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Environmental Fatigue Test to See Strain Hardening Effect of CF8M Stainless Steel in PWR Condition

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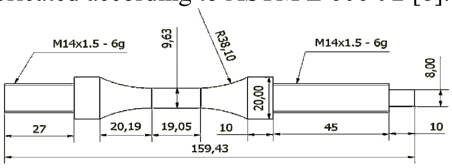
1. Introduction

It has been known that environmental fatigue is to be a cause of component crack initiations in pressure boundary of nuclear power plant (NPP) primary side [1-2]. In operating NPPs, fatigue design follows ASME B&PV Sec. III codes and fatigue crack evaluation is performed according to ASME B&PV Sec. IV. However, current fatigue design practice with ASME B&PV Sec. III does not regard environmental effects of stainless steel fatigue. Some fatigue data to date have shown not to be marginal enough for environmental fatigue [2-4]. For a last couple of decade many experimental tests for stainless steels environmental fatigue have been performed. They have tested lots of SS316NG and SS304 materials in light water reactor (LWR) of various operating conditions [4-7].

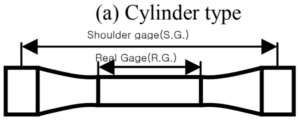
In this study, a low cycle environmental fatigue test rig of Korea Electric Power Research Institute (KEPRI) [10,11] was used to see characteristics of the cyclic strain hardening effect of CF8M used for reactor coolant system (RCS) piping of a domestic vintage NPP**.**

2. Experiment method

Test specimen blocks are manufactured according to CMTR (certified material test report) of a domestic power plant. It would be the best policy to test the real material used in NPP. So the test material block was made in a local steel company. Test specimens (Fig. 1) were fabricated according to ASTM E 606-92 [8].



(a) Cylinder type



(b) Real gage and Shoulder gageΔL of specimen

Fig. 1 Configuration of specimen

Fatigue load was achieved by a strain control method. Fatigue life was counted at the cycle numbers which were 25% load reduction from the first tension load [9].

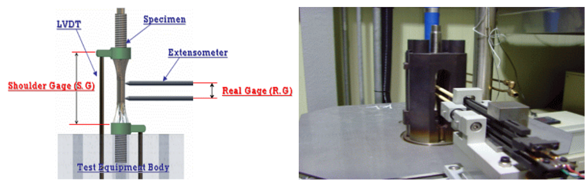
Table 1. Experimental conditions

Load ratio	Strain rate	Strain amplitude	Temper-ature	Pressure	Dissolved oxygen
-1	0.04 %/s	0.6 %, 0.8 %	315 °C	15 MPa	5 ppb

Fig. 2 Low cycle environmental fatigue test rig

3. Cyclic strain hardening of SA351 CF8M

Stainless steel SA351 CF8M has the features of cyclic strain hardening (CSH) in the case of a low-cycle fatigue test with strain-control. An extensometer is attached to the gage part of test specimens and a fatigue test can be conducted according to direct strain control in the case of fatigue test in the air, but in an experiment with the autoclave under the water chemistry condition of high temperature and high pressure, strain can not be measured directly from the gage. Another method is required to carry out the fatigue test in an environment of the pressurized water reactor (PWR), considering CSH.



a) Relations of real gage and shoulder gage   b) Installation of extensometer

Fig. 3 Relation and installation of extensometer and LVDT

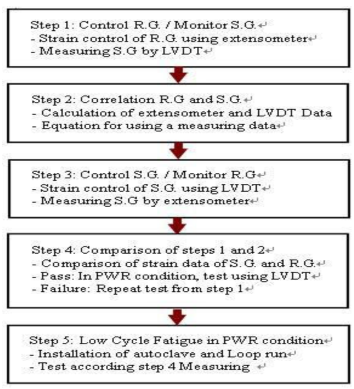
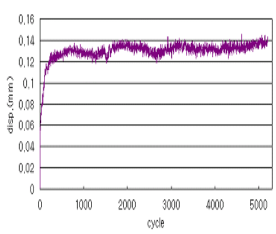


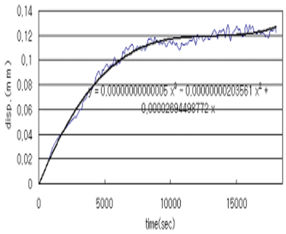
Fig. 4 Test flow for considering cyclic strain hardening

Figure 4 exhibits the process to conduct a low-cycle fatigue test in the environment of PWR operation. With the equation, displacements of the LVDT installed in a S.G. are controlled according to cycles.

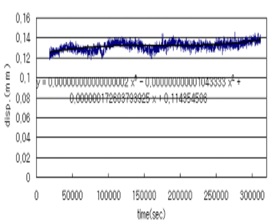
Figure 5 shows the 2-stage equation process and experiment results by using correlations of R.G. and S.G. parts in Step 1. The equation is presented by 2 stages, and it is due to the fact that 1 equation is difficult to represent properly fatigue curves because the initial and middle stages of the fatigue test have different features of the shoulder gage.



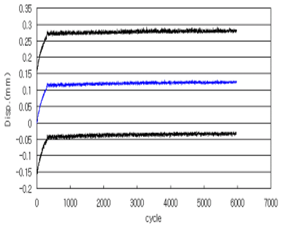
a) LVDT displacements in the shoulder gage part according to cycles



b) Equation of step 1



c) Equation of step 2



d) Control and displacement of LVDT through equation

Fig. 5 2-step equation of cycle and LVDT

4. Result and Conclusion

The test was carried out under the strain amplitude of 0.6% and 0.8%, and as for the strain amplitude of 0.4%, a test is being conducted. Fig.6 shows the maximum load per cycle. As shown in the figure, the CHS effect appears with the load being increased in early stages below 200-cycle, and it goes into a stable stage and then reaches the limit life. Fig.7 shows the comparison between the results of this study and those of previous similar studies. When comparing with the results of an experiment in the PWR condition that Korea Electric Power Research Institute (KEPRI) carried out, prior to the development of the technology in this study, by defining correlations between real and shoulder gage parts through FEM analysis, it is thought that the fatigue life through FEM analysis has an inclination to be more conservative than that through this experiment, but it also shows the similar inclination each other. Thus, those results in this study prove the effectiveness of FEM analysis and the reliability of the test equipment.

- To reflect CSH effects, the displacements of the LVDT in the shoulder gage part of the test spacemen were classified into 2-stage according to cycles with equations. The CSH effect appeared in the real gage parts of the CF8M environmental low cycle fatigue test spacemen was simulated through the process of this study.
- As a result by comparing with other fatigue life features, the test results were similar to the tendencies of existing data, and the curve of this study was shown to be lower than ASME Mean Curve and RT air Curve.

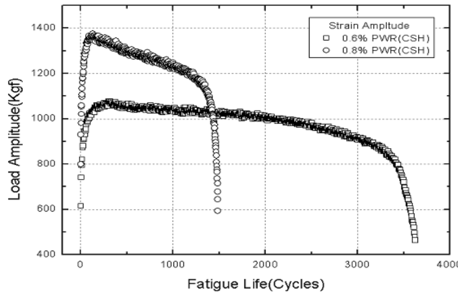


Fig. 6 Relation of maximum load and fatigue life

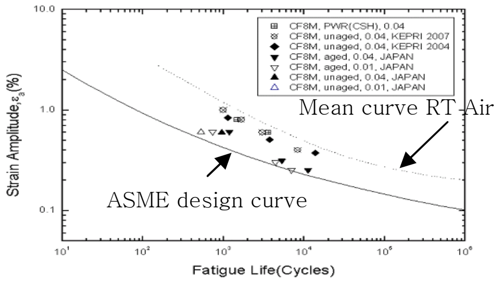


Fig. 7 Comparison of data with others

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