The Effect of Dynamic Sodium on the Low Cycle Fatigue Properties of 316L(N) Stainless Steel

EXECUTIVE SUMMARY

The use of liquid sodium as a heat transfer medium for Liquid Metal Fast Breeder Reactors (LMFBRs) necessitates the assessment of the compatibility of structural materials, and the influence of long-term exposure to sodium on the Low Cycle Fatigue (LCF) and creep-fatigue interaction properties of reactor structural materials. LCF tests conducted in flowing sodium environment at 823 and 873 K on 316L(N) stainless steel, exhibited a similar trend in cyclic stress response in air and sodium. The fatigue lives are significantly improved in sodium environment when compared to the data obtained under identical testing conditions in air environment. The lack of oxidation in sodium environment is considered to be responsible for the delayed crack initiation and consequent increase in fatigue life. Comparison with RCC-MR design codes shows that the design curve based on air tests is conservative.

OUTLINE

In nuclear reactor applications the components are often subjected to repeated thermal stresses, as a result of temperature gradients which occur on heating and cooling during start-ups and shut-downs and/or transients. Therefore there is a need for comprehensive understanding of cyclic deformation behaviour and the micromechanisms which influence such behaviour. Further the use of liquid sodium as a heat transfer medium for Liquid Metal Fast Breeder Reactors (LMFBRs) necessitates the assessment of the compatibility of structural materials, and the influence of long-term exposure to sodium on the Low Cycle Fatigue (LCF) and creep-fatigue interaction properties. Currently the design of core and structural components of LMFBRs is being carried out utilizing test data generated in air. The actual environment seen by these components during service involves sodium. Moreover, the current trend being life extension of power plants, it is important to accurately determine the life of components in the actual environment, so as to determine any leverage for extension of life beyond the design life. With this view an elaborate programme has been initiated at Mechanical Metallurgy Division to evaluate the effects of dynamic sodium on the Low Cycle Fatigue (LCF), creep and creep-fatigue interaction behaviour of indigenously manufactured reactor materials such as 316L(N) stainless steel and modified 9Cr-1Mo ferritic steel and their weldments. The present report gives an update on the experiments conducted till date on the LCF properties of indigenously developed 316L(N) stainless steel in dynamic sodium environment.

The Low Cycle Fatigue (LCF) tests on 316L(N) austenitic stainless steel and modified 9Cr-1Mo ferritic steel were performed as per ASTM E 606 standards under fully reversed total axial strain control mode employing a triangular waveform. Tests were conducted at 823 K and 873 K at a constant strain rate of $3 \times 10^{-3}$ s$^{-1}$ with strain ranges varying from ±0.4% to ±1.0%. Sodium temperature was maintained within ±2K of the test temperature and sodium velocity was maintained at 2.5 m/s in the test chamber. The oxygen level in the sodium loop was maintained at less than 2 ppm.

The results of the LCF tests conducted at 823 K is given in Fig. 1. It is observed that the LCF lives of the fatigue tested specimens in sodium environment are significantly higher than the identical tests in air. The increase in life varies from a factor of about 5.5 at lower strain ranges to about a factor of 3 at the higher strain ranges used for the tests. The generally accepted reason for increase in life in sodium environment when compared to air environment is the lack of oxidation effects in high purity sodium. Metallographic investigations of the fracture surfaces show that environmental effects are virtually absent in a low oxygen sodium environment. Specimens are absolutely free from oxides or any other corrosion products. On the other hand fatigue tests conducted in air at high temperatures show substantial oxidation. It has been suggested that crack growth occurs from two sources, one being mechanical and the other being oxygen penetration at the crack tip; obviously in high purity, low oxygen sodium there will be virtually no contribution from the second source and hence the crack growth rate will be lower.
Loop details

The cold leg region comprises of the cold trap, plugging indicator, oxygen meter and a sampler device. The hot leg region comprises of the test sections for fatigue and creep-fatigue interaction studies. Sodium is being circulated through test section by an electromagnetic pump of 5 cum/hr capacity through a heat exchanger and heater vessel of 38.5 kW capacity. The return line from the test section goes to the degassing chamber and connects just before the EM pump through a heat exchanger and air cooler. The sodium flow velocity being maintained at the test section is 2.5 m/sec.

Fatigue test chamber

A special chamber has been designed to carry out these tests. Cylindrical specimen with a gauge diameter of 9 mm and a gauge length of 21 mm were used in this programme. The details of the fatigue test chamber used for conducting LCF tests in flowing sodium environment are given in figure 3. The specimen is enclosed within a miniature primary bellow surrounding which, a secondary bellow was provided for safety. Two flanges are provided from the upper and lower portions of the specimen gauge length from which an arrangement was made to house the LVDT for strain measurement.

Comparison with Codes:

The data generated in Mechanical Metallurgy Division in sodium environment is compared with the data provided in the RCCMR code for 316L(N) material at 873 K in Figure 2. The data pertaining to sodium tests lie above the upper bound curve of the air data. These results clearly indicate that design against LCF with air data is conservative.

This work validates indigenous 316L(N) stainless Steel and indigenous sodium to be used in PFBR as far as LCF properties are concerned, and clearly brings out the fact that design of components based on air data is conservative.

Publications arising out of this study and related work