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Influence of Proportion of Abrasive Particles in conveyor Liquid on Ultrasonic Cavitation Machining Process

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***Abstract*—Utilizing the energy which is released of collapsing a bubble to remove molecules (or atoms) from the workpiece surface is called cavitation machining (CM) process. This energy is applied to abrasive particles in liquid and threshes them to the workpiece surface. On the base of procedure the bubbles are produced, cavitation machining is classified in two categories: Hydrodynamic Cavitation Machining (HCM), and Ultrasonic Cavitation Machining (UCM). In these processes, Material Removal Rate (MRR) is effectively conducted by two categories of parameters: first, the parameters which are associated with abrasive particles, and the second, are the parameters which determine cavitation rate in conveyor liquid. Proportion of abrasive particles in conveyor liquid is an important parameter which is associated with abrasive particles. Altering the amount of abrasive particles in liquid can change Material Removal Rate (MRR). This paper shows experimental results on influence of proportion of abrasive particles in conveyor liquid on ultrasonic cavitation machining process. Also a proper ratio in which the material removal rate is maximized will be presented.**

***Index Terms*—Abrasive particles, Ultrasonic cleaner, Ultrasonic cavitation machining, workpiece surface.**

I. Introduction

ONE of the main reasons for using non-traditional machining processes is their capability in machining new engineering materials economically and efficiently. Appearance of new engineering materials in advanced technological industry, like aerospace, missile, nuclear reactors, turbine, and automobile industries, has led to more noticeable role of NTM processes in industrial environment [1], [2].

Conventional edged cutting tool machining processes often face difficulties in advanced industrial applications due to the following reasons:

(a) Low machinability of the newly developed engineering materials.

(b) Requirements for higher dimensional accuracy.

(c) Higher production rate and economy [3].

Possibly, the most important difference between conventional machining processes and non-traditional machining processes is the shape and size of chips. In NTM processes material is removed in the shape of atoms or molecules, individually or in groups, while in traditional machining processes the size of chips is relatively large. Hence, high precision and accuracy which are the requirements for modern industry cannot be achieved using conventional machining process, and in these cases, it should refer to NTM processes [1], [4].

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For the first time, Hadi [5] proposed the Cavitation machining method as a NTM process in order to pursue the aims of NTM processes.

Cavitation refers to the formation and subsequent dynamic life of bubbles in liquids subjected to a sufficiently low pressure. The required low pressure can be created either by an imposed acoustic field produced by a piezoelectric or magnetostrictive transducer or can be formed due to the flow of a liquid through a constricted passage as in a venture throat. Depending upon its origin, cavitation is termed as acoustic or hydrodynamic [6], [7]. Cavitation machining process is a method in which the energy released of collapsing a bubble is engaged to thresh the abrasive particles to the workpiece surface. This causes a molecular (or atomic) chip removal of workpiece surface. HCM and UCM are two methods of cavitation machining process.

To maximize the efficiency, material removal rate (MRR) should be maximized in this process. MRR can be controlled by two categories of parameters: first, are parameters which associated with abrasive particles, and the second are parameters which associated with cavitation process.

One of the parameters associated with abrasive particles is the proportion of abrasive particles in conveyor liquid. Theoretically, an increase in amount of abrasive particles, in a constant volume of liquid, leads to multiply strokes on workpiece surface. Hence, MRR should increase while the proportion of abrasive particles increases [5].

This paper presents experimental results of the influence of proportion of abrasive particles on material removal rate. The assessments were conducted on the way of ultrasonic cavitation process. Unlike the theory, the results showed that there is a threshold point for proportion of abrasive particles in conveyor liquid. Surrounding this point, the MRR decreases and for the proportion of abrasive particles on this point, the MRR will be maximized.

This paper is organized as follows. First, relevant literature on NTM processes and cavitation machining process are reviewed. Second, experimental results about proportion of abrasive particles in conveyor liquid will be discussed. And finally, conclusion and further research direction are provided.

II. LITERATURE REVIEW

A. NTM processes

The improved accuracy of machine tools has led to tighter tolerances on the individual machine components manufactured by conventional processes. It has also led to the development of new or unconventional processes when conventional approaches could not meet accuracy requirements [8]. Nowadays, many NTMs are being used in the industry such as; electro discharge machining (EDM), beam machining processes (Laser beam machining (LBM), electron beam machining (EBM), ion beam machining (IBM) and plasma arc machining (PAM)), electrochemical machining, chemical machining processes (chemical blanking (CB), photochemical machining (PCM)), ultrasonic machining (USM), and jet machining processes (abrasive jet machining (AJM), water jet machining (WJM), abrasive water jet machining(AWJM)), but these processes have their own limitations regarding workpiece material, shapes, etc [1], [9].

B. Cavitation machining process

Cavitation machining approach was proposed as a new NTM process. In this method, the cavitation erosion is intensified using abrasive particles in liquid. Depending upon the way bubbles are produced, cavitation machining is classified in two categories:

- Hydrodynamic Cavitation Machining (HCM)
- Ultrasonic Cavitation Machining (UCM)

In HCM, a hydraulic system mixes the liquid and abrasive particles together with proper proportion, and drives them to the orifice and to the workpiece container. The orifice is used in order to control the entrance pressure of the workpiece container. Workpiece container is a cylindrical part which supports the workpieces. Two mechanisms lead to chip removal from the workpieces surface:

- Flow the conveyor liquid: the conveyor liquid flows in workpiece container and drags the abrasive particles on the workpiece surface; hence molecular (or atomic) chip removal is expected.
- Cavitation process: the orifice decreases the entrance pressure of the cylinder, so cavitation bubbles are appeared. The bubbles travel to the wall of the cylinder and collapse there. The energy released of exploded bubbles is applied to the abrasive particles and threshes them to the workpieces surface. The result is chip removal from the surfaces.

In UCM machining, the acoustic field is produced in the liquid by a piezoelectric or magnetostrictive transducer. The acoustic field causes local pressure decreases; hence cavitation bubbles are formed in the liquid. The workpiece is hanged in the neighborhood of piezoelectric. A collision between cavitation bubbles and the workpiece surface causes bubbles to collapse. The abrasive particles in the liquid stroke the workpiece surface and cause molecular (or atomic) chip removal.

In order to maximize the output, some parameters should be considered and controlled. These parameters are classified in two categories:

- Parameters associated with abrasive particles

TABLE I
PARAMETERS ASSOCIATED WITH CAVITATION

Parameter	Influence on Cavitation
Density of energy flux	This parameter is defined as follows: $$j = \frac{1}{T}\frac{1}{2\rho c}\sum_{k=1}^{M} n_k p_k^2 \quad (1)$$ Where T is the sampling period duration, ρ the density, C the sound celerity of liquid, M the number of pressure intervals, n_k the number of pulses measured by means of a pressure sensor in a single interval, p_k the value of pressure amplitude corresponding to each single interval midpoint, k the consecutive number of the interval. An increase in density of energy flux increases the cavitation. The minimum amount of J to create cavitation is 10 mW/m^2 [10].
Cavitation number	This parameter is defined as follows: $$\sigma = \frac{p - p_v}{\rho v^2/2} \quad (2)$$ Where p is the pressure at a reference point in the flow (upstream pressure), p_v is the vapor pressure of the liquid at the reference temperature, ρ is the liquid density and v is the characteristic velocity at the reference point [11]. Another definition for cavitation number can be shown as (3). This is not strictly correct from a fluid dynamics perspective but makes comparisons with data from different experimental arrangements simpler, since the effect of flow velocity is eliminated and only experimental conditions relating to injection, gas and vapour pressures are considered. $$\sigma = \frac{p_{inj} - p_v}{p_g - p_v} \quad (3)$$ Where p_{inj} is the injection pressure, p_g is the gas pressure and p_v is the vapour pressure [12]. Decrease of this number results in more cavitation. This parameter is only mentioned in hydrodynamic (not acoustic) cavitation. Upstream and downstream pressures in hydraulic systems affect this parameter. These pressures can be controlled by an orifice [13].
Grain size	This parameter affects cavitation erosion. In the case of steel, if the grain size is bigger, more cavitation erosion is resulted [14].
The amount of pH in case of using water as the liquid	More cavitation is achieved when the pH value is decreased. In other words, the cavitation for acidic water is more than the cavitation for basic water. More acidic water causes more cavitation [14].
Flow rate	Increasing flow rate can increase both of cavitation and energy of bubbles. This parameter is controlled by the pressure variances. More pressure variances between two points, more flow rate [15].
Temperature of liquid	Rise of temperature to a certain rate can increase cavitation; hence, controlling the temperature can preside over cavitation [16], [17].
Surface tension	The size and the number of large bubble clusters reduced due to the reduction of surface tension. Hence, cavitation increases as the surface tension increases [18].
Vapour pressure	When vapour pressure increases, the number of bubbles is increased. Vapour pressure has a direct relation with the purity. It means that when the purity of the liquid increases, consequently, the vapour pressure is increased. Also for different fluids in same temperature and purity, different vapour pressure is expected. Hence, to increase the cavitation rate, a liquid with the maximum vapour pressure and purity should be selected [19].
Tensile stress	This parameter is contributed with cavitation erosion. Applying tensile stress on the surface (or part) which is on the way of exploded cavitation bubbles can increase the erosion rate for that surface (or part). It should be said that the tensile stress is in the round of elastic deformation [20].
Gas (air) content in the liquid	When the gas content in the liquid is increased, the number of bubbles is increased. Hence, cavitation grows when the gas content in the liquid is increased [13].

like the particle shape, size, material type, and proportion of abrasive particles in liquid. These parameters should be in the way the MRR is maximized.

- Parameters which determine cavitation rate and cavitation erosion in conveyor liquid. These parameters are mentioned in table I. To achieve the maximum MRR, selection of these parameters should be in the way that the bubbles number and energy are maximized [5].

Cavitation machining was lately proposed, hence, there is no work on influence of different parameters on it. The decision about the influence of parameters associated with the cavitation on MRR is relatively simple. More the cavitation, more the MRR. But more precautions should be considered to give opinion about the other parameters. An experiment was designed to find out how altering the proportion of abrasive particles in liquid can affect the MRR. The effect of proportion of abrasive particles in conveyor liquid on the MRR was evaluated by direct observations after the tests.

III. EXPERIMENTAL SET UP

For fast and homogenous producing of cavitation bubbles in the experiments, an ultrasonic cleaner apparatus was used. The specifications of this apparatus are shown in table II. By referring to this table is observed that there are 5 tuning times on the apparatus that in these experiments for all samples the time of 380 second was selected. The input current to this apparatus is 220 volts AC voltage. 5 samples with 14 mm in diameter and 35 mm in length were selected for the experiments. The samples material was CK45 steel. In the selected ultrasonic cleaner apparatus the piezoelectric vibrates a round flat plate. The samples in the water in distance of 10 mm from the plate were fixed. Water as the conveyor and producer of cavitation bubbles and aluminum oxide as the abrasive material were used. The particles mesh size was 300. A manual compressor was used for turbulence in the mixture and preventing of sedimentation abrasive particles. For all of the experiments, a constant amount of 5% washing agent was mixed by water. Temperature and pressure were the same for all of the experiments.

IV. RESULTS AND DISCUSSIONS

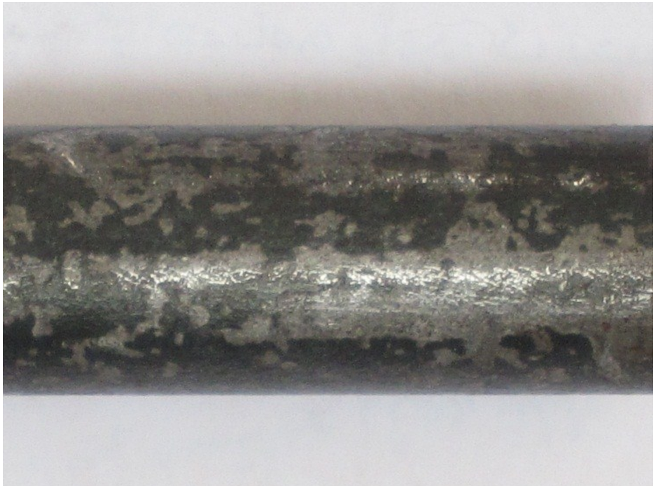
The abrasive particles were mixed with water with proportion 5, 10, 15, 20, and 25 percent, respectively, and entered to the apparatus. The view of the eroded surface of these parts has been shown in the figures 1a to 1e. Referring to these figures is observed that the removal rate increases for the proportions of 5% to 15%, respectively, and in the proportion of 15% of abrasive particles in the water is maximum. For proportion of 20% of abrasive particles, the material removal rate decreases and for proportion of 25% the material removal rate is insignificant. According to these experiments the maximum removal rate in UCM is when the proportion of abrasive particles in the water is 15%.

Because the bubble producing surface is a flat surface and the samples are cylindrical, the distance of different points on the circumference of the cylinder is different, thus circumferential removal rate is not equal and in the farther points from the flat surface the removal rate is less.

TABLE II
SPECIFICATION OF ULTRASONIC CLEANER APPARATUS

Character	Quantity
Power	60 watt
Volume	1.2 liters
Input	$\begin{cases} AC\ 100-120\ V, 60\ Hz \\ AC\ 220-240\ V, 50\ Hz \end{cases}$
Frequency	40 kHz
Adjustable times	90, 180, 280, 380, and 480 S

a.



b.

c.

d.

e.

Fig. 1. (1a). Machined sample by 5 percent of abrasive particles in water.
(1b). Machined sample by 10 percent of abrasive particles in water.
(1c). Machined sample by 15 percent of abrasive particles in water.
(1d). Machined sample by 20 percent of abrasive particles in water.
(1e). Machined sample by 25 percent of abrasive particles in water.

For the points that have least distance from the flat surface (the points on the perpendicular line from the center of the work pieces to the flat surface) the removal rate is maximum. The reason could be, in the nearest points to the flat surface the bubbles hit the abrasive particles to the surface perpendicularly and all of the force resulted from bubble explosion is applied to the surface whereas in the farther points the bubbles hit abrasive particles on the surface obliquely and so the erosion rate is less. Also in the points near the flat surface the number and density of the bubbles is more and so the removal rate is more. It can be concluded that if the distance of all of the points in the surface of the work piece be equal with the surface of the vibrating plate the bubbles density in all of the points is equal so this apparatus is suitable for polishing surface of flat samples (not cylindrical ones).

Similar experiments done for aluminum parts (grade 7076) in diameters 20 mm and length of 35 mm. the results showed that the removal rate for aluminum work pieces is less than steel ones but the obtained surface finish for these parts is better than steel parts. Also for proportion of 15% of abrasive particles in water the removal rate is maximum.

Similar experiments were done for steel (CK45) samples with this difference that the washing agent was eliminated. The removal rate was less than before. May be because the existence of washing liquid causes producing foam in the liquid and intensifies formation of cavitation bubbles and the bubble density around the specimen increases and removal rate is increased.

The power of the used apparatus is 60 Watts that is relatively low. It means that the power of producing cavitation bubbles for this apparatus is low. For increasing removal rate a more powerful apparatus may be used. If the abrasive particles in the water considered as non-purity their increase in the water decreases the amount of cavitation. For compensating it a more powerful apparatus can be used. In these apparatuses the piezoelectric changes to magnetic cores and higher power is accessible.

V. Conclusion

- In this paper the effect of proportion of abrasive particles in the conveyor liquid was studied. The results showed that the best proportion of abrasive particles in the conveyor liquid for achieving to maximum removal rate is equal to 15%.
- Removal rate for aluminum parts is less than steel, in the same experimental conditions, but the better surface finish for this material in comparison to steel parts could be achieved.
- Mixing some washing agent with the water causes formation of foams in the solution, hence, the number of cavitation bubbles is increased and the more material removal rate is achieved.

Appendix

The CK45 designation for selected steel is according to Din standard. The designation for this steel in other standards is followed:

In BOHLER, v945, in ROCHLING, RM4, in POLDI, W6H, in SS/ASSAB, 1672, in SAE/ASTM, 1045, in B. S, 080M46, in UNI, C45, in GOST, 45, and in JIS, S45C.

Chemical composition for this steel is as bellow:

%C is 0.42-0.50, %Si is less than 0.40, %Mn is 0.50-0.80, %Cr, Ni, Mo, V, W, and the others are 0.

Specifications and applications are:

Heat treatable non alloy steel, good strength and hardening ability, suitable forming and machining for making parts with mean cross area under mean load in automobile industries, automobile and motorcycle parts, shafts and gears, pins and rollers.

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I think cavitation process and energy of burst bubbles could be used in different areas. So I introduced Machining process with usage of cavitation and I did some experiments which can be found in my papers (WCE-ICME195 and ICME 330).
I am willing to have cooperation with those who are interested, in order to develop this subject.

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