quote an average improvement in surface finish of almost an order of magnitude and a great increase in the maximum feed rates at which the surface finish was acceptable.

From work of DebkalpaGoswami et al., [20] he stated that In USM process as the low-frequency electrical energy is first converted to a high-frequency electrical signal, which is then fed to a transducer. The high frequency electrical energy is transformed into mechanical vibrations by transducer, which are then transmitted through an energy-focusing device. This will cause the tool to vibrate along its longitudinal axis at high frequency. The tool and tool holder are designed considering to their shape and mass that resonance will be achieved within the frequency range capability of the machine for efficient material removal rate.

On the other hand, with the increased values of frequency of vibration, mean diameter of abrasive grains and volumetric concentration of abrasive particles in slurry material removal rate will be increasing. Therefore, the expected value of maximum Material removal rate can be obtained at higher values frequency of vibration.To maximize the value of material removal rate subjected to given SR constraint,

DebkalpaGoswami[20] Considered amplitude of ultrasonic vibration, frequency of ultrasonic vibration, mean diameter of abrasive particles, volumetric concentration of abrasive particles and static feed force of an USM process as the control parameters.With using artificial bee colony(ABC) The optimization of USM process was also carried out, particle swarm optimization (PSO) and harmony search (HS) algorithms, and the results obtained were compared with that of using GA.

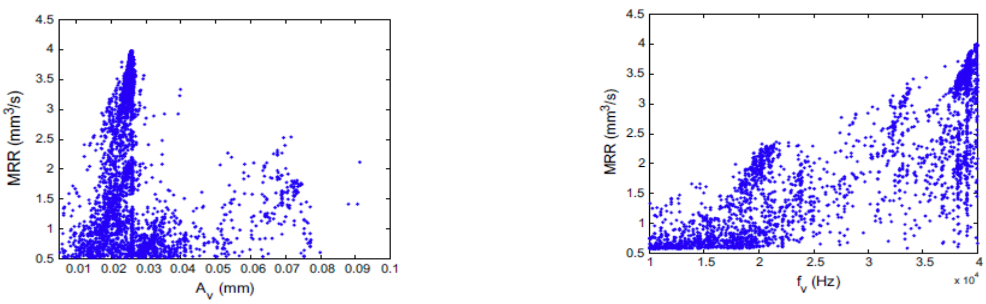

Figure 31: Effects of amplitude and frequency of USM process on MRR.

For the considered USM process figure (31), shows at lower values of amplitude of vibration and maximum MRR can be achieved.The considered optimal setting for process parameters were obtained as amplitude of vibration=0.0611 mm, frequency of vibration =40,000 Hz.
From RavipudiVenkata Rao et al., [21],The term ultrasonic is used to describe the vibratory wave of frequency above that of upper frequency limit of the human ear. Due to the action of abrasive grains material is removed in USM process. As the tool oscillates normally to the work surface at high frequency the abrasive particles is driven onto the surface of work.In USM process the model for the optimization is calculated based on the present work of model optimization considered by [21]. The five decision variables considered for this model are amplitude of vibration 'Av' (mm), frequency of vibration 'fv' (Hz), mean diameter of abrasive grain 'dm' (mm), volumetric concentration of abrasive particles in slurry 'Cav', and static feed force 'Fs' (N).

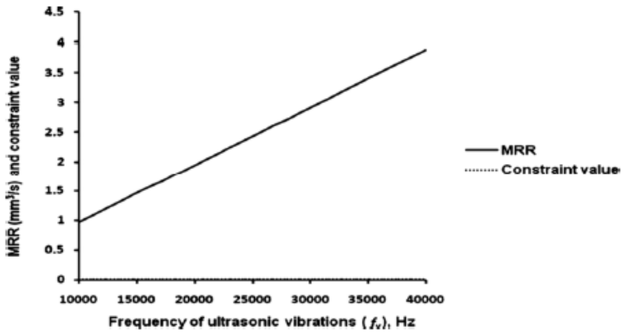

Figure 32: Variation of MRR and constraint value with frequency of ultrasonic vibrations

From Figure (32) above shows the variation of constraint value with frequency of ultrasonic vibrations and MRR. As shown in the Figure (32), as we increase the frequency the material removal rate also increases respectively. So the higher value of frequency is desired for the ultrasonic vibration. Also, as the surface roughness constraint is having a constant positive value, the selection of upper bound value frequency of ultrasonic vibration, i.e., 40000 Hz, is appropriate.

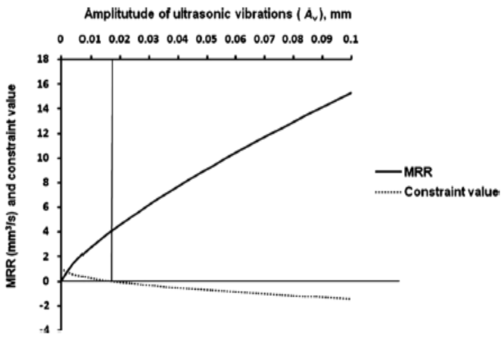

Figure 33: Variation of MRR and constraint value with amplitude of ultrasonic vibrations

Figure (33) shows the variation of MRR and constraint value with amplitude of ultrasonic vibrations. As shown in Fig (33), with increase in amplitude of ultrasonic vibration the MRR also increases. From this point of view, the higher value of amplitude should be selected. However, as shown in Fig (33) the constraint of surface roughness is violated for any value of amplitude of ultrasonic vibration more than 0.01614. Therefore, the optimum value of amplitude of ultrasonic vibration is equal to 0.01614 mm obtained by using the ABC algorithm is appropriate.To predict the effects of amplitude of the tool tip, the static load applied, and the size of the abrasive on the MRR and the surface Roughness [21] developed an analytical model. He concluded that with increase in the amplitude of the tool vibration, the static load applied, and the grit size of the abrasive would result in an increase in the Material removal rate and roughening of the machined surfaces.
From Singh et al., [22], In the USM process the conversion of low frequency electrical energy to a high-frequency electrical signal takes place, which is then fed to a transducer. The transducer is used to convert high-frequency electrical energy into mechanical vibrations, which are then transmitted through an energy-focusing device. This causes the tool to vibrate along its longitudinal axis at high frequency (usually ≥20 kHz). The tool and tool holder must be designed with consideration given to mass and shape so that resonance can be obtained within frequency range capability of the USM machine for efficient material removal rate.

The major USM process variables effecting material removal rate, accuracy, and surface finish are tool/horn design, power, amplitude, abrasive size and frequency. The amplitude (ξ) of the tool motion affects the material removal rate and obtains the maximum size of the abrasive particles which can be used. Therefore the amplitude should be equal to the mean diameter of the abrasive grit used in order to control cutting rate.

From [22] USM is assumed to be stress and damage free process, so it is recommended for contour machining as it can automatically adjust the output high frequency to match exact resonant frequency of the tool assembly. This also displays any small errors in set up and tool wear, giving minimum acoustic energy loss and very small amount of heat generation.

CONCLUSION:

This review paper has not presented any of the new work in the ultrasonic machining but attempt has been made to show the process parameter of the ultrasonic machining by collecting the information from various sources. Where in this review paper its main aim is to provide the information about the various parameter of affecting the ultrasonic machining which helps in the many industrial and the research which is oriented with the USM.

In this paper some of the important features of the ultrasonic machining are summarize as follows.

1. The mechanism of the ultrasonic machining, and the advantages of the USM with respect other non-traditional machining.
2. The process parameter that affect the MRR, surface finish, accuracy, machining speed and other important characteristics.
3. Effect of the abrasive particle size and the slurry concentration on the characteristic of the ultrasonic machining.
4. Effect of the Static load applied on characteristic of the ultrasonic machining.
5. Effect of the amplitude and the frequency on the characteristic of the ultrasonic machining.

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