Improvement of Fatigue Strength of Light Metallic Materials by Cavitation Shotless Peening

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ABSTRACT
Cavitation normally causes severe damage in hydraulic machinery such as pumps, valves and so on. However, cavitation impact can be utilized to surface treatment to improve fatigue strength of metallic materials in the same way as shot peening. A peening method using cavitation impact was named as “cavitation shotless peening” or “cavitation peening” as shots are not required. As increase of surface roughness induced by cavitation shotless peening was relatively small comparing with that of shot peening, improvement of fatigue strength of light metallic materials would be better than that of shot peening. In the present paper, the aluminum alloy and the magnesium alloy treated by cavitation shotless peening were tested by a rotating bending fatigue test. It was revealed that the fatigue strength of the aluminum alloy JIS AC4CH and magnesium alloy JIS AM60B were improved 40 % and 20 %, respectively.

KEY WORDS
Fatigue strength, Surface treatment, Cavitation, Residual stress, X-ray

INTRODUCTION
In recent years, it was suggested that impacts at cavitation bubble collapses was used for inducing compressive residual stress like shot peening (SP), and it was revealed that collapsing cavitation bubbles makes improving corrosion resistance and fatigue strength. Cavitation impacts utilized for surface modification is called “cavitation shotless peening (CSP) (H. Soyama, K. Sasaki, D. Odhiambo, et al., 2003)” or "cavitation peening (CP) (H. Soyama, 2006)" as shots are not required.
CSP is not required for shots. So, increase of surface roughness of materials peened by CSP is smaller than that of SP, because solid contact is not occurred. Especially, increase of surface roughness of peened light metallic materials is small. So, it is revealed that CSP makes improving fatigue strength greater than SP (H. Soyama, 2006, and H. Soyama, K. Saito, and M. Saka, 2002).
Normally, a cavitating jet was produce by injecting a high-speed water jet into water filled chamber. In the present paper, this kind of jet was called a cavitating jet in water (CJW). Soyama successfully realized a cavitating jet in air (CJA), injecting a high speed water jet into low speed water jet, which was injecting into air directly (H. Soyama, 2004). It was found that the capability of optimized CJA was greater than that of CJW and even a normal water jet in air (H. Soyama, 2004). One of the reasons is unsteady interference between a high speed water jet and low speed water jet (H. Soyama, 2007).
In the present paper, to verify the improvement of fatigue strength of light metallic materials with CSP using CJW and CJA, fatigue strengths of non-peened specimen and peened specimen by CSP of magnesium alloy and aluminum alloy were investigated with rotating bending fatigue testing machine.

EXPERIMENTAL APPARATUS AND METHODS

In testing machine using CJA, nozzle diameters for the high and low speed water jet were 1 mm and 20 mm, respectively. The injection pressures for high and low speed water jet were 30 MPa and 0.05 MPa, respectively. In testing machine using CJW, nozzle diameter was 2 mm. The injection pressure was 30 MPa, and the pressure of tank was 0.32 MPa.

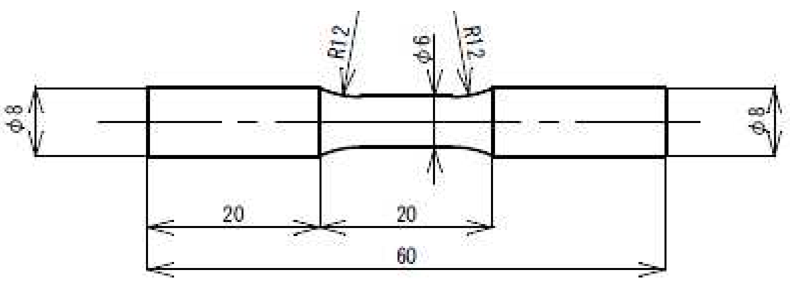
The tested materials were magnesium alloy, Japan Industrial Standard (JIS) AM60B, and two kinds of aluminum alloys, JIS AC4CH and JIS AC8AH. The diameters of AM60B and AC8AH for rotating bending fatigue test were 8 mm in parallel portion, and the diameter of AC4CH was 6 mm. Figure 1 illustrates the shape of specimens.

To investigate effects of CSP, residual stresses of the tested materials were measured. The residual stress of AM60B was measured using X-ray diffraction apparatus with two dimensional position sensitive proportional counter (2D PSPC) by 2D method (B. B. He, K. L. Smith, 1997) (H. Soyama, 2005). The diffractive plane was the (103) plane of Mg, and the diffractive angle 2θ is 102 degrees. Exposure time is 20 minutes per one flame changing with X-ray incidence angle χ and rotating angle of specimen ϕ, and it is measured 15 flames. The used Young's modulus was 40 GPa. The residual stresses of AC4CH and AC8AH were measured using X-ray diffraction apparatus with scintillation counter by $2\theta - \sin^2\psi$ method. The angles between the normal of surface and the normal of the lattice planes ψ were 10, 20, 26.9, 32.7, 38 degrees', and the diffractive plane was the (222) plane of Al and the diffractive angle 2θ is 156.7 degrees. The stress constant is -94 MPa/degree.

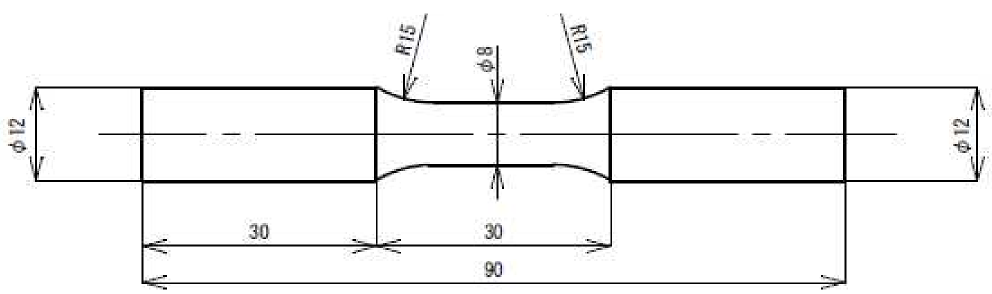
The processing time per unit length t was defined from scanning speed v and number of scans n as follows:

$$t = \frac{n}{v} \qquad (1)$$

When the test specimens for rotating bending fatigue test were peened by CSP, they were being rotated and moved at constant velocity for axis direction per a rotation.



(a) Specimen of AC4CH



(b) Specimens of AC8AH and AM60B

Fig. 1 Schematic illustrations of the specimens for rotating bending fatigue test

RESULTS

To investigate effects of CSP for magnesium alloy AM60B, residual stresses of the tested materials were measured with plates. After polishing the specimen with #2000 emery paper, the residual stress of the surface of the specimen was about – 40 MPa before peened by CSP. After the specimen was peened by CSP with CJA, the compressive residual stress was increased for – 100 MPa. It was revealed that the specimen of AM60B was induced compressive residual stress like that of iron and steel materials.

Figure 2 illustrates the relationship between the residual stresses σ_R of the specimens of aluminum alloys AC4CH and AC8AH peened by CSP with CJA and processing time per unit length t. The residual stresses of both the specimens of AC4CH and AC8AH were saturated for – 90 MPa at t = 5 s/mm. After that, the values of the residual stresses were constant. It was decided that 10 s/mm was processing time for CSP with CJA to use rotating bending fatigue test, because the residual stresses were saturated completely. And it is decided that processing time of CSP with CJW was 2 s/mm based on the papers (H. Soyama, K. Sasaki, K. Saito, et al., 2003).

Figure 3 illustrates the result of rotating bending fatigue test of the specimen of magnesium alloy AM60B peened by CSP with CJA. Non-peened specimen was ruptured at 1.4×10^5 cycles when the amplitude of the bending stress σ_a was 85 MPa, and peened specimen by CSP was not ruptured at 10^7 cycles when the amplitude of the bending stress σ_a was 100 MPa. Namely, the fatigue strength of magnesium alloy was improved by CSP.

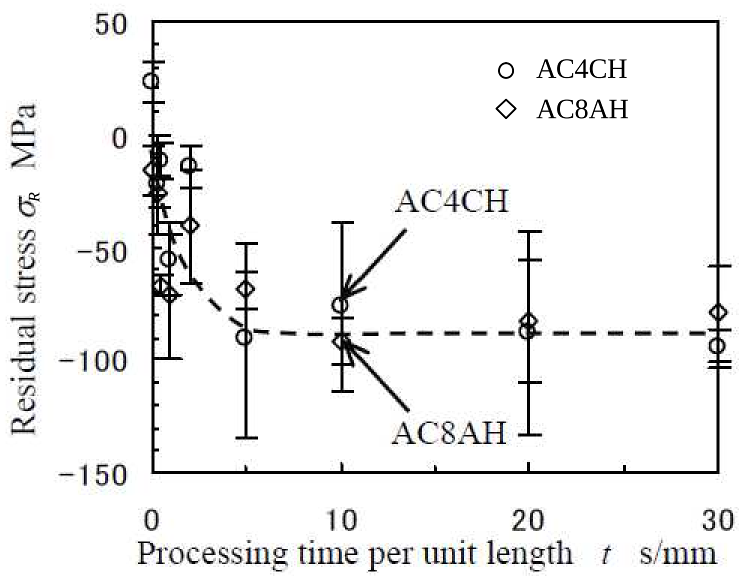


Fig. 2 Residual stress changing with processing time

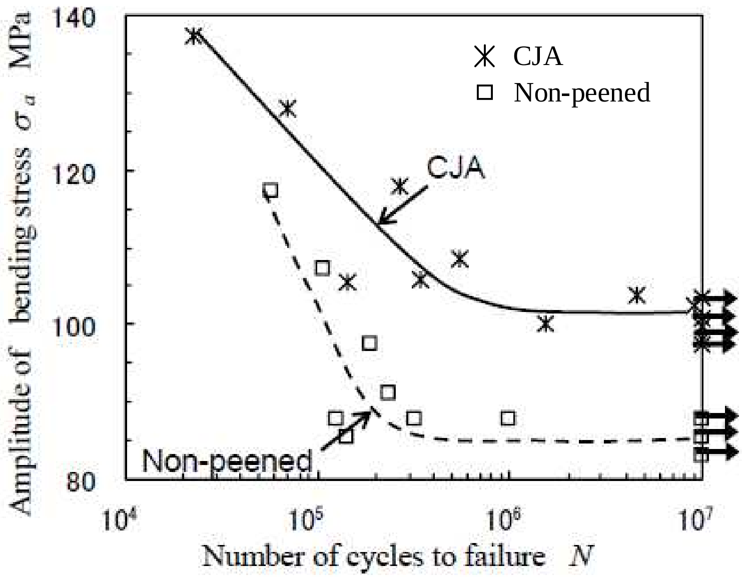


Fig. 3 Improvement of fatigue strength of magnesium alloy AM60B by cavitation peening

Figures 4 and 5 illustrate the results of rotating bending fatigue test of the specimens of aluminum alloy AC4CH and AC8AH peened by CSP with CJA and CJW. The fatigue strengths of the specimens peened by CSP were improved. The fatigue strength of the specimen of AC4CH peened by CSP with CJA is grater than peened by CSP with CJW, and the fatigue strength of the specimen of AC8AH peened by CSP with CJW is grater than peened by CSP with CJA. Both injection pressures of CJA and CJW were 30 MPa, but the power of the jet of CJW was 4 times greater than that of CJA, because the nozzle diameter of CJA was 1 mm, and the nozzle diameter of CJW was 2 mm. In addition, the nozzle whose diameter was 2 mm was not able to be used for CJA, because the low speed water jet needed to shield the high speed water jet to the region of elapsing cavitating bubbles.

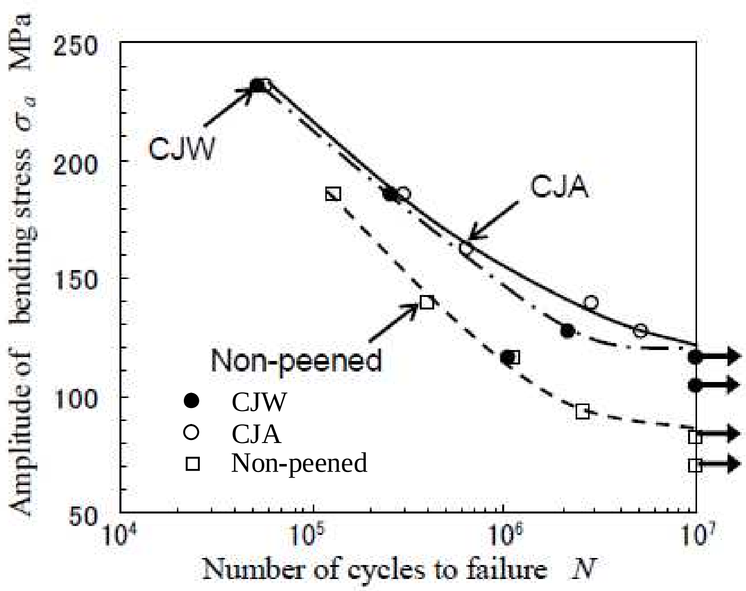


Fig. 4 Improvement of fatigue strength of aluminum alloy AC4CH by cavitation peening

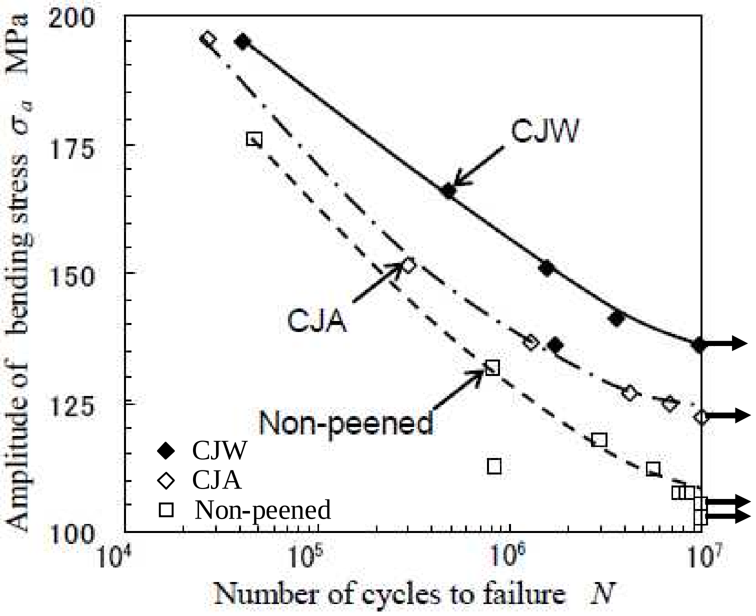


Fig. 5 Improvement of fatigue strength of aluminum alloy AC8AH by cavitation peening

CONCLUSION

To verify the improvement of fatigue strength of light metallic materials such as magnesium and aluminum alloys peened by CSP using the impact force of elapsing cavitating bubbles, the specimens of magnesium alloy (AM60B) and aluminum alloys (AC4CH and AC8AH) were peened by CSP and investigated fatigue strength with rotating bending fatigue test machine. In the result, compressive residual stresses were induced and fatigue strengths were improved for all specimens.

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