SINGULARITY OF CAVITATION SHOTLESS PEENING COMPARED WITH SHOT PEENING

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ABSTRACT

Cavitation impacts, which are normally causes severe damage in hydraulic machinery, can be utilized for peening instead of impacts induced by collision of shots. Peening method using cavitation impacts is named as cavitation shotless peening, as shots are not required. In the present paper, mechanism of cavitation shotless peening including how to generate cavitation bubbles and its optimization was presented, and singularity of cavitation shotless peening compared with shot peening was discussed by investigating the peened surface using X-ray diffraction method. It was revealed experimentally that full width at half maximum FWHM of X-ray diffraction from surface treated by cavitation shotless peening was decreased, although FWHM from shot peened surface increases. It means that cavitation shotless peening released micro-strain which was introduced by machine finishing and heat treatment, although cavitation shotless peening introduced compressive residual stress in the materials.

KEY WORDS

Residual stress, Fatigue strength, X-ray diffraction, Cavitation

INTRODUCTION

A peening method using cavitation impacts at bubble collapse has been developed (H.Soyama et al., 1996; K.Hirao et al., 1996; H.Soyama et al., 2000; H.Soyama, 2000; H.Soyama et al., 2001; H.Soyama et al., 2002; H.Soyama et al., 2003a; H.Soyama et al., 2003b; D.Odhiambo and H.Soyama 2003; H.Soyama, 2004; H.Soyama et al., 2004; H.Soyama, and D.O.Macodiyo, 2005; H.Soyama, 2007) It has been applied to reduce stress corrosion cracking in nuclear power plants (N.Saitou et al., 2003). As the peening method using cavitation impacts does not require shots in case of shot peening, it is called “cavitation shotless peening CSP” or “cavitation peening CP”. In case of CSP, mechanism of producing impact is totally different from that of shot peening. Thus, the surface peened by CSP show the singular characteristics compared with that of shot peened surface.

In the case of CSP, cavitation was produced by injecting a high-speed water jet into a water filled chamber. Cavitation bubbles take place in shear layer around a high-speed water jet, which is called a cavitating jet in water. Recently, a cavitating jet in air was developed by injecting a high-speed water jet into a low-speed water jet which was injecting in air (H.Soyama, 2004). The cavitating jet in air does not require a water-filled chamber, this means that CSP can be applicable to pipe line of plants or large components, which can not be put into a chamber. And also ability of the optimized cavitating jet in air is most powerful compared with normal cavitating jet in water and a high-speed water jet in air (H.Soyama, 2004).

As the generation mechanism of impact at cavitation bubble collapse is totally different from that of shot collision, the pressure distribution of individual cavitation impact is different from Hertz contact. It causes the difference of residual stress distribution, work hardening and so on. The pressure distribution at cavitation bubble collapse was visualized using Fry etching technique. It was also found that full width at half maximum FWHM of X-ray diffraction from the surface decreased by CSP. It was main reason that the micro-strain was decreased by CSP, as the micro-strain was evaluated a fundamental parameter method.

In the present experiments, several types of cavitating jet apparatus were used for treatment of CSP. One of them was the cavitating jet in water and the other was the cavitating jet in air. As the cavitation impacts were induced by the shock wave at bubble collapses (see Fig. 1), when residual bubbles after cavitation bubble collapses were taken into the cavitating jet the cavitation intensity was reduced by cushion effects, although the cavitation was developed. Actually, impact from cavitation consist of many tiny bubbles as shown in Fig. 1 was more intense compare with that of a single spherical bubble. In order to increase intensity of cavitation impact, the low speed water jet was injected around a high speed water jet of cavitating jet in water to avoid residual bubbles or the water chamber was pressurized by controlling flow rate from the chamber. The other way to avoid cushion effect was realized by pressurizing a chamber in which cavitating jet in water was injected. In the present paper, the mechanism of CSP including optimization of a cavitating jet and the singularity of CSP such as micro-strain and distribution of residual stress compared with shot peening was presented.

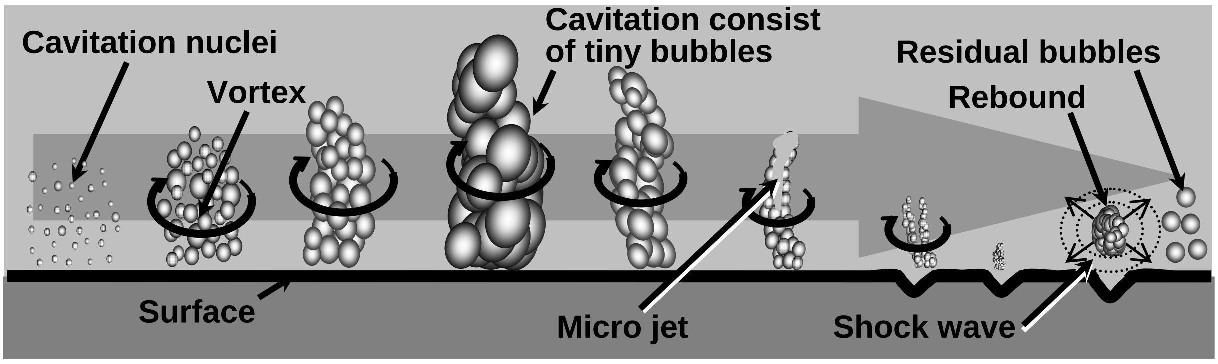


Fig. 1 Schematic diagram of cavitation consist of tiny bubbles and residual bubbles

METHODS

In order to treat materials by CSP, apparatuses using the cavitating jet in water and air were used. Figure 2 illustrates the apparatus of the cavitating jet in air for CSP. Figure 3 shows the schematic diagram of a concentric nozzle for the cavitating jet in air. A high speed water jet was pressurized by a plunger pump and was injected into a low speed water jet, which was injected into air. The maximum injection pressure of the high speed water jet in the present experiments was 30 MPa. Capability of the cavitating jet in the air was changing with the injection pressure of the low speed water jet, then injection pressure of the low speed water jet was optimized by an erosion test. In the present experiments, it was assumes that the greater the loss mass reveals the greater the jet's capability. Specimens for the erosion test were made of pure aluminum JIS A1050.

In order to examine fatigue strength of non-peed specimen and peened specimen by CSP and shot peening, a rotating bending fatigue test and a plate bending fatigue

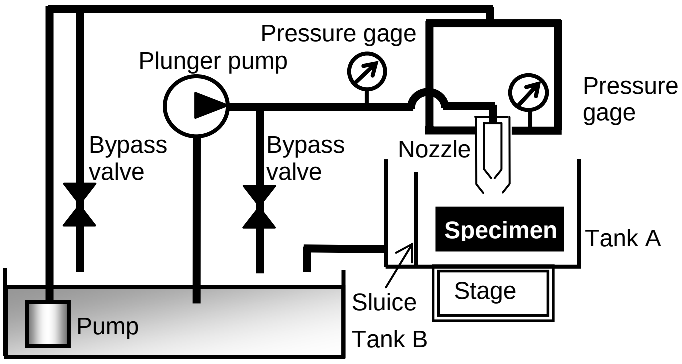


Fig. 2 Apparatus of cavitating jet in air for CSP

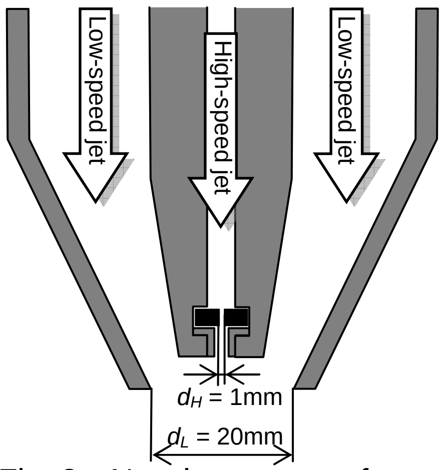


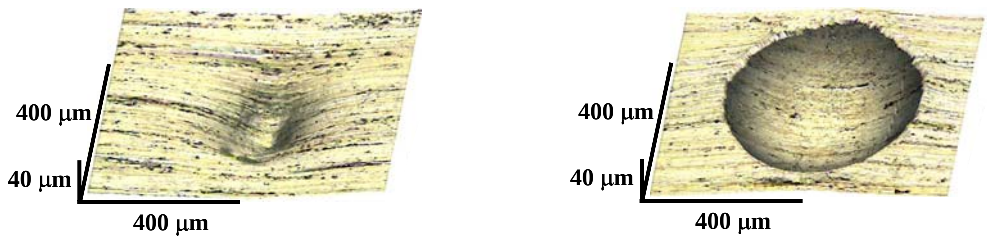
Fig. 3 Nozzle geometry for cavitating jet in air

test were carried out. Residual stress of specimen was evaluated by an X-ray diffraction method. To visualize plastic deformation area induced by the impact at cavitation bubble collapse, Fry's etching technique was used and tested materials was 0.2% Swedish steel. There were five procedures for the etching; the first step is annealing at 650 ^{o}C for 2h; the second is to apply plastic deformation; the third is strain aging treatment at 400 ^{o}C for 1h; the forth is mirror polishing the observation surface; the final step is etching using Fry's solution (A.Fry, 1921). Fry's solution consists 16 mL hydrochloric acid, 10 mL water, 10 mL ethyl alcohol and 2 g $CuCl_2$. Etching is conducted under ultra sonic vibration for 10 min. Observation section surface is polished with a cloth spread compound on.

RESULTS

In order to make clear difference between CSP and shot peening, plastic deformation pits induced by each individual impact was revealed in Fig. 4. Tested material was pure aluminum to show shape of plastic deformation precisely. A single impact by CSP was produced by the cavitating jet in water at following condition; injection pressure was 30 MPa, nozzle size was 1.9 mm. In order to simulate a plastic deformation pit of shot peening, ball shape indent which diameter was 1.6 mm was put into the specimen at 40 N load to produce nearly equivalent plastic deformation volume and depth of the pit induced by CSP. In the case of CSP, the plastic deformation volume, depth and diameter were 2.3 mm^3, 35 μm and 450 μm. Those of ball indentation were 2.2 mm^3, 32 μm and 480 μm. Although the edge of pit induced by ball indentation had sharp edge, the pit induced by CSP was very smooth. The shape of pit induced by CSP might be good for boundary-lubrication condition.

Figure 5 illustrated plastic deformation area simulated by using finite element method FEM and Fry's etching technique induced by a ball indentation. The dark area in

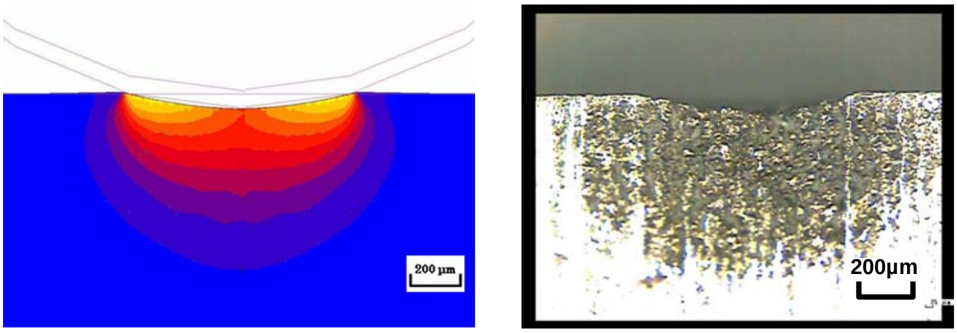


(a) CSP (b) Ball indentation

Fig. 4 Plastic deformation pit induced by sigle load on pure aluminum

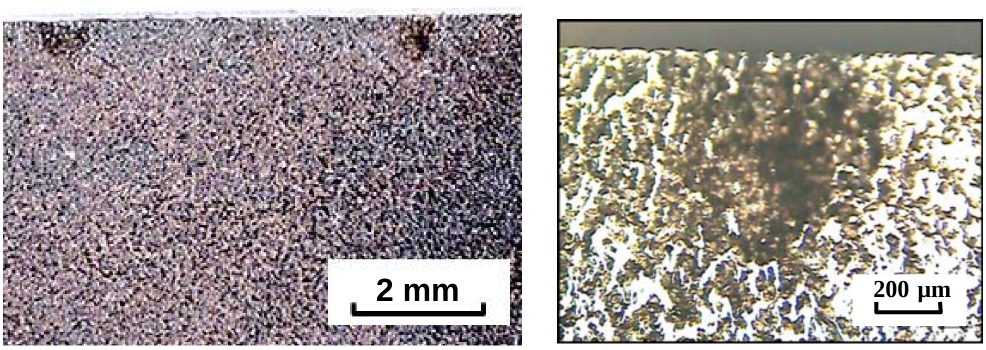
Fig. 5 (a) well corresponded to the plastic deformation area simulated by FEM. Thus, Fry's etching technique can reveal plastic deformation area. Figure 6 shows the plastic deformation area induced by cavitation impacts by using Fry's etching technique. Obviously, dark area which corresponded to the plastic deformation area is observed. This means that the cavitation impacts can introduce plastic deformation in metallic materials. It confirmed the results of re-crystallization technique using pure aluminum (Macodiyo, 2003). Although the depth of plastic deformation was about 400 μm both case of ball indentation and cavitation impact in Figs. 5 and 6, the width of plastic deformation area induced by ball indentation was about 800 μm and that of cavitation impact was about 400 μm. Namely, ratio of depth and width of the plastic deformation area induced by cavitation impact was different from that of ball indentation. This results suspects that individual load distribution induced by cavitation impact will be different from that of ball indentation, i.e., Hertz contact. Considering plastic deformation shape in Fig. 4, individual impact distribution at CSP would be a kind of triangular shape distribution, which reveals that the load at the center is large and load is gradually decreasing with distance from the center.

In order to demonstrate the difference between CSP and shot peening, tool alloy steel (Japanese Industrial Standard JIS SKD61) was treated by CSP and shot peening. Tested material was treated by normal heat treatment for forging die. Figures 7 and 8 show the surface of specimen by laser microscope and X-ray diffraction pattern using two dimensional position sensitive proportional counter (2D PSPC). Most interesting fact in Fig. 8 that X-ray diffraction pattern was narrower by CSP. This means that CSP can release micro strain. Figure 9 revealed the



(a) Finite element method (b) Fry's etching technique

Fig. 5 Plastic deformation area induced by a ball indentation



(a) Overall view (b) Enlarged view

Fig. 6 Plastic deformation area induced by CSP

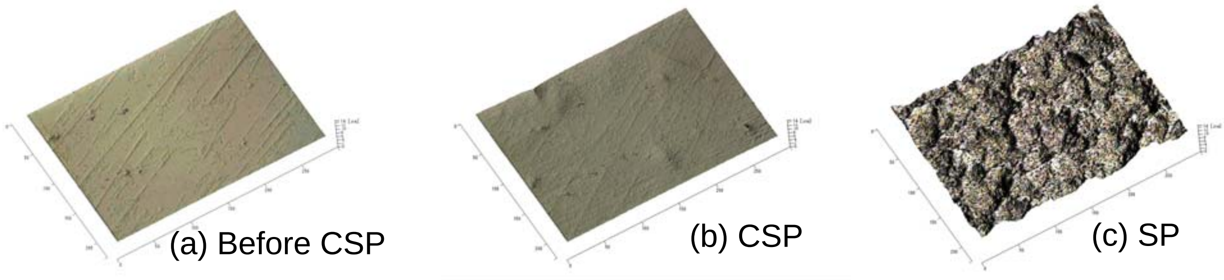


Fig. 7 Aspect of surface of tool alloy steel (JIS SKD61)

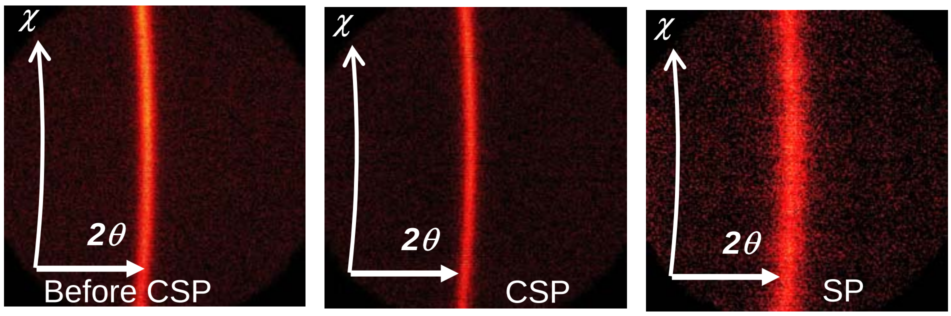


Fig. 8 Two dimensional X-ray diffraction pattern from the surface (JIS SKD61)

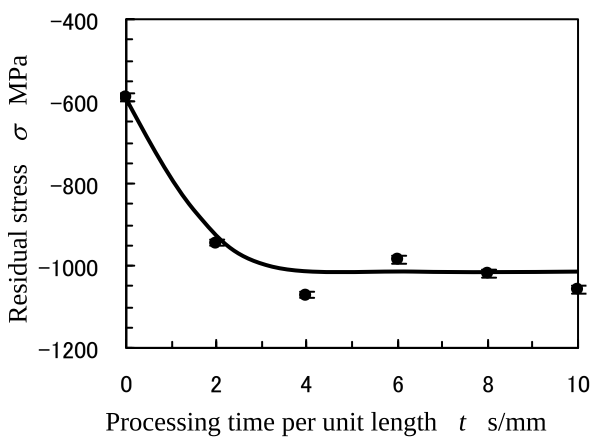


Fig. 9 Introduction compressive residual Stress by CSP (JIS SKD61)

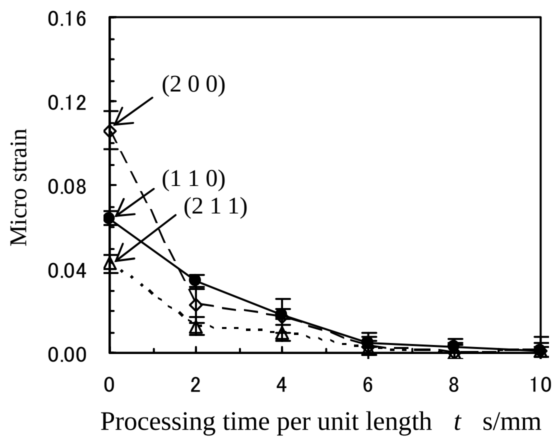
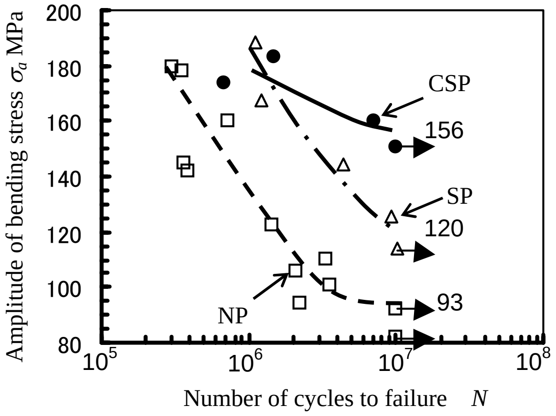


Fig. 10 Release of micro strain by by CSP (JIS SKD61)

residual stress of the surface as a function of processing time per unit length by using X-ray diffraction method. Figure 10 shows the micro strain of the surface measured by a fundamental approach. In case of shot peening, the residual stress on the surface was about -800MPa, CSP can introduce compressive residual stress deeper than shot peening at the present condition (H.Soyama, 2004). CSP can introduce compressive residual stress and release micro strain, which can is introduce by heat treatment or mechanical finishing.

Figure 11 illustrates the result of a rotating fatigue test using aluminum alloy (JIS AC4CH). The fatigue strength at 10^7 was 93 MPa for non-peened NP, 120 MPa for shot peening SP and 156 MPa for CSP. Namely, CSP can improve fatigue strength. Figure 12 shows total number of cracks after heat cycle test which simulates thermal fatigue of die. CSP can reduce cracks compared with fine particle bombarding FPB, shot peening SP and hard shot peening HSP for both salt bath nitriding SBN and gas nitriding GN materials.



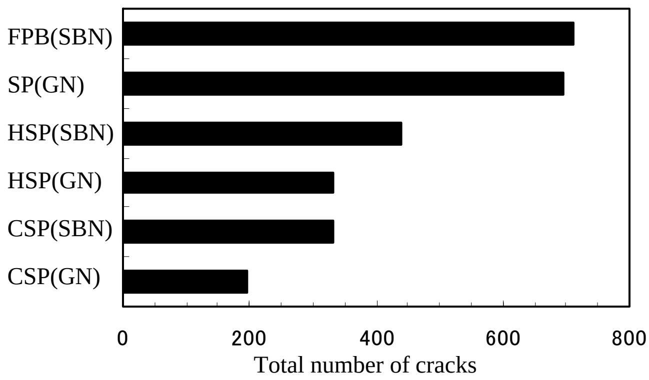


Fig. 11 Improvement of fatigue strength of aluminum alloy by CSP

Fig. 12 Reduction of crack on die after heat cycles by CSP

CONCLUSION

In order to make clear the characteristics of cavitation shotless peening compared with shot peeing, the surfaces treated by CSP and shot peening were examined. It was revealed that the surface peened by CSP was very smooth and the individual impact distribution of CSP was quite different from that of shot peening. It was also shown that CSP released micro strain which was induced by mechanical finishing or heat treatment, introducing macro strain, i.e., compressive residual stress.

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