（様式３）

論　文　内　容　の　要　旨

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Most of the current investigations pertaining to the fatigue behaviour of structural materials are dedicated to either low cycle fatigue (LCF) or high cycle fatigue (HCF) loading even though it is a well known fact that engineering components experience a varying load history throughout their service life. To secure long term reliability in engineering components, effect of random fatigue and multi-level loading on mechanical behaviour is fast becoming an important field of research. Currently, this is a significant issue in sodium cooled fast reactors (SFR) where components of the primary sodium circuit are prone to damage induced by LCF as well as HCF. LCF was caused in the components of the main vessel by sharp thermal transients during start-up and shut-down of the reactor. On the other hand, thermal striping and stratification in the mixing tee-junctions coupled with oscillations in the sodium free level in the main vessel during steady state operation cause significant high cycle fatigue (HCF). The presence of HCF cycling at locations where LCF is significant is the most damaging scenario since HCF damage gets superimposed on the LCF, leading to strong LCF-HCF interactions. Apart from this, strong creep damage is also prevalent in the locations where LCF and HCF damage are present, due to static pressure loads during the steady state operation of the reactor. Hence, a thorough investigation into the interaction between different damage modes prevailing during the reactor operation (LCF, HCF and creep) is deemed necessary for ensuring better structural integrity of the reactor components. As of now, investigations pertaining to LCF-HCF interaction have been very few and limited mostly to ambient temperature. To simulate LCF-HCF interaction under SFR operating conditions, experiments need to be carried out at elevated temperatures, especially in the range of 823-923 K which encompasses SFR operating temperature. Accordingly, an extensive investigation is planned to study the LCF-HCF interaction over a wide range of temperature from ambient to 923 K, using [illegible] n a type 316LN austenitic stainless steel which is the favoured candidate material for the in-core structural components in SFRs. There have been only limited attempts at developing life prediction models, particularly under extreme loading conditions as in LCF and HCF. The conventional method of damage evaluation under random loading is to sum up all the LCF and HCF cycles as per the Palmgren-Miner rule which suffers serious limitations with respect to accuracy under LCF-HCF interactions wherein the difference in life levels is significant. This was addressed in the present study by revisiting these models in the light of LCF-HCF interaction and estimating the value of the constants on the basis of rigorous experimentation.

Sequential tests carried out at 923 K showed that remnant HCF lives decreased drastically with increase in prior fatigue exposure as a result of strong LCF-HCF interactions. The rate of decrease in remnant lives varied as a function of the applied strain amplitude. A *threshold damage* in terms of prior LCF life-fraction was found below which no significant LCF-HCF interaction takes place. Similarly, a *critical damage* during the LCF pre-cycling marking the highest degree of LCF-HCF interaction was identified which was found to depend on the applied strain amplitude. Investigation carried out on the fracture surface and substructure showed formation of isolated *striation pockets* and *microtwins* as the major manifestations of LCF-HCF interaction. All these features appear within the window of effective LCF-HCF interaction and hence are a strong function of the applied strain amplitude as well as the degree of prior LCF exposure. Influence of dynamic strain aging (DSA) under sequential LCF and HCF loading was investigated by conducting HCF tests on specimens subjected to prior LCF at temperatures where DSA is highly pronounced i.e., 823-873 K. The cyclic hardening owing to DSA caused an early crack initiation through an increase in the cyclic stress response under LCF. On the other hand, the DSA-induced strengthening suppressed the crack initiation phase under HCF where the applied stress remains fixed. This mutually contrasting influence of DSA on LCF and HCF results in an anomalous fatigue behaviour in terms of remnant HCF life under LCF-HCF interaction. Detailed fracture surface examination revealed that extensive hardening associated with DSA leads to an extended zone of faceted appearance with river markings (Stage-I crack) under HCF cycling which reduces the crack growth rate by delaying the transition of crack from Stage-I to Stage-II, thereby leading to an extension of life in such cases. On the other hand, a highly striated fracture surface indicating a quick transition in crack from Stage-I to Stage-II, was observed for loading conditions with minimal or no influence of DSA, thus leading to lower life compared to the previous case.

Influence of the synergistic effects of LCF, HCF, creep and their interactions was studied at ambient to 923 K using multi-step load sequences where specific number of small amplitude HCF cycles (termed as *blocks*) were introduced at the stabilized cyclic load under LCF for a given strain amplitude and repeated until failure. Cyclic life was found to decrease with the increase in HCF block size. However, the extent of decrease in cyclic life also depends on the LCF strain amplitude as well as temperature which is attributed to the additional damage incurred by creep and ratcheting. However, in the DSA regime at 823-873 K, the decrease in cyclic life and the accumulation of inelastic strain got saturated with increase in block-size. Typically, transgranular fatigue fracture, intergranular creep fracture or dimpled rupture was identified when failure was dictated by LCF, creep and ratcheting respectively. However, HCF damage was found to act as a catalyst by joining small transgranular (LCF) or intergranular (creep) cracks, thus facilitating the crack propagation through strong synergistic LCF-HCF-creep interaction.

Towards life-prediction under LCF-HCF interaction, the earlier models on *damage curve approach* was suitably modified taking into account the complexities associated with LCF-HCF interactions, with the objective of predicting the remnant HCF life after prior exposure to LCF. The accuracy of the method was checked and validated through the experimental data pertaining to LCF-HCF interaction, primarily at 923 K. Apart from life-prediction in two-level loadings (sequential LCF-HCF interaction), attempt was also made to predict life under combined (block) cycling, based on the concept of ΔK_{th} (fatigue crack threshold) which is known to be affected significantly by the loading history (sequence of blocks in the present case).