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CAVITATION PEENING BY USING CAVITATING JET IN AIR

H. Soyama1 and K. Homma1

1 Tohoku University, 6-6-01 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan

ABSTRACT

Cavitation impacts, which normally cause severe damage in hydraulic machinery, can be utilized for peening without shots. Peening by using the cavitation impacts is called cavitation peening. In case of cavitation peening, the cavitation was produced by a cavitating jet, which was a high-speed water jet injecting into water filled chamber. In the present paper, "a cavitating jet in air" without any water filled chamber was realized by injecting a high-speed water jet into a low-speed water jet, which was injecting into air, using concentric nozzle. The injecting condition of the cavitating jet in air was optimized by measuring jet capability. The suitable cavitating jet in air was more powerful compared with a normal cavitating jet, which was the cavitating jet in water. The improvement of fatigue strength by the cavitating jet in air was demonstrated.

SUBJECT INDEX

Fatigue Strength, Residual Stress, Cavitation, Jet

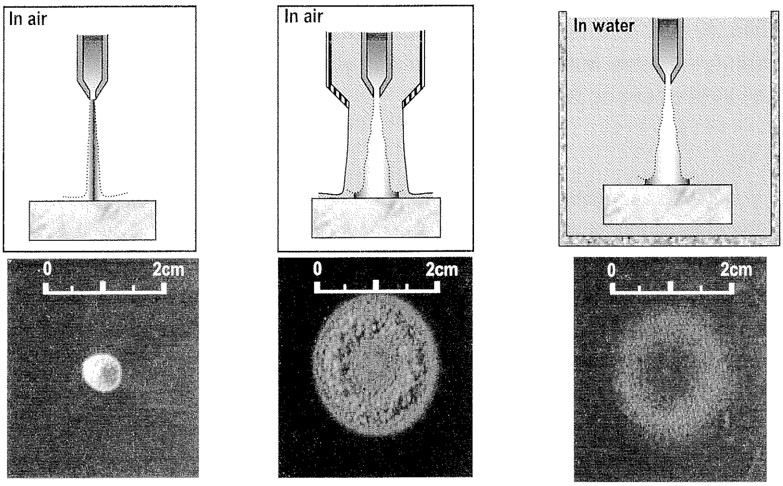
INTRODUCTION

Normally, cavitation produces severe damage in hydraulic machinery. However, the cavitation impact at cavitation bubble collapse can be used for surface enhancement such as improvement of fatigue strength of metallic materials as the same way as shot peening, but without any shots. Peening using cavitation impact is called "cavitation peening" (Soyama et al., 2002; Odhiambo and Soyama, 2003, Macodiyo et al, 2004; Soyama and Macodiyo, 2005). A cavitating jet is normally produced by injecting a water jet into a water-filled chamber (Soyama et al., 1996a; Soyama et al., 1996b). In the present paper, it is called "a cavitating jet in water." If "a cavitating jet in air" without a water-filled chamber was realized, the applications of cavitation peening can be expanded.

Soyama et al. (1996c) and then Hirano et al. (1996) proposed practical use of a cavitating jet in water to introduce compressive residual stress. Recently, many reports about introduction of compressive residual stress into metallic materials included peening by a normal water jet have been reported (Daniewicz and Cummings, 1999; Soyama et al., 2000; 2003; 2004; Kunapon et al., 2004; Ramulu et al., 2002; Rajesh et al., 2004). The improvement of corrosion resistance of carbon steel by using a cavitating jet was also demonstrated (Soyama and Asahara, 1999).

The improvement of fatigue strength of metallic materials by using a cavitating jet in water was already revealed by Soyama et al. (Soyama, 2000; Soyama et al, 2001; Soyama et al., 2002; Odhiambo and Soyama, 2003, Macodiyo et al, 2004, Soyama and Macodiyo, 2005). The cavitating jet can be useful in semiconductor manufacturing as gettering technique to removing the unwanted impurities from the active device region of silicon wafer (Kumano and Soyama, 2004; Kumano et al., 2004).

The most important parameter in the improvement of fatigue strength in metals is compressive residual stress. Soyama has revealed that the cavitating jet in air can introduce more compressive residual stress compared to a cavitating jet in water (Soyama, 2004). A cavitating jet in air was produced by injecting a high-speed water jet into a concentric low-speed water jet. A typical ring erosion pattern of a cavitating jet was obtained by the cavitating jet in air, as shown in Fig. 1 (b). In Fig. 1, the injection pressure, the nozzle size and exposure time were kept constant. As shown in Fig. 1, the mass loss induced by the cavitating jet in air was biggest. Namely, the cavitating jet in air was most powerful jet. The surface modification of cavitation peening, the surface was not eroded, as the exposure time as very short. The application of the cavitating jet in air will be expanded as the water-filled chamber was not required.



(a) Normal water jet
(Water jet in air)

(b) Cavitating jet in air

(c) Cavitating jet in water
(Water jet in water)

Fig. 1 Jet capability of a normal water jet and cavitating jets in air and water (Soyama, 2004)

In the present paper, in order to demonstrate the improvement of fatigue strength of a cavitating jet in air, fatigue strength of the peened specimen was investigated by using bending fatigue tests.

METHODS

The cavitating jet in air was produced by injecting high-speed water jet into low-speed water jet, which was injecting to air, using concentric nozzle. To find suitable injecting condition, the capability of the jet was investigated by an erosion test of aluminum specimens to save test time of the erosion test. This assumes that the greater mass loss revealed the greater jet's capability. The residual stress of specimen was measured using an X-ray diffraction method. To determine the improvement of fatigue strength of steel, specimens with and without peening by a cavitating jet in air were tested using fatigue tests. Duralumin Japanese Industrial Standard (JIS) A2017 and stainless steel JIS 316L were chosen as material for the fatigue tests.

The treatment condition of duralumin was follows; the injection pressure of the high-speed water jet p_1 was 20MPa, the injection pressure of low-speed water jet p_2 was 0.21 MPa; the nozzle diameter of high-speed water jet d_1 and low-speed water jet d_2 were 0.8 mm and 30 mm, respectively; standoff distance s was 45 mm; and processing time per unit length t_p was 20 s/mm. Duralumin specimen was tested by a rotating bending fatigue test. The treatment condition of stainless steel was follows; p_1 = 30MPa, p_2 = 0.09MPa, d_1 = 1 mm, d_2 = 20 mm, s = 35 mm. The nozzle was moved as the processing time per unit length t_p = 1 s/mm and it moved 4 mm step wisely. Stainless steel specimen was tested by a plate bending fatigue test.

RESULTS

Figure 2 illustrates the results of a rotating bending fatigue test of duralumin. Figure 2 shows the plots of stress amplitude versus number of cycles to failure. The fatigue limit was considered to be at 10^7 cycles. Although the fatigue strength at 10^7 without peening was 132 MPa by Little's method (1972). On the other hand, the fatigue strength of cavitation peening was 193 MPa. Namely, the fatigue strength was improved about 46 % by cavitation peening.

Figure 3 shows the S-N curve of stainless steel by a plate bending fatigue test. The fatigue strength of non-peened specimen was 272 MPa, while that of specimen peened by cavitation was 331 MPa. Thus, the fatigue strength of cavitation peening increased by 22% compared with the non-peened specimen.

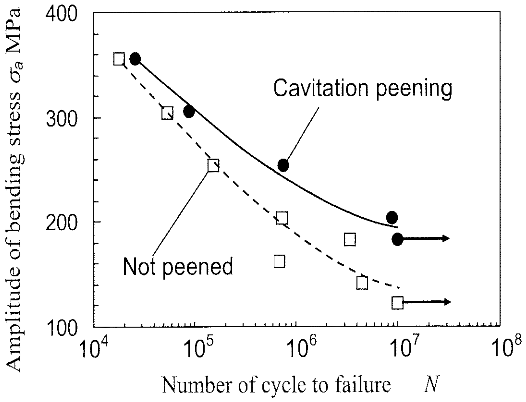


Fig. 2 Improvement of fatigue strength of duralumin by cavitation peening

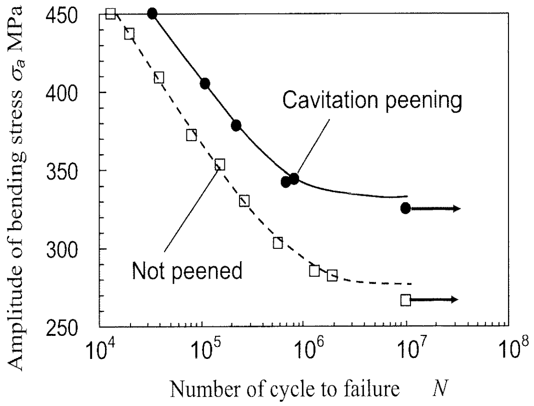


Fig. 3 Improvement of fatigue strength of stainless steel by cavitation peening

Figure 4 illustrates the distribution of residual stress changing with distance from the surface. The residual stress was measured by an X-ray diffraction method removing the surface by electro-etching. The material in Fig. 4 was stainless steel. The residual stress without peening was about 0 MPa. After the peening by the cavitating jet in air, the residual stress on the surface was about –550 MPa. This means that the cavitation peening using a cavitating jet in air can introduce the compressive residual stress into stainless steel. At 100 μm, the residual stress was about –300 MPa and it was –200 MPa at 200 μm. The introduction of residual stress was one of the reasons why the cavitation peening improves the fatigue strength.

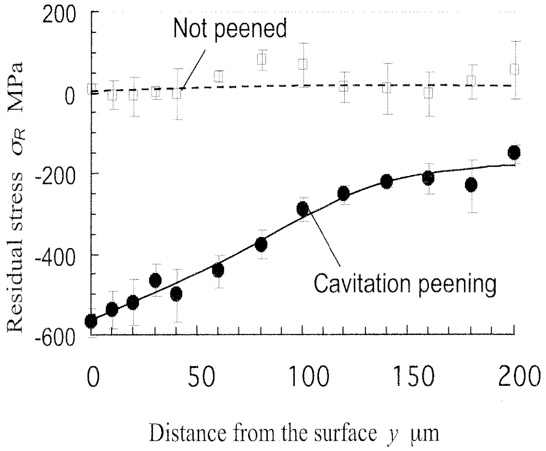


Fig. 4 Introduction of residual stress into stainless steel by cavitation peening

CONCLUSION

In order to demonstrate the improvement of fatigue strength by a cavitating jet in air, the fatigue test was investigated using a rotating bending fatigue test and a plate bending fatigue test. The fatigue strength at 10^7 cycles was improved 46 % for duralumin and 22 % for stainless steel peened by the cavitating jet in air.

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