# §14. The Influence of a Complex Inclusion on the LCF Behavior of Reduced Activation Ferritic/Martensitic Steels

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Reduced activation ferritic/martensitic steels (RAFs), such as F82H, are the primary near-term candidate for ITER test blanket modules (TBMs) and some components of the DEMO fusion reactor. During operation, materials for TBMs can be subjected to thermal cycling caused by start-up and shut-down procedure or plasma disruption. Thermal cycling would cause elastic and elastic-plastic cyclic deformation giving rise to fatigue in blanket structural materials. It is considered that fatigue properties depend on the material factors such as inclusion distribution, surface morphology. The objective of this report is to evaluate the effect of inclusions on low cycle fatigue (LCF) behavior of RAFs.

The materials used in this study were the RAFs F82H-IEA heat and the CA200-ESR. In order to minimize the occurrence of inclusions, the CA200-ESR steel was processed through electro-slag remelting (ESR) of F82H steel. LCF tests were performed using cylindrical specimens with gage length and diameter of 12 and 4 mm, respectively. All tests were carried out at room temperature in air. LCF tests were conducted under strain control mode at different total strain amplitudes under fully reversed axial loading ($R$= -1). To investigate the size and composition of the inclusions, the fracture surfaces and samples before testing were examined by a scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) microanalysis.

The relationship between the number of cycles to failure, $N_f$, and total strain range, $\Delta\varepsilon_t$, is presented in Fig. 1. The $N_f$ was defined as the number of cycles up to the point where a drop of 25% of the tensile stress range occurs in comparison with the stabilized cycle values. As shown in this figure, the $N_f$ of CA200-ESR was longer than the fatigue lifetime of F82H-IEA heat. For the higher total strain range, $\Delta\varepsilon_t$ = 1.0%, the $N_f$ of CA200-ESR was increased to about twice that of F82H-IEA heat.

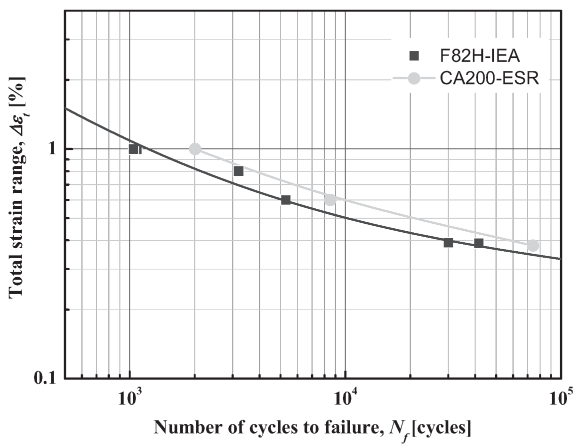


Fig. 1 Comparison of the LCF lives between F82H-IEA heat and CA200-ESR.

The size distribution and composition of inclusions are shown in Fig. 2. Two types of inclusions, the complex inclusion consisted of $Al_2O_3$ and $TaO_x$ ($Al_2O_3$-$TaO_x$), and the simple inclusion consisted of $TaO_x$, were found in F82H-IEA heat. For the results of EDS analysis on CA200-ESR, the simple inclusion consisted of $Al_2O_3$ was detected, but inclusion such as $Al_2O_3$-$TaO_x$ and $TaO_x$ was not detected. The total number density of inclusions for CA200-ESR is less than that of F82H-IEA heat, and the simple inclusion consisted with $Al_2O_3$ is dominant.

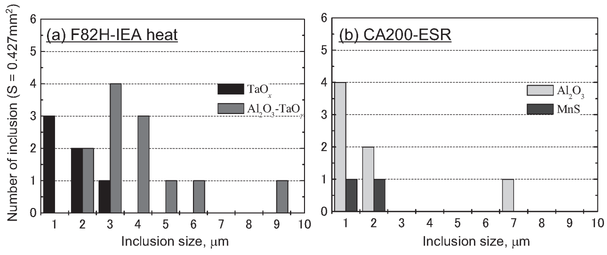


Fig. 2 The distribution of inclusions which obtained (a) F82H-IEA heat and (b) CA200-ESR.

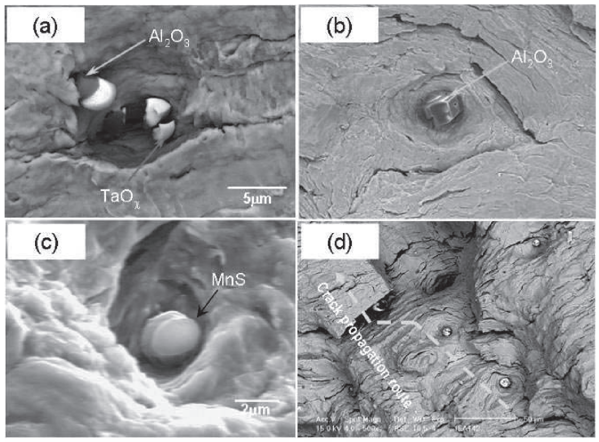


Fig. 3 Fracture surfaces of LCF tested specimens.

The fracture surfaces of LCF tested specimens are presented in Fig. 3. For the F82H-IEA heat steel, the crack initiation from the Ta-oxide site in the complex inclusion (Fig. 3(a)) is more extensive compared with the simple inclusion case (Fig. 3(b) and (c)). Fig. 3(d) shows the growth and coalescence of the crack and voids occurring at inclusions. When a crack growth by void coalescence, the crack exhibits a tunneling effect, and it grows faster due to the higher stress triaxiality. Moreover, the distribution of inclusions influences the crack propagation path and rate. From these results, it can be considered that the fatigue properties of F82H-IEA steel would be dependent on a distribution of a complex inclusion with Ta-oxide.