Effect of Tensile Stress on Cavitation Erosion and Damage of Polymer

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Abstract. Cavitation erosion tests for epoxy, unsaturated polyester, polycarbonate, and acrylic resin were conducted under various tensile stress conditions (Tensile-Cavitation test). A new testing device was designed to conduct the Tensile-Cavitation test and observe specimen surface during the experiment based on ASTM G32. When tensile stress of 1.31 MPa was loaded on epoxy resin, cracks occurred on the specimen after 0.5 hours during cavitation erosion. When no tensile stress was loaded on the epoxy resin, the damage was general cavitation erosion only. As well as the epoxy resin, unsaturated polyester resin applied tensile stress of 1.31 MPa and polycarbonate resin of 6.54 MPa indicated erosion damages and cracks. When tensile stress of 6.54 MPa was loaded on acrylic resin, the erosion damage was almost the same as the results without tensile stress. We confirmed that anti-cavitation property of epoxy resin was higher than those of acrylic and polycarbonate without tensile stress while the damage of epoxy resin was much serious than that of acrylic resins under tensile stress loadings.

1. Introduction

Cavitation erosion occurs in fluid machinery like pumps and valves. Repairing of the machineries have been paid attention for extending life and decreasing maintenance cost by polymer materials. So far, the evaluation method of the repairing part has not been well established yet. There are many studies to examine anti-cavitation properties of materials [1], [2], [3], while anti-cavitation properties of coating materials in pumps may be affected by tensile stress. Our previous study [4] reported that cracks were generated in epoxy resins under tensile stress loads in cavitation erosion tests. In this study, cavitation erosion test was conducted for various polymer materials (epoxy, unsaturated polyester, polycarbonate, and acrylic resins) by applying tensile stress (Tensile-Cavitation test) in order to examine the mechanism of cavitation damages.

2. Experimental procedure

New testing equipment was designed. It can monitor specimen condition during Tensile-Cavitation test. Figure 1(a) shows schematic of the device. Tests were carried out based on ASTM G32 [5].
Magnetostrictive vibrating device generates the ultrasonic wave that is amplified by horn and results in vibration of the disk made of stainless steel. Cavitation is generated around the stainless disk. The magnetostrictive vibrating device’s frequency was 19.5 kHz, and the half amplitude is 25 µm. Specimen was placed at the distance of 1mm from the disk. The specimen was fixed by chucks and applied tensile stress through the stainless wire by weight. Chucks were fixed on two linear guides, and it can move in a tensile direction. If creep deformation occurs on specimen, specimen can be applied a constant tensile force and specimen position can be adjusted easily. Mirror placed in water tank was inclined to observe the specimen condition by video camera placed in front of the equipment outside of the tank. Testing liquid was distilled water whose temperature was kept at 25°C by the circulation tank. Figure 1(b) shows closed-up view of the test section. Specimen and stainless disk can be observed in the mirror.

(a) Schematic of the test section  
(b) Enlargement of test section

Fig. 1 Testing device

To confirm applied tensile load by the weight, strain gages were put on both sides of epoxy resin. Stress was calculated by the strain signals, Young’s modulus and cross sectional area of the specimen. It was found that the applied load was about 70% of the weight. Therefore, we use the magnitude of tensile stress that is 0.7 times smaller of the weight.

Specimens were epoxy (EP), unsaturated polyester (UP), polycarbonate (PC), and acrylic resin (PMMA). EP and UP specimens were made by mixing main agent and curing agent to form the dog bone shape of the general specimen. PC and PMMA specimens were readymade and shaped by machining.

3. Results and Discussion

3.1. Epoxy resin (EP)

Figure 2 shows extracted pictures from the movie in the Tensile-Cavitation test for epoxy resin. Figure 2(a) shows epoxy surface after 28 hours without tensile stress. Only cavitation erosion was observed after 2.5 hours without tensile stress. Figure 2 (b), (c) shows epoxy specimen applied tensile stress of 1.31 MPa. We can also see the stainless disc of the tip of the horn behind the specimen. After 0.5 hours, crack was generated. After 2 hours, several cracks were generated and gradually developed. Some cracks were combined into one large crack. Figure 2 (d) shows epoxy surface after test. Epoxy resin was broken after 7.5 hours. Cavitation erosion was also observed as well as the case without tensile stress. We confirmed that cracks were generated in epoxy resin by tensile stress under cavitation loading. In this case, crack was observed earlier than the occurrence of cavitation-erosion without tensile stress. By microscope observations, it was revealed that micro cracks were generated around the voids after the test. The voids were created due to the entrainment of the air when the specimens were prepared. We considered that the stress concentration occurred around the voids due to the cavitation impact under tensile stress loading and micro cracks were generated and gradually developed into the macroscopic cracks.
3.2. Fractography

Fracture surface of EP ruptured by Tensile-Cavitation tests was observed. The specimen was applied tensile stress of 0.5 MPa and ruptured after 25.2 h. Figure 3 (a) is a monitoring image after 4 h when a crack was observed. Figure 3 (b) shows fracture surface near starting point of crack observed by laser microscope. Left side of this image is erosion surface and near the origin of fracture. Near the surface, mirror area and beach marks were observed. Around the middle of this figure, many small cracks were observed (Scaly pattern). From these results, cracks were expected to be developed by fatigue from the erosion surface side.

3.3. Results of Four resins

Tensile-Cavitation tests for UP, PC and PMMA were carried out as well as epoxy resin. Figure 4 (a) shows relation of stress and crack initiation time about EP, UP and PC. Closed symbol means crack initiation time. Opened symbol means finishing time of the test without crack in the specimen. This graph shows that the higher tensile stress is loaded on EP, the earlier crack is generated. Cracks were not observed when EP was applied tensile stress of less than 0.24 MPa. Cracks were not observed when UP was applied tensile stress under 0.62 MPa. It is believed that the threshold tensile stress exists. Cracks were observed on PC plane specimen applied tensile stress of 6.54 MPa. However, crack was not observed on PC applied tensile stress of 6.54 MPa when PC specimen had two holes to make stress concentration areas. The damages with stress concentration specimen by holes can be different from the specimen without stress concentration with tensile stress 6.54 MPa. Crack was not observed on PMMA applied tensile stress of 6.54 MPa. We are planning to conduct Tensile-Cavitation test for PMMA plane specimen applied higher stress and confirm whether crack is generated. Figure 4 (b) shows relation of stress and erosion initiation time about EP, UP, PC and PMMA. Although erosion was generated in all materials, we cannot find the relation between stress and erosion initiation time so far.
3.4 Discussion

It is suspected that crack is generated on EP, UP and PC applied tensile stress of more than threshold value. Although cracks were observed on EP and UP earlier than erosion, on PC later than erosion. EP and UP specimen included many voids mixed in preparing (molding) process. PC specimen included no voids. It seemed that mixed voids and micro cracks by cavitation erosion resulted in macroscopic cracks. Voids and micro cracks are necessary to be observed by microscope when cracks begin to generate. We will investigate the relation of crack generation and voids size in the future works. From observation of fracture surface, cracks were expected to be generated and developed by fatigue. Moreover, an EP specimen was ruptured only by applying tensile load after cracks were well observed. This implies that once crack length exceeds the threshold, stable fracture occurs. We will further investigate the initiation mechanism of cracks and fracture mechanics.

4. Conclusion

We made a new testing device that enabled us to monitor specimen condition in order to reveal the damage behavior of polymer materials applied tensile stress and cavitation erosion. Tensile-Cavitation tests for EP, UP, PC and PMMA were carried out. On EP without tensile stress, erosion was generated after 28 hours. However, on epoxy applied tensile stress of 1.31 MPa, crack started to be observed after 0.5 hours and specimen was broken after 7.5 hours. Cracks were generated on UP and PC under tensile stress. Tensile stress enhanced damages on EP, UP and PC. It is suspected that crack is generated on EP, UP and PC applied tensile stress of more than threshold value. Anti-cavitation property of EP without tensile stress showed stronger than that of acrylic. However, crack was generated on EP applied tensile stress of 1.31 MPa. Crack was not generated on PMMA applied tensile stress of 6.54 MPa. Anti-cavitation property under tensile stress was reversed. When polymer materials are used to coat for repairing, anti-cavitation property considering cavitation erosion and tensile stress will be required for its reliability. We observed fracture surface of EP specimens and confirmed beach marks near the erosion surface.

References

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