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Ultrasonic Machining Process

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Abstract - **Ultrasonic Machining is the oldest form of machining process which can be used to machine brittle materials such as glass and ceramics. The paper says about Parametric Optimization of Ultrasonic Machining Process Using Gravitational Search, Latest Machining Technologies of Hard to Cut Materials by Ultrasonic Machining Process, Ultrasonic assisted milling of reinforced plastics, recent advancements in USM, Recent developments in micro USM. The parameters involved in it are MRR and Tool Feed Mechanism.**

Keywords: Ultrasonic Machining, Optimization, Tool feed mechanism, Metal Removal Rate.

I. Introduction

Ultrasonic machining, or strictly speaking the "Ultrasonic vibration machining", Ultra sonic machine is used mainly for machining Brittle material the process of material removal is done by USM is with high frequency and low amplitude with presence of abrasive particles. Ultrasonic machining (USM) is the removal of hard and brittle material it is an axially oscillating tool at ultrasonic frequencies [18-20HZ].During that oscillation the abrasive slurry of B4Cor Si C which is continuously sent to a zone where machining is done B/w a tool and a work piece .The abrasive particles are therefore Hammered into the work piece surface and from chips of particles from the surface of work piece.

Ultrasonic machining is usually used for machining brittle materials. Therefore they are generally used for material which s having high hardness .by this ultrasonic machining is done by help of micro cracking mechanism.

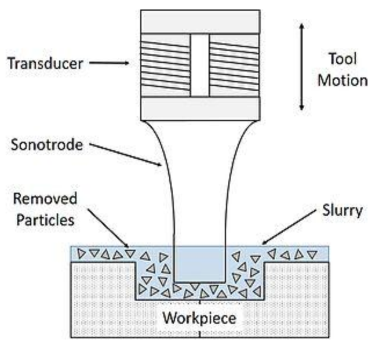

Figure 1: Ultrasonic Machining

Ultrasonic machining is basically operated by micro chipping or erosion on the work piece and abrasive slurry is continuously passed to the working zone which sufficient frequency and amplitude the slurry particles are in vibratory motion which will impact the surface of the work piece which will induce stress in it high stress contact area is usually achieved by fixing small gap between the slurry particle and work piece .USM is used to machining complex and intricate profiles. USM is used for machining brittle material such as single crystal, glass etc.

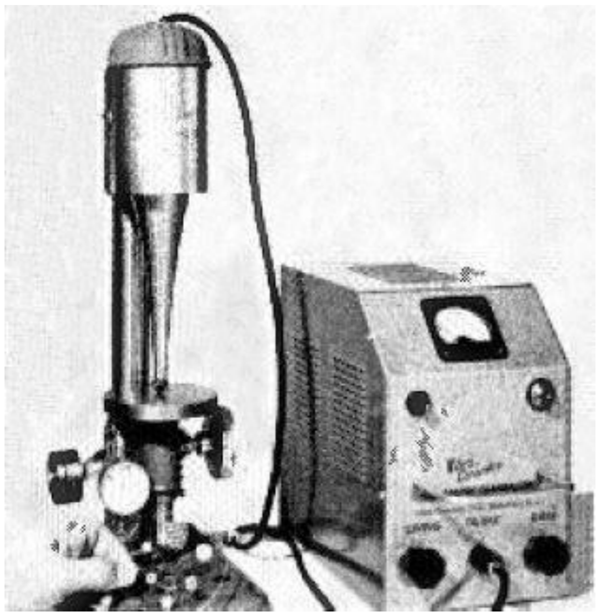

Figure 2: This is the oldest model if ultrasonic machining of 1955

II. Working Principle

When a tool is supplied with an electric current an high frequency will generate vibration of less amplitude and slurry is made to strike the workpiece with greater velocity on to the workpiece cause impact on the workpiece which leads to fracture on the workpiece surface and by this material is removed between the tool and workpiece the accuracy in shape and dimension of the workpiece can be obtained by giving small gap between the workpiece and tool. The tool s fed along the axis parallel to tool feed. In case of larger depth slurry weight is locked by 60% by help the slurry to flow over the given depth of workpiece.

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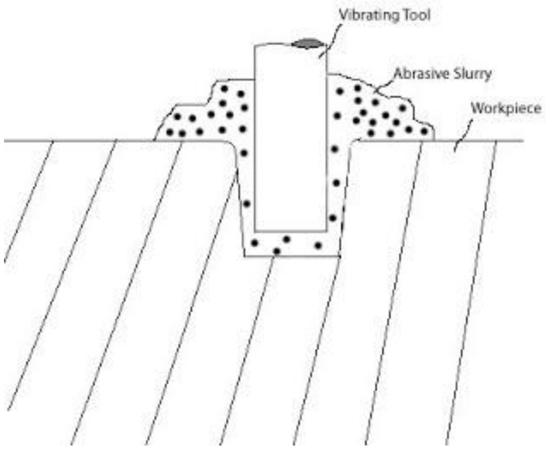

Figure 3: Shows that the working principle of ultrasonic machining process

III. USM Process

They are three different type of process involved in USM machining process which are listed below

- Converting low frequency of electrical power to high frequency electrical power and is sent to transducer
- In transducer will convert the high frequency electrical power to high frequency mechanical vibration motion
- These vibrations will be guide and amplified .and which is then supplied to the tip of tool

3.1 Types of USM

1. Rotary Ultrasonic vibration machining (RUM): In RUM, a vertically rotating tool is allowed to revolve about the axis of the sonotrode. The surface of the tool is impregnated with diamonds that is used to grind down the surface of the part. Abrasive slurry is not used in this type of machine for material removal.

2. Chemical-Assisted USM: In this machining, a chemically reactive abrasive fluid is used for the machining process.

3.2 Parametric Optimization of Ultrasonic Machining Process Using Gravitational Search

Debkalpa Goswami et.al.2015 according to them in increase of modern technology in fields of carbide, ceramics, and nominees in aerospace, nuclear it is essential to develop nontraditional machining process like ultrasonic machining process. Ultrasonic machining is a precision machine which does not creates change in thermal, chemical, or electrical properties in a material. This process makes low material removal rate and less surface damage. It is used to machine high hardness material and ductile material.

The ultrasonic machining is characterized for mainly low material removing rate and proper precise method should be maintained while the process. And the surface roughness also will be maintained in ultrasonic machining process. Singh and Khamba have studied about controllable machining parameters like power rating, tool type and slurry type etc.

Dvivedin and Kumar have studied working piece material, grit size, slurry concentration. The method of teguchi is applied to obtain parametric setting and optimized an ultrasonic machining process of genetic algorithm (GM). Studies on slurry concentration and slurry grit size and input parameters as the single response from ultrasonic machining process is made.

3.3 Latest Machining Technologies of Hard to Cut Materials by Ultrasonic Machining Process

Florian Feucht a et.al2014 according to them advanced materials are very demanding for machining technologies. And some of the key requirements in them are quality of parts and cost of a tool, process stability and reliability are also of particular interest for high value added parts.

Application of high performance ceramics and glass in several fields of industry is based on specially designed properties like temperature, stability and wear resistance and some of the vibration assisted machining has been shown in is best suited technology due to its lower process forces improved surface quality and reduced tool wear, an example for ultrasonic machining is deep hole drilling process. Ultrasonic machining is mainly used for aerospace technology and very demanding land suitable technology and used for drilling thin wall and light weight structures with good quality when compared to similar methods. Ultrasonic machining technology is been applied to trim the surface of other high valued added work piece.

Ultrasonic machining is used for high quality ceramic watch cases for high surface quality ceramic watch complex shaping. Ultrasonic machining is proven more efficient tool offering solutions to the challenges of advanced materials like compounds like titanium and aluminum. This material is increasingly applied to aerospace industry to produce faster and lighter aircraft and advanced surface of the engine outer body is made.

Ultrasonic assisted machining of this material has the potential to solve several challenges like large tool wear, high process forces and temperature tool and cutting-edge technologies.

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Ultrasonic machining process the machining of fiber reinforced materials or fiber pull out is more challenging. However, the free particles generated by the milling process have to be extracted from the cutting zone in order to not build up on tooling surfaces. This shows the integration, structure and effects of the ultrasonic technology for the machining of advanced and hard to machine materials.

There are two core elements is ultrasonic machining first is electronics, a frequency generator is integrated into the milling center, second one is and most notability is the ultrasonic actuator. This system is HSK tool holder with a piezoelectric oscillator. In the inhomogeneous character of fiber reinforced materials, it is very difficult to machine a composite material efficiently. Milling process can be performed by an advanced technique providing high precision edge and surface quantity in order to avoid to workpiece to brake due to high cutting speed of the cutter.

Therefore, due to high cutting speed there is a increase in a temperature and hence the cooling liquids are used. Ultrasonic oscillation is superimposed onto a conventional spindle rotation, the cutting edge of the tools are periodically lifted from the material this process reduces the force and allows the lower spindle due to fiber break up is delivered by the oscillation. Ultrasonic vibration of a tool prevented a buildup and therefore a clean cutting edge is maintained leading to almost no visible adhesion which results in constant machining process.

3.4 Ultrasonic assisted milling of reinforced plastics

According to E.Uhlmann et.al2017, as a demand for light weight design is increasing, especially in a transport industry, fiber reinforced plastic are applied due to their high specific strength, stiffness, toughness, fatigue, and creep resistance, wear and corrosion resistance, good attenuation properties'. Recent studies says that globally required quantity of carbon fiber reinforced plastic (CFRP) will double than from 58000 ton in 2015 to 2020. Aim of the presented work of ultrasonic of reinforced plastics are some below.

An approach, a suitable parameter field was defined and tests performed with uncoated cemented carbide tools by comparing the cutting forces and workpiece qualities. Milling tests were undertaken on a 5-axis milling machine from Sauer GmbH, Stipshausen, Germany type ultrasonic 260 composite with a rotational speed up to n = 30,000 rpm when using ultrasonic assistance. The ultrasonic actuators of the latest generation have five rings of piezo-ceramics and shrink chucks, which in combination results in an improved energy transmission and therefore a higher vibration amplitude at the tool tip. To ensure an effective and suitable dust extraction. This equipment contains a filter system, which guarantees an average dust concentration of less than 0.1 mg/m3 at the pressure-side of the extraction. The used milling tools from Hufschmied Zerspanungs system GmbH, Bobingen, Germany are specially developed for the milling of FRP and swing under optimized chucking conditions with a natural frequency of f = 22,130 Hz and an amplitude of almost A = 12 μm peak-to-peak. They made of uncoated carbide with a cobalt content wCo = 6 M-%, a hardness 1620 HV 30 and an average grain size dWC = 1.3 μm. Used workpiece material by bmw ag, munich, german y is a meshwork of carbon and glass fibres in an epoxy resin. The difference between conventional and ultrasonic assisted milling of fiber reinforced plastic was analyzed as carbon fibers having a diameter and angle and woven around the carbon fibre. To identify the effect of ultrasonic assistance, a suitable parameter field was identified for the trials. The parameters widths of cut are, depth of cut ap and feed per tooth fz were kept at a constant level. The first chosen cutting speed vc was set to a high value of vc = 377 m/min (n = 24,000 rpm). To generate a discontinuous cut at the tool tip, the vibration velocity must be higher than the rotational speed of the milling tool. Based on the kinematics of an ultrasonic supported turning process according to Brecher et al. A calculation was made to identify the cutting speed vc which enables a discontinuous cut (vc = 37.7 m/min). Initial values for this calculation were vibration frequency and amplitude.

3.5 Recent Advancements in Ultrasonic Machining

Pradeep Kumar et. Al (2015), in their paper wrote about the base mechanism used in USM by referring Soundararajan et al.'s investigation. It stated that material removal process for non-porous materials was done by direct hammering of the abrasive particles by vibrating tool and with very high velocity force on the workpiece material. For materials such as glass, it had high MRR and good surface finish.

Later by referring Lee's paper, they studied about ceramic materials USM. Their study shows that increasing the grit size of abrasives, tool vibration amplitude, and static load increase the MRR and this enhances surface roughness. It was reviewed later by Thoe et al. who showed that there is no damage to workpiece and that the process was stress free and free from any damages. He also stated that the tool used must have fine elastic strength, high wear resistance and fatigue strength. The slurry particles must not be too viscous, should have high sp. Heat for cooling. Higher the slurry conc., and higher the abrasives, MRR is also high. He stated that the horn and design of tool play a vital role in MRR. Combination of ultrasonic process with electric discharge machining, increases the metal removal rate for ceramic coated nickel-based alloys.

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In case of magnesia stabilized zirconium, increase in speed of tool rotation or decrease in abrasive particles and their diameter, increase in MRR can be seen. Geo investigated and found out that using of kerosene, increases the surface roughness of materials. He found that USM gives the best cutting operation than others. Jianxin explored that ultrasonic and diamond saw turning gave better surface quality than electro-discharge machining. Beak experimented on enhancement of surface quality of the glass in USM by Sacrificing Coating. The coating of wax is done on the glass so that if any scratches are formed, it forms on the wax layer and not on the glass. Hence, he proved that wax coating gives better surface finish for brittle and hard materials. Finally, Egashira tested on drilling holes of less than 10 micro meters without damaging the workpiece and the tool. This was possible with ultrasonic machining easily.

3.6 Recent Developments in Micro-Ultrasonic Machining

Vivek Jain et. al (2011), In their paper, wrote about the below mentioned topics by referring various review papers. Micro Ultrasonic Machining is derived from macro Ultrasonic Machining; it finds its huge advantage in machining of non-conductive, brittle and hard materials which are having capability to generate surfaces free from thermal damage.

This process has a high edge over the highly competitive LIGA process and applicable to a broad range of materials. Ultrasonic Machining is an old machining process technique, which has evolved and variously termed as Ultrasonic Machining, Impact Grinding or Slurry Drilling which depends on cutting action of slurry flowing between the vibrating tip of a transducer and workpiece. USM has wide range of applications in aerospace, optics and automotive fields. The first USM tools mounted on drilling and milling machines was built during 1953-1954. By 1960s, USM was used independently used in variety of applications. During mid 1990s, for the very first time, micro USM technique was coined by Masuzawa of Tokyo University. Micro USM is similar to Macro USM but it requires very small sized tool, smaller amplitude and micro sized abrasive particles.

3.7 Micro USM Process

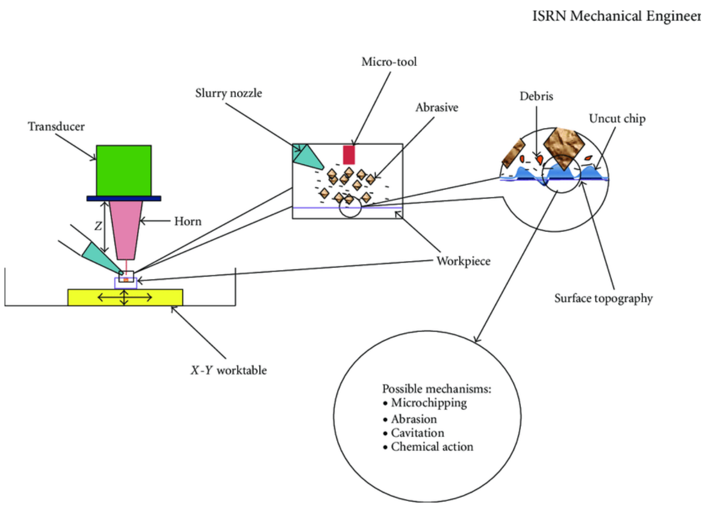

Figure 4: Micro USM Process

The above Figure shows the setup of micro USM process, it consists of a tool system and slurry supply unit. It employs the vibration of the ultrasound with a frequency range of 20-40 kHz. The tool is mechanically vibrated at an ultrasonic frequency and amplitude of few micrometers.

3.8 Developments in Micro USM Machine Tools

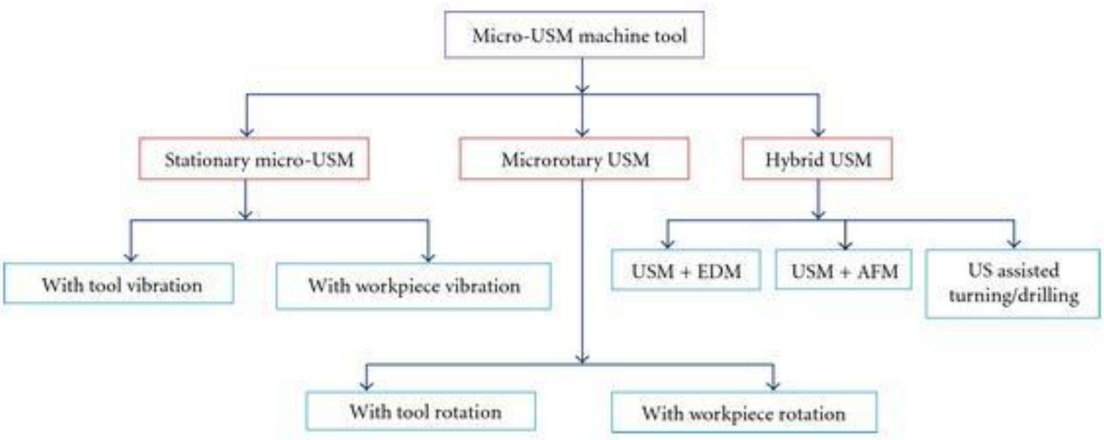

Figure 5: Developments in Micro USM Machine Tools

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This type of machining comes from micro tool in which there is no rotary motion involved. Here a simple cylindrical shaped tool was used and only vibration was given to micro tool. Since USM has major drawback of tool wear, it leads to tool shortening and therefore imposes obstacles in maintaining consistent vibration amplitude at the tool tip. It varies at different locations along the tool axis and tool wear changes the place of tool tip and causes inconsistency. Applying ultrasonic vibration to the workpiece has made machining process preferable since it eliminates influence of tool wear on vibration amplitude on the tip in case of applying vibration to tool.

This further enhances machining by increasing the efficiency of abrasive particles around the machining zone and remove debris. Rotary USM as indicated below is a cost-effective and hybrid machining process for drilling holes. It combines the material removal mechanisms of diamond grinding and USM resulting in greater MRR.

Here the hollow tool can be given rotational motion also and it can even vibrate. Since the tool has rotation, it also has sliding and rolling contacts between abrasives and workpiece. This claims in better Material removal rate. The major requirements for micro- Rotary USM are the micro sized tool and a machining system capable of putting smaller loads on the micro tool with required control mechanisms and necessary feedback control's.

IV. Metal Removal Rate

Sanjay Agarwal et.al (2015), explained the mechanism of metal removal rate in rotary ultrasonic machining by studying the deformation and fracture point of brittle material like glass so, Agarwal studies the impression of indenter to know the hardness of glass crank resistance and other parameter of fracture of failure. The mechanism of MRR in ultrasonic machining mainly occurs by shocking moment and mechanics of abrasive as explained in figure.

$$P_c = \lambda \frac{K_{IC}^4}{H_v^3}$$

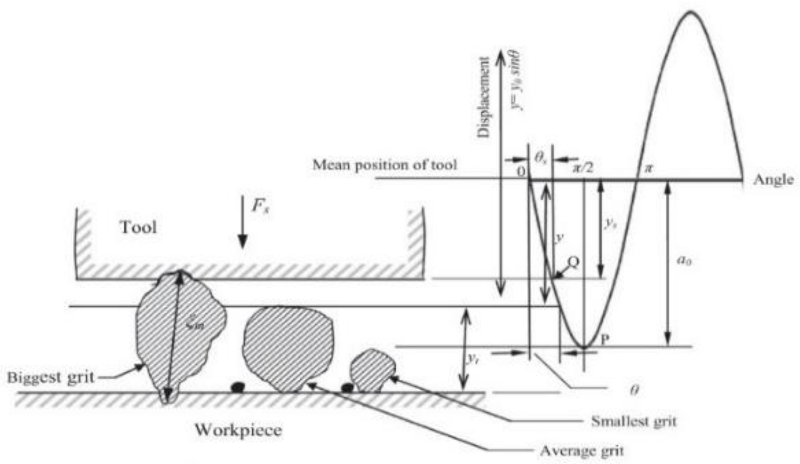

Figure 6: Material Removal Rate

Indentation is one of the most important events in MRR in ultrasonic machining process the process of initiation and propagation of crank and chip formation of brittle material is study with reference. The shear field helps in formation of crack which can be further classified into two components due to applied field and residual stress field. The residual stress component expression is expressed. The sum of the elastic and residual stress gives us the net stress acting on indentation. As they are two principal crack system median and radial cranks by the assumption made by penny was like the crank geometry the stress intensity factor residual field force kr.

And elastic field force *Ke* may be obtained in terms of factor *r* χ, *e* χ, p (shocking force) Pr (residual crank mouth opening force and other factor, the reversibility of elastic component and the irreversibility of residual term, as refer can be written for the irreversibility of residual term, as refer can be written for both loading and unloading condition he considered the loading and unloading conditions can obtain this expression. This provides the quantitative analysis of the median and radical crank system in indentation this model provides us the rationale differs between terms median and radial. By study made by S. Agrawal is reasonable to suggest that radical can be used or describing any property related to surface dimension so the above described study of indentation

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provides the practical knowledge of ultrasonic machining process of brittle material like glass.

$$P_c = \lambda \frac{K_{IC}^4}{H_v^3}$$

V. Theoretical Analysis for Shocking Force and MMR

This section is discussed on the development of analytical model for shocking force and for metal removal rate based on the mechanics of material removal in ultrasonic machining process.

5.1 Nature of Material Damage

In USM process, the mechanism of metal removal can be as discussed as the effect of impact of indentation and fracture. The impact indentation means that the grit pushed by the end face of the tool head parameter the work piece surface with a given speed. The impact is combined the effect of both grits and the tool head which energy and momentum pass through the grits to work piece. As shown figure the tool moves from it position Q it touches the larger grains, which forced into the tool comes to the surface of the work pieces. Amplitude a_0 from tool motion in sinusoidal.

$$Y = a\text{Sin } 0\ \theta$$

The force between the tool and the abrasive particles is effective small portion of the cycle and the free sinusoidal motion it was assumed that the motion of tool remain sinusoidal under the loaded condition, the force F_c acts between θ_s and $\frac{\pi}{2}$ as shown in figure. Total depth of indentation is given by

$$\delta w = a0 - y_s$$

Y_s - Distance between the tools has moved downward from its position.

VI. Geometry of Indentation and Real Contact Zone Width

Description of surface of work piece and behavior of grain is very difficult to predict due to random arrangement of grain. Some assumption was made to predict the MRR. As per the model the abrasive is a spherical budge as shown in Figure 2 grit diameter ξ help in knowing the type of abrasive particle. So, it is assumed that local spherical budges have a uniform diameter ξb

By indentation process the abrasive grit onto the work piece and tool. The spherical bulges contact b/w the work piece and tool from a contact zone b/w abrasive grit and work piece which is generally circular in shape and can be measured by its diameter indentation depth is characterized δ_w'

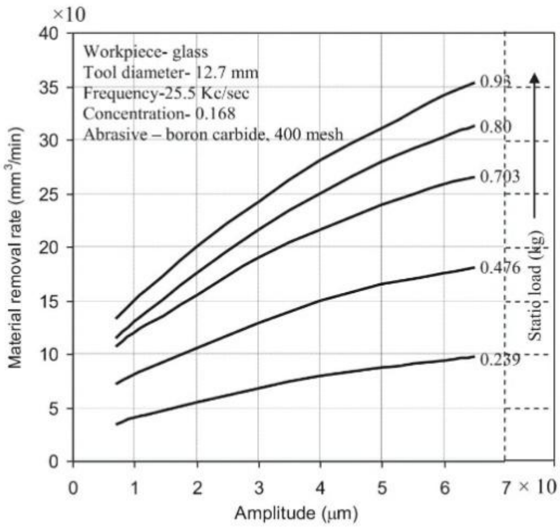

Figure 7: MRR vs Amplitude

6.1 Theoretical Results and Experimental Verification and Discussion

They took glass as model for testing because it's isotropy, homogeneity and general availability. Its young modulus is 70Gpa, Poisson ratio 0.17, hardness of glass is 505Gpa, fracture toughness is 0.75Mpa and material of tool was considered by taking mild steel. The parameter of cutting was considered.

6.2 Theoretical Analysis of Material Removal Rate

A theoretical analysis of material removal rate can be made by considering impact of abrasive grain of work piece and tool.

6.2.1 Nature of Material Damage

Figure 1 Shown the material removal rate mechanism of USM. Tool moves downward from it mean position which touches grain. When tool continues to move down force exert on the workpiece grain which result in fracture of workpiece he assumed the abrasive particles are incompressible and obtain the depth of indentation by using depth of penetration and tool motion with its amplitude by assuming the motion of tool is sinusoidal.

$$\delta_w + \delta_t = a_0 - y_s,$$

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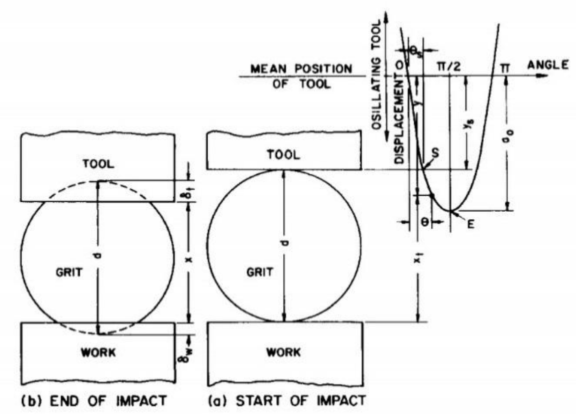

Figure 8: Mechanism of Material Removal Rate

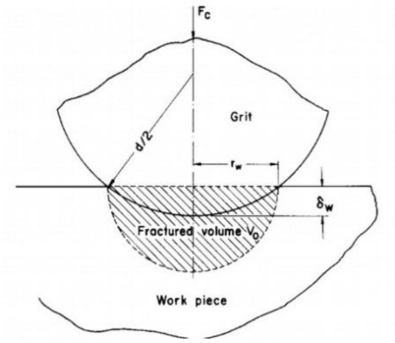

Figure 9: Geometry at Grit-Work Interface

6.2.2 Rate of Material Removal

Considering the grit-work interface after indentation fig 8 by taking radius of the contact indentation zone in the work piece assuming small volume fractured per grit. The active grain taking part in metal removal process are this having diameter b/w x and d_m so the MRR is given by

$$v = \frac{2.29Nf}{(1+q)^{3/2}\bar{d}} \int_{x}^{d_m} [(d-x)d]\left[1-\left(\frac{d}{\bar{d}}-1\right)^2\right]^3 \mathrm{d}d.$$

6.2.3 Average Number of Particles in Working Gap

The average number f particles N and the distance x need to be determined the number of particles N is found from the weight of abrasive particles of slurry.

$$N = \frac{C}{\left(\frac{1}{\rho_f}+\frac{C}{\rho_a}\right)}\left(\frac{\pi D^2}{4}\right)\left(\frac{\bar{d}}{0.57\rho_a}\right)\left(\frac{\bar{x}}{\int_{d_0}^{d_m} d^3\left[1-\left(\frac{d}{\bar{d}}-1\right)^2\right]^3 \mathrm{d}d}\right).$$

VII. Conclusion

As we see in ultrasonic machining process, it may be an old method or the latest advanced type of ultrasonic machining process. Ultrasonic machining is mainly used for machining brittle materials, glass, ceramics and metals. We can see the method of machining process in the article above, and its type of machining. Also we can the parametric optimization of ultrasonic machining process by gravitational search process, which is one of the advanced type of machining process and this process is limited for some extent due to complex procedure and requires a skilled operator, about it can be seen in detail and in further research we can even study about fire work ultrasonic machining process system. In the latest technology in ultrasonic machining process, we can see that the ultrasonic machining can even cut a thick metal when latest technology is used and we come to know about it. We can use ultrasonic machining process for milling and we can also mill the plastic in ultrasonic machining process. As time passes, the technology of ultrasonic machine also gets modernized and advancement in technology, so we can see some of the recent advancement in ultrasonic machining at present as given above. Ultrasonic machining is also used for micro components which can be milled or machined and the process, methods and its advancements can be seen above. We come to know about the process parameters of ultrasonic machining and its tool feed mechanism, and material removal rate of the various ultrasonic machining processes. We have provided some of the satisfactory pictures and graph for ultrasonic machining process above. These are some of the main topics of ultrasonic machining process which we have studied and worked on it, and we thus conclude our review report here.

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