Creep-Fatigue Damage Characteristics for a Welded Cylindrical Structure of Austenitic Stainless Steel

Hyeo-Yeon Lee, Jong-Bum Kim, Seok-Hoon Kim, Young-Sang Joo, Jae-Han Lee
a Mechanical Engineering Division, KAERI, Dukjindong, Yuseong, Deajeon,305-606, Korea, hylee@kaeri.re.kr

1. Introduction

In the design and assessment of a high temperature structure, it is important to ensure the structural integrity for the welded joint subjected to a creep-fatigue load because a statistical investigation [1] shows that 29 events out of 46 leaks in liquid metal reactors were caused at the welded joints. As for the structural integrity due to thermal ratchet load at the welded joint, KAERI has performed the test and analysis work for a cylindrical structure with welded joints[2].

As a continuation of the study on welded joints at a high temperature structure, a creep-fatigue structural test and analysis work is now on-going and this paper present the interim findings for the structural test and analysis work. Recently the structural and analysis work for the Y-piece made of a 316L stainless steel structure has been carried out[3]. The objectives of the present structural creep-fatigue test with the welded cylindrical specimen are to compare the creep-fatigue damage mechanisms for the 304 and 316L stainless steels, to compare the different behavior of the welding methods in a high temperature austenitic structures and to quantify the conservatism of the design guidelines for a high temperature structure.

2. Details of the Welded Cylindrical Specimen

The structural test model is a welded cylindrical structure as shown in Fig. 1. The materials at the upper half and lower half part are 304 and 316L stainless steel, respectively. The two welding methods, GTAW(Gas Tungsten Arc Welding=TIG) and SMAW(Shielded Metal Arc Welding) were applied for the 304 and 304(similar welding), for 316L and 316L(similar welding) and the 304 and 316L (dissimilar welding).

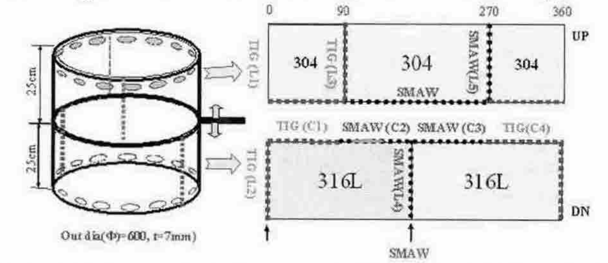

Fig. 1 Schematic Diagram of the Welded Structural Specimen

Eight defects were machined to examine the defect behavior and to apply a high level of the stresses on the specimen. Six defects are through a thickness having a length of 40mm and height of 0.3mm. Two defects are surface defects having a length of 40mm and a height of 0.3mm, and machined up to half of the thickness as a rectangular shape.

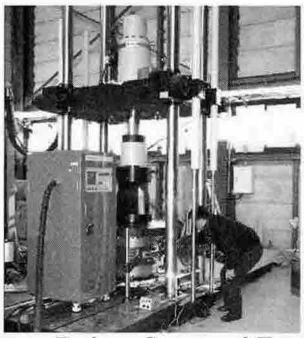

Fig. 2 Creep-Fatigue Structural Test Facility

The creep-fatigue test facilities consist of an actuator-hydraulic pump related system (IST system, 1MN capacity) and inductance heating unit (50kW capacity) as shown in Fig. 2.

3. Loading Conditions

The mechanical load of 60ton from the hydraulic actuator system is applied at each load cycle, which induces a nominal stress of 45.1MPa in the axial direction..

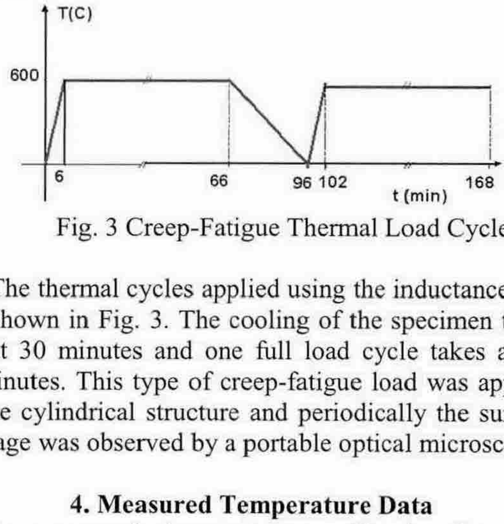

Fig. 3 Creep-Fatigue Thermal Load Cycle

The thermal cycles applied using the inductance coil are shown in Fig. 3. The cooling of the specimen takes about 30 minutes and one full load cycle takes about 95minutes. This type of creep-fatigue load was applied to the cylindrical structure and periodically the surface damage was observed by a portable optical microscope.

4. Measured Temperature Data

The measured temperature profile in the axial direction of the present test is shown in Fig. 4. About a 15cm span at the middle of the cylinder were observed at 600°C during a steady state.

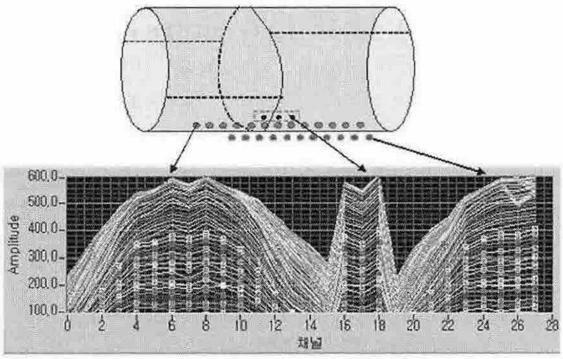

Fig. 4 Measured Temperature Data

5. Evaluation of the Creep-Fatigue Damage

A preliminary damage evaluation of the specimen was carried out using a simplified FE model and thermal loads. The FE model is a 3-D half symmetric with two defects as shown in Fig. 5. Primary load of 60ton was applied at the upper end of the cylinder and simplified temperature blocks ranging from 150°C(at bottom) to 550°C (at mid part) was given as the thermal loads.

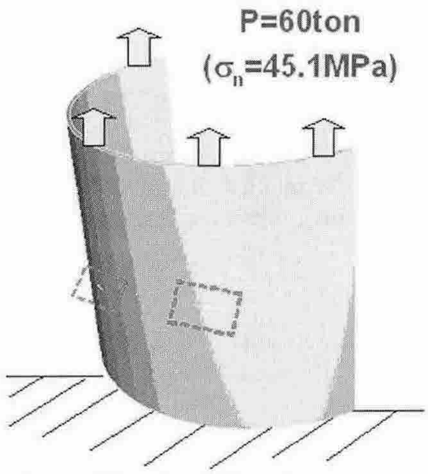

Fig. 5 Mechanical Load and Boundary Conditions

The analysis results for the 3D FE model showed that the maximum Mises stress was 210MPa and the maximum axial stress was 273.1MPa. The maximum axial strain was computed as 0.115% as shown in Fig. 6. All the maximum values occurred near the notch tip.

Evaluation of the creep-fatigue damage according to the ASME Subsection NH[4] has been carried out for these stress levels. The calculated total strain was calculated to be 0.948% and the corresponding fatigue lifetime was higher than 1×10^6. The calculated stress-to-rupture time was about 1,500 hours.

The structural creep-fatigue test will be continued until damage is observed and the surface grain boundaries will be observed periodically to quantify the degree of the damage under a creep-fatigue loading.

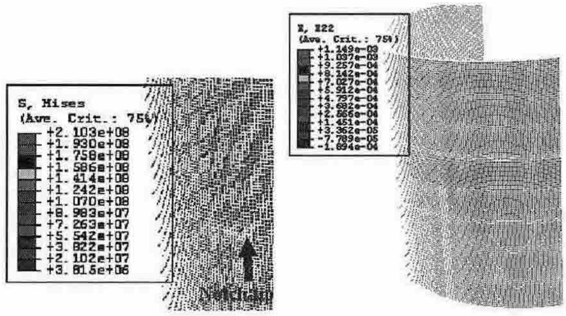

Fig. 6 Stress and Strain profiles for the Welded Structure

6. Conclusion

A creep-fatigue test for the welded cylindrical structure of austenitic 304 and 316L stainless steel with 8 defects has been carried out. The creep-fatigue damage mechanism for the 304 and 316L stainless steel and the two welding methods of GTAW and SMAW will be compared. The preliminary creep-fatigue damage evaluation showed that the damage was very small. The preliminary analysis results showed that the fatigue and creep damage were small but the evaluation with the actual thermal load and FE model may give different values. It is expected that the damage maps of GTAW vs. SMAW as well as the 304 and 316L stainless steels will be generated for a creep-fatigue loading.

Acknowledgements

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

References

[1] A Study on the Sodium Leak Accidents for the Structural Material in Liquid Metal Reactor, KAERI/AR-616, KAERI, 2001.

[2] H.Y.Lee, J.B.Kim, J.H.Lee, "Evaluation of Progressive Inelastic Deformation for the Welded Structure Induced by Spatial Variation of Temperature," *International Journal of Pressure Vessel and Piping*, vol. 81. No. 5, pp. 433-441, 2004.

[3] J.B Kim, C.K Park, H.Yeon. Lee, J.H Lee, "Creep-fatigue damage evaluation of 316SS Y-junction structure in Liquid Metal Reactor," ICAPP '04, June 13-17, Pittsburgh, 2004.

[4] ASME Section III Division I Subsection NH, Class 1 Components in Elevated Temperature Service, ASME, 2001.