Utilization of Secondary Jet in Cavitation Peening and Cavitation Abrasive Jet Polishing

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Hao Pang, Gracious Ngaile*

North Carolina State University, Raleigh, NC, USA, 27606

Abstract

The cavitation peening (CP) and cavitation abrasive jet polishing (CAJP) processes employ cavitating jet to harden the surface or remove the surface irregularities. However, a zero incidence angle between the jet and surface limits the efficiency of these two processes. This limitation can be improved by introducing a secondary jet. The secondary jet interacts with the main jet, carrying bubbles to the proximity of the workpiece surface and aligning the disordered bubble collapse events. Through characterizing the treated surface of AL6061 in terms of the hardness distribution and surface roughness, it was found out that the secondary jet can increase the hardening intensity and material removal rate within a localized region and can create a patched pattern of hardness distribution if more than one secondary jets were utilized.

Keywords: Cavitation, Peening, Jet polishing

1. Introduction

In recent years, cavitation peening (CP) and cavitation abrasive jet polishing (CAJP) processes have attracted much attention due to their advantages over the conventional surface treatment processes, such as shot peening, laser peening, grinding and abrasive jet polishing (AJP). Compared to their conventional counterparts, CP and CAJP are more suitable for treating surfaces of complicated geometries. They can also be used to process internal surface since they employ fluid as the work medium. The heat damage to the workpiece is minimal since the fluid continuously removes the heat during the process. Futhermore, cavitation based techniques enhance the productivity as the cavitation energy is harnessed to strengthen the surface or remove the surface irregularities [1-2].

In the cavitation peening (CP), a cavitating flow is first generated by a venturi type nozzle or an orifice , and then ejected onto the workpiece, which is positioned at a distance from the nozzle. Fig. 1 shows a schematic diagram of CP. The throat geometry of the nozzle creates a pressure drop and leads to vaporization of the liquid, which is referred to as cavitation. These vaporous bubbles exiting the nozzle bear tremendous energy and can release this energy in the form of the pressure wave and micro-jet when they collapse under a high recovery pressure, for example, the stagnation neighborhood of the workpiece. When the pressure wave and the micro-jet impact the workpiece surface, plastic deformation occurs on the surface, leading to work hardening of the workpiece material [3].

Similarly, in cavitation abrasive jet polishing (CAJP), the slurry, which is a mixture of abrasive particles and fluid, is pumped through the nozzle to generate the cavitating jet. The jet sprays on or flows through the workpiece and polishes it. Fig. 2 is a schematic diagram of CAJP. The abrasive particles with high kinetic energy flatten or cut off irregular asperities on the workpiece surface, leading to the lower surface roughness. Meanwhile, CAJP additionally uses cavitation to remove the asperities and accelerate abrasive particles by the pressure wave and micro-jet so that the polishing efficiency is enhanced [4-5].

The previous researches manifest the positive role of cavitation in peening and jet polishing. However, these two processes are confronted with several challenges. First, when the CP is used to treat workpieces with complicated geometries, the incidence angle α shown in Fig. 1 may be zero. Qin et al. [6]. found out that the effective process area and process efficiency sharply decreased in this extreme case. Changing the incidence angle via rotating the nozzle or workpiece may be limited by the spatial interference between them. Meanwhile, an actuator is required for rotation. Second, when the incidence angle α is zero, the hardness distribution created by the CP is still unknown. There is the potential for further improving the efficiency of CAJP, where the cavitation energy is not fully harnessed. For example, the bubbles which collapse far away from the workpiece surface, or the micro-jets which are not directed towards the surface are underutilized [7-8].

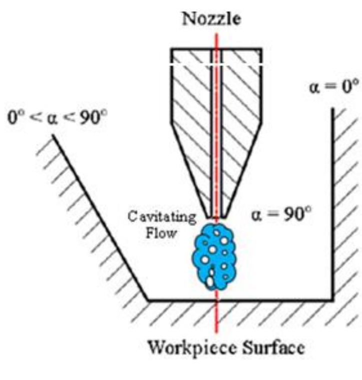

Fig. 1. Cavitation Peening (CP)

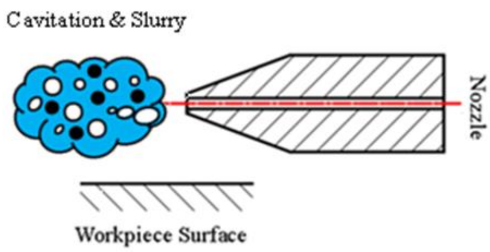

Fig. 2. Cavitation Abrasive Jet Polishing (CAJP)

The case where the incidence angle is zero or the workpiece surface is parallel to the cavitating jet is commonly seen in CP and CAJP, especially in the latter. The workpiece-jet configuration with zero incident angle calls for improvement. In this study, a cavitation device which mimics the case of zero incidence angle or a parallel type of workpiece-nozzle configuration was developed. A novel approach was proposed to control the hardness distribution and enhance process efficiency by introducting secondary jets. The hardness distribution and surface roughness of the treated specimens by this approach were measured and analyzed.

2. Multiple Jets Cavitation Approach

In order to mimic the situation of zero incidence angle, a cavitation device with multiple jets configureation shown in Fig. 3 is developed. Fig. 4 shows a cutaway of the device on the XZ plane. The fluid is pushed through the nozzle formed by a valve nose (#7) and the conical wall of the main housing (#3). The pressure drop ΔP due to the constriction effect generates the cavitation. The pressure drop ΔP can be changed by advancing or retracting the valve nose (#7) via the control shaft (#1). The bubbles exiting from the constriction flow through the chamber which incorporates the sample (#5) for surface treatment.

The proposed approach employs secondary jets (Jet#1, #2 and #3 in Fig. 3 and Fig. 4), which cross the main cavitating jet from the nozzle and impacts the sample surface to control the hardening pattern, enhance the peening intensity and increase the material removal rate. The secondary jet brings about two benefits. First, the secondary jet carries the bubbles to the proximity of the workpiece surface. This results in less attenuation of the pressure wave amplitude and micro jet velocity. Second, the secondary jet creates a pressure gradient and causes an identical asymmetry for the bubble collapse. The asymmetry implies that the pressure is higher on the side of bubbles far from the surface than on the side of the bubble close to the surface. As a result, the chaotic micro-jets [Fig. 5a], which occurs when no secondary jet is used can be aligned towards the solid surface in the presence of the secondary jet as shown in [Fig. 5b].

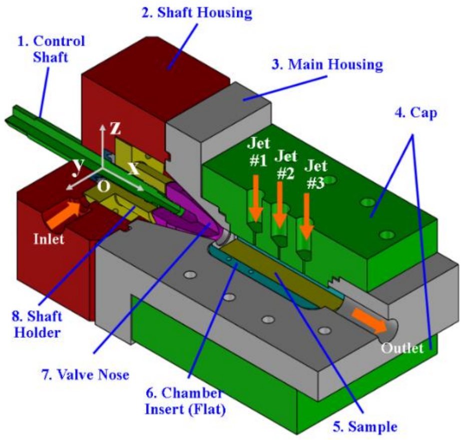

Fig. 3. Multiple jets cavitation device

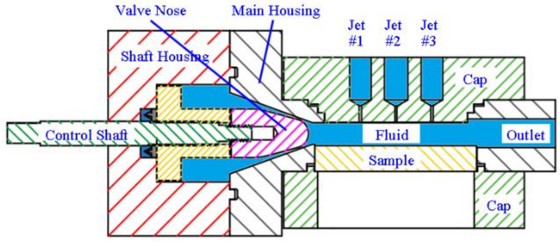

Fig. 4. Cutaway of the cavitation device

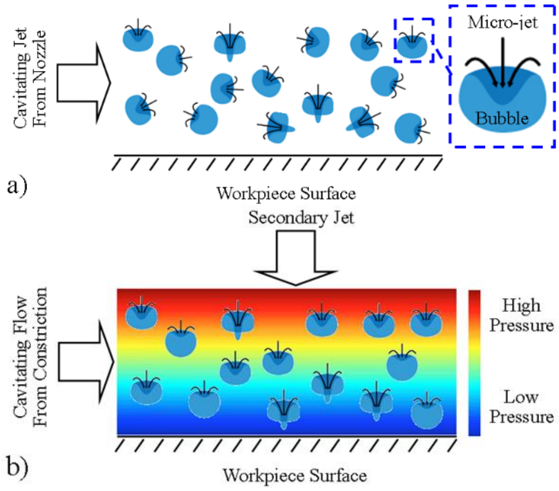

Fig. 5. Cavitation (a) without and (b) with secondary jet

3. Test Setup

The cavitation device [Fig. 3] is connected to the system as shown in Fig. 6. The pump sucks the water from the tank and pushes it through the cavitation device. Another pump (pump B) is used to drive the secondary jet. Because there are three locations for the secondary jets in the cavitation device, a manifold is used to distribute the fluid and each channel can be independently opened and closed. The cavitating flow from pump A and the secondary jet from pump B interact in the cavitation device shown in Fig. 3. The overall setup is shown in Fig. 7.

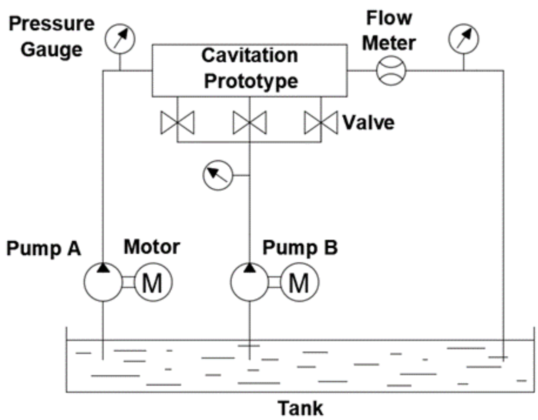

Fig. 6. Hydraulic Circuit of Overall System

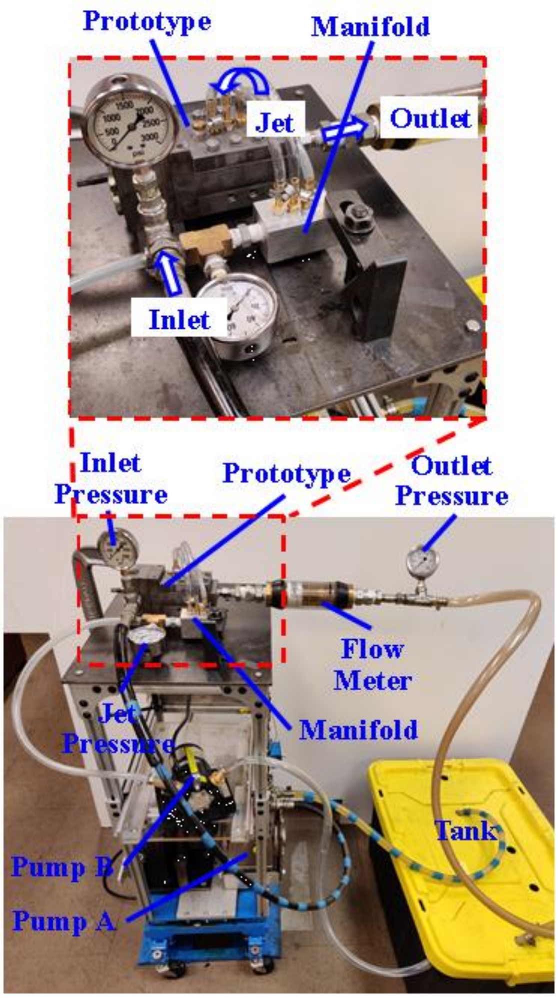

Fig. 7. Overall System

4. Materials and Procedures

The prototypes above are run to treat the specimen made of the Aluminum 6061 TO. This material has the Knoop hardness (HK) of 43 kgf/mm^2. In order to evaluate the mass removal by the cavitation, all specimens are kept to have the same surface roughness before processing. The average surface roughness R_a is 0.11 ~ 0.14 μm and valley depth surface roughness R_v is 0.58 ~ 0.59 μm.

During processing, the pressure drop between the inlet and outlet of the cavitation device is 4.1 MPa and the flow rate of the cavitating flow is 14 liters per min. The inlet pressure of the secondary jet is 138 KPa and its flow rate is 3 liters per min. The bore diameter for the secondary jet is 1 mm.

The processed specimen is characterized in terms of hardness and surface roughness. The Knoop hardness test is carried out using the Leco M400 microhardness tester. The surface roughness is measured using Mitutoyo SURFTEST SJ-310. The micrograph of the surface morphology is obtained using the confocal laser scanning microscope (CLSM), Keyence VKx1100.

4. Results and Discussion

In order to study the effects of the secondary jet on peening or hardening intensity, the hardness distribution on the treated surface was evaluated. The specimens under no secondary jet and under the secondary jet (#2) are compared in terms of the hardness distribution along the centerline of the specimen and are labeled as AL_NJ and AL_J2 respectively. Note: the centerline refers to x-axis in Fig. 3.

It was found out that the secondary jet affected the hardness pattern and increased the hardening efficiency at a localized area. As shown in Fig. 8, in the absence of the secondary jet, the hardness of AL_NJ increases at first with the distance from the nozzle and then decreases. In contrast, when the secondary jet is employed, a localized hardening phenomenon is observed on the specimen region corresponding to the jet location. The rest of the region is little hardened. This indicates that the secondary jet can concentrate the release of the cavitation energy within the neighborhood of the jet location and harden a localized region. Meanwhile, the maximum hardness achieved by the secondary jet is 10% higher than the case without the secondary jet. Note: In Fig. 8 AL_Virgin refers to the unprocessed specimen.

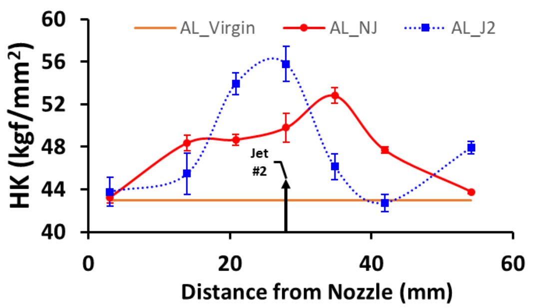

Fig. 8. Hardness Distribution on the Specimen under No Jet and under Secondary Jet

In addition to strengthening the surface, the cavitation also alters the surface morphology of the workpiece, which is a dominant mechanism of removing the surface irregularities in CAJP. As shown in Fig. 9b, the cavitation creates clusters of dents on the surface which have crater-like section profiles. Fig. 9a shows the surface condition of virgin material.

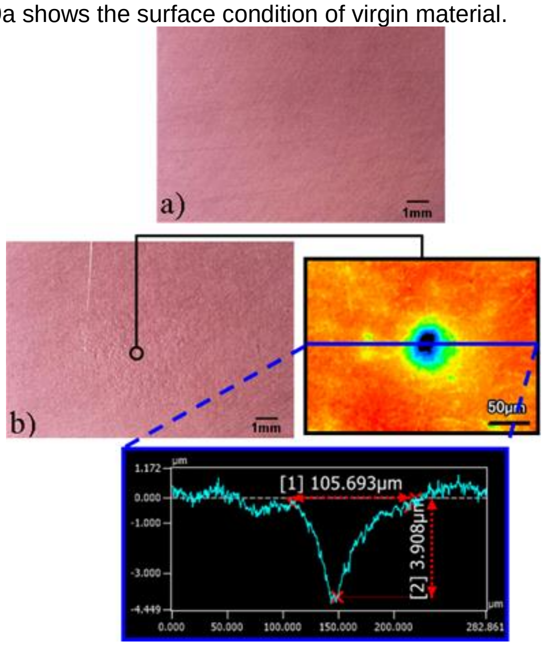

Fig. 9. Surface Morphology before a) and after b) Cavitation-based Treatment

Fig. 10 shows that in the most hardened region of AL_NJ and AL_J2, the surface roughness is higher in AL_J2 than in AL_NJ. R_a and R_v of AL_J2 is 67% and 90% higher than those of AL_NJ respectively. In addition, the dents visible to the naked eyes appear on AL_J2 and are not observed on AL_NJ. These findings indicate that the secondary jet can locally increase the material removal rate by concentrating the cavitation energy.

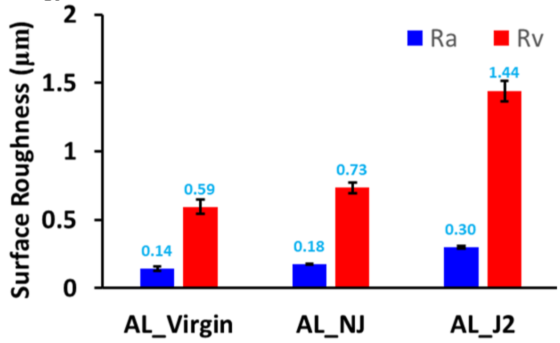

Fig. 10. Surface Roughness ($R_a$and R_v) of Specimen under No Jet and under Secondary Jet

The surface treatment results observed with a single secondary jet (jet #2) clearly shows that the jet can be used to locally enhance hardening intensity and increase material removal rate.

The influence of multiple secondry jets on hardening pattern was also examined. Jet # 1 and Jet # 3 were used [Fig.3]. Fig. 11 shows that a single jet results in a hardness profile with a single peak, whereas two secondary jets lead to two peaks. Among these peaks, the upstream one is higher than the downstream one. This is because the bubbles exiting from the nozzle release most of their energy at the location of the upstream jet and the exhausted bubbles do not have sufficient energy to create such a high hardness peak as the upstream one when they undergo second rounds of collapse at the location of the downstream jet. These observations imply that there is a potential of creating a patched pattern of hardening if multiple secondary jets are used.

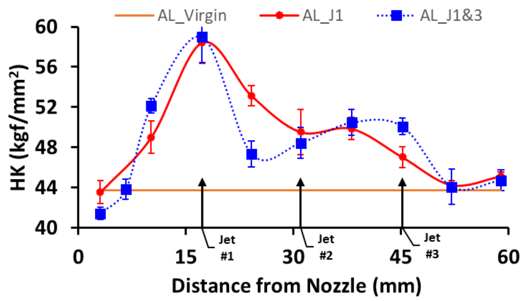

Fig. 11. Hardness Distribution on the Specimen under Jet #1 and under a Combination of Jet#1 and Jet #3

5. Conclusions

In this study, a novel approach was proposed to improve cavitation peening (CP) and cavitation abrasive jet polishing (CAJP) in the case that the work fluid jet is parallel to the workpiece surface. The approach introduces a secondary jet, which interacts with the main cavitating flow thus shortening the distance from the bubble collapse sites to the workpiece surface. The introduction of secondary jets also align the disordered micro-jet towards the surface. The following conclusions are drawn from this study.

The secondary jet can concentrate the release of cavitation energy within a specific region, increasing the hardening intensity. The maximum hardness achieved by the secondary jet is 10% higher than the case without a secondary jet.

Under the same process conditions, the surface roughnesses found in the cases with and without the secondary jet were $R_v = .44\ \mu\text{m}$ and $R_v = .73\ \mu\text{m}$ respectively. This contrast shows that the secondary jet can enhance material removal rate, which is favorable for process efficiency of CAJP.

The study demonstrates the potential for creating patched hardening patterns of interest by employing multiple secondary jets.

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