Liquid droplet impingement erosion behavior of low-alloy steels under simulated secondary water chemistry of pressurized water reactors

S. C. Yoo[1], S. Kim[2], J. Ham[1], Y. Lee[1], D. J. Lee[3], K. M. Hwang[3] and J. H. Kim[1*]

[1]Department of Nuclear Engineering, School of Mechanical, Aerospace and Nuclear Engineering, Ulsan National Institute of Science and Technology, Ulsan, Republic of Korea
[2]Authorized Nuclear Inspection Department, Korea Institute of Materials Science (KIMS), Changwon, Republic of Korea
[3]Korea Electric Power Cooperation Engineering & Construction (KEPCO E&C), Gimcheon, Republic of Korea

[*]Corresponding author: kimjh@unist.ac.kr

1. Introduction

Most of pipe components used in secondary system of nuclear power plant are made with carbon or low alloy steel. Those component were reported to be fracture or wall-thinned due to flow accelerated corrosion (FAC) or erosion such as flashing, cavitation and liquid drop impingement erosion (LDIE) [1,2]. Among this, FAC and LDIE are frequently regarded as the main corrosion mechanism of this components. FAC is corrosion which accelerated by high temperature and high velocity of water or wet steam. Meanwhile, LDIE is accelerated erosion caused by the impact of high-speed droplets or jets.

Among these mechanisms, LDIE have not been fully understood in literature due to lack of studies about many parameters such as droplet velocity, diameter or number of droplets, pH, temperature, impact speed, and so on. LDIE is controlled by many different factors as listed above. Also, the experimental setup for LDIE is difficult. Every parameter should be carefully controlled and estimated to achieve qualified result. Several testing methods were suggested by American standard for material testing (ASTM) standards. Among these, ASTM G-73-10 suggest a test method which is relatively easy to construct the facility and control the important parameters such as droplet size and impact speed, etc. However, a few laboratories have this facility, and this leads to the lack of experimental data regarding LDIE.

Several researchers in Japan performed the LDIE test with water droplet accelerated by water jet facility [2–5]. However, it is hard to design the facility with such concept, also it is difficult to control precisely. Previous research [6] in Korea report the effect of droplet speed, size and material hardness. Many interesting and important results and suggested, however, still there exists lack of data in long-term operation.

In this study, based on the experiment conducted in previous study [6], long-term LDIE experiment was conducted to figure out the LDIE behavior of low alloy steel and carbon steel.

2. Experiments

Materials used in this study were A106 Gr. B and A335 P22 which have chemical composition presented in table 1

Table 1. Chemical compositions of materials used in this study

	A106 Gr. B	A335 P22
C	0.28	0.15
Si	0.1	0.5
Mn	1.16	0.6
P	0.03	0.025
S	0.03	0.025
Cr	0.4	2.6
Mo	0.15	1.13
Cu	0.4	-
Ni	0.4	-
Fe	Bal.	Bal.

Specimens were prepared to 10 x 30 x 3 mm^3 as shown in figure 1. Those specimens were mounted to rotating facility to simulate high impact speed of liquid drop to specimen surface. Detailed experimental procedures are explained in previous study [6].

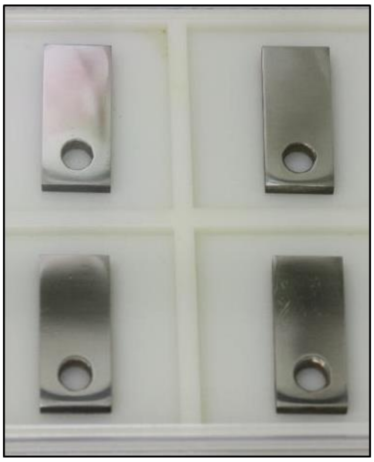

Figure 1. specimens used in this study. Upper ones are A106 Gr. B and lower ones are A335 P22 specimens every specimen was polished before experiment.

Detailed experimental condition is listed; temperature of 30 °C, impact speed was 120 m/s, size of liquid drop was 700 μm (controlled via differential pressure), dissolved oxygen concentration was below 5 ppb, pH was 4 and test duration was 500 h.

3. Results and Discussions

As shown in figure 2, A106 Gr B seems high LDIE rate at the early stage. However, the erosion rate of A335 P22 getting increased after 170 h of exposure, and it becomes have higher LDIE rate than A106 Gr. B.

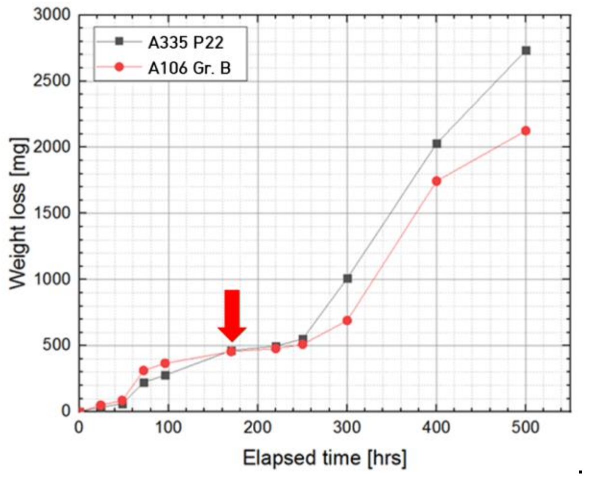

Figure 2. weight loss rate of A335 P22 and A106 Gr. B during 500 hours of exposure.

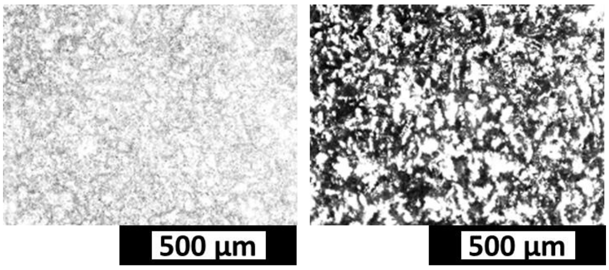

Figure 3. Optical microscopy of A106 Gr. B (left) and A335 P22 (right) after 400 hours of exposure.

Figure 3 shows optical microscopy of A106 Gr. B and A335 P22 after 400 hours of exposure to LDIE experiment. It seems that A335 P22 undergoes erosion more severe than that of A106 Gr. B.

It is suspected that A335 P22 have higher chromium contents and magnetite formed on A335 P22 should be less than that of A106 Gr. B. Generally, magnetite has higher hardness than ferrite matrix and have higher resistance to erosion.

4. Conclusion

LDIE of carbon steel and low alloy steel in secondary system of nuclear power plant becomes issued due to wall-thinning and corrosion problem. To understand the nature of LDIE, long-term experiment was conducted with A106 Gr. B and A335 P22.

At early stage of experiment, A106 Gr. B shows higher weight loss rate, however, after exposure time of 170 h, A335 P22 shows higher weight loss rate. It is suspected that A335 P22 have higher chromium contents and magnetite formed on A335 P22 should be less than that of A106 Gr. B. Generally, magnetite has higher hardness than ferrite matrix and have higher resistance to erosion.

Acknowledgment

This work was supported by Korea Electric Power Cooperation Engineering & Construction (KEPCO E&C) and by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Trade Industry and Energy (MOTIE) (No. 20194030202400).

References

[1] V. Kain, Flow accelerated corrosion: Forms, mechanisms and case studies, in: Procedia Eng., 2014. doi:10.1016/j.proeng.2014.11.083.

[2] N. Fujisawa, T. Yamagata, K. Hayashi, T. Takano, Experiments on liquid droplet impingement erosion by high-speed spray, Nucl. Eng. Des. (2012). doi:10.1016/j.nucengdes.2012.06.022.

[3] M. Naitoh, H. Okada, S. Uchida, H. Yugo, S. Koshizuka, Evaluation method for pipe wall thinning due to liquid droplet impingement, Nucl. Eng. Des. (2013). doi:10.1016/j.nucengdes.2013.02.018.

[4] N. Fujisawa, T. Yamagata, K. Saito, K. Hayashi, The effect of liquid film on liquid droplet impingement erosion, Nucl. Eng. Des. (2013). doi:10.1016/j.nucengdes.2013.07.039.

[5] S. Hattori, Effects of Impact Velocity and Droplet Size on Liquid Impingement Erosion, in: Int. Symp. Ageing Manag. Maint. Nucl. Power Plants, 2010.

[6] K.M. Hwang, H.K. Seo, C.K. Lee, W.C. Nam, Development of a LDIE Prediction Theory in the Condition of Magnetite Formation on Secondary Side Piping in Nuclear Power Plants, World J. Nucl. Sci. Technol. (2016). doi:10.4236/wjnst.2017.71001.