1-8 Investigation of Strength of Structural Material Using Controlled Temperature Fluctuation Loading

—High Cycle Thermal Fatigue Tests in Sodium for Fast Reactor Design—

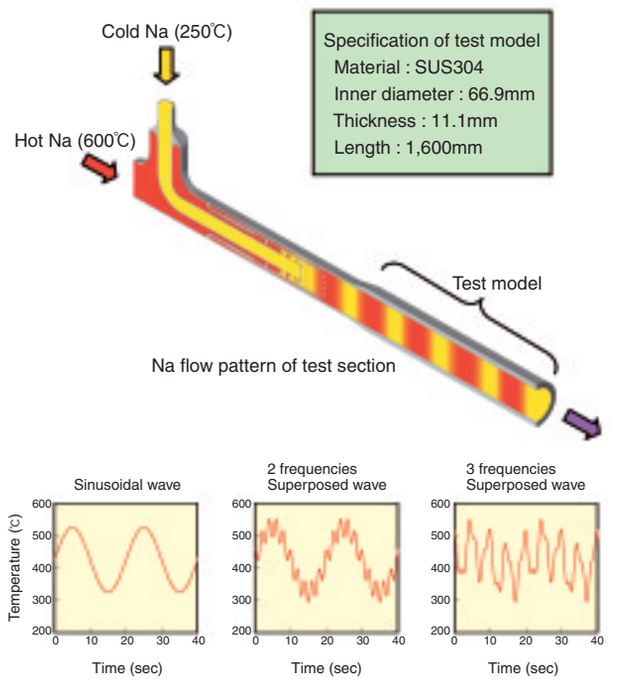

Fig.1-20 Test section structure and Na temperature histories

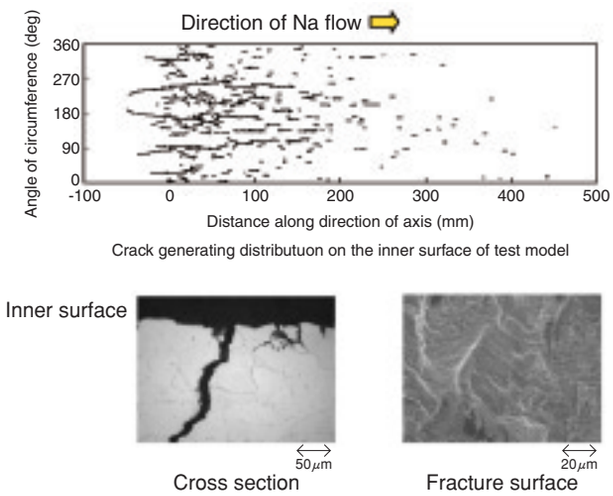

Fig.1-21 Fatigue damage observation after 160,000cycles at frequency 0.05Hz

Metallurgical observation of the damaged test model clarifies crack initiation, propagation, and mechanism, and gives verification data for an assessment method.

In nuclear power plants, it is necessary to assess possibilities of material failure by high cycle thermal fatigue due to the mixing of different temperature fluids, because thermal stress could occur in structural material by the cyclic temperature fluctuations of the fluids. It has been established that thermal stress depends on the frequency of temperature fluctuations. Therefore, we propose a high cycle thermal fatigue assessment method that includes the frequency effect in the thermal stress assessment, in the development of high temperature structural material assessment technology. In order to confirm the validity of this assessment method, we developed sodium (Na) temperature controlled thermal fatigue test equipment (SPECTRA). SPECTRA can accurately control the frequency of temperature fluctuation using Na, which is a coolant for a fast reactor. The thermal fatigue tests were then carried out for SUS304 steel, which is one of the main structural materials of fast reactors.

SPECTRA use electromagnetic pumps to control continually the ratio of high (600°C) and low (250°C) temperature Na fluids to produce temperature variations with various waveforms and frequencies. The temperature variations then initiate and propagate fatigue cracks in the test model of structural material (Fig.1-20). Major features of this equipment are (1) it can control temperature variation with sine wave frequency parameters while there is constant flow, (2) it can provide axially symmetric temperature variation in the test model to avoid complex thermal stress distribution, (3) it can efficiently obtain the data on the crack initiation as well as the crack propagation with one test model, giving the axial distribution of large and small thermal stresses, (4) it can generate temperature variations with superposed wave forms by combining different frequency waves, and so on.

The thermal fatigue tests were carried out under sine wave temperature variations with frequencies between 0.05-0.5Hz, which were generated by SPECTRA. In these tests, Na temperature was controlled at an average of 425°C and with a fluctuation of 200°C. The total flow rate was kept at 300 ℓ /min by mixing high/low temperature Na fluids each flowing at 150 ℓ /min in an antiphase manner into the test model.

From the test results, it was proved that there was a difference in the initiation and propagation of cracking, depending on the frequency. For example, at frequency 0.05 Hz, after 160,000 cycles of temperature variation, a crack occurred at the inner surface of the test model and penetrated to the outer surface (Fig.1-21). However at frequency 0.2Hz, even after 260,000 cycles, the inner surface crack did not reach the outer surface. There is a significant difference in fatigue life with these two frequencies. Therefore, it has been confirmed that even under the same amplitude of temperature fluctuation, depending on the difference of frequency, the thermal stress on the structural material will change, impacting on its fatigue life, the test proving the phenomenon that was previously known through theoretical modeling. These results will be used as verification data of the high cycle thermal fatigue assessment method.

In the future, we are planning to perform a test of superposed short period and long period waves. This test will be to assess the specific qualities of structural materials under random variations caused by actual irregular temperature fluctuations. In this way, the effects of complex temperature variations on structural materials will be studied.

Reference

Kawasaki, N., Kobayashi, S., Hasebe, S. et al., SPECTRA Thermal Fatigue Tests under Frequency Controlled Fluid Temperature Variation-Transient Temperature Measurement Tests-, Proceedings of 2006 ASME Pressure Vessels and Piping Division Conference (PVP2006) /International Council on Pressure Vessel Technology (ICPV11), Vancouver, Canada, 2006, ICPV11-93548, 8p., in CD-ROM.