Lifetime of a welded structure subjected to thermal-mechanical loadings: application to exhaust manifolds

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Exhaust manifolds are usually designed in cast-iron. However, when increasing the engine performance, the output gas reaches higher temperature, and other types of material like welded steel plates are considered to design exhaust manifolds. These components are subjected to complex thermomechanical loadings which must be taken into account in fatigue design. To limit the computational costs, only a few loading cycles are simulated and a fatigue criterion is used to estimate the lifetime of the structure. This study proposes a junction model combined to a fatigue criterion to assess the lifetime of a welded structure. The model is simple enough to be integrated into a computation on a complete structure and the fatigue criterion is available for thermal-mechanical loadings.

To build this model, butt welded joints in ferritic stainless steel plates were characterized. Tension tests were made at ambient temperature on butt welded specimens and on butt welded specimens after smoothing out the weld bead. A speckle was applied on the surface of the specimens, in order to monitor the evolution of the strain fields by image correlation. For welded specimen, the geometry has a significant influence on strain localization since it modifies the deflected shape of the specimen. When the bead is smoothed out, the influence of the microstructure is observed: the strains seem to localize in the thermally affected zone. The junction model uses a unique elasto-visco-plastic law for plate and weld. The stiffness of the weld is modelled thanks to additional shell elements calibrated to reproduce the deflected shapes of the welded specimens.

Then isothermal low cycle fatigue tests were completed up to specimen crack initiation. Fatigue lifetime of welded specimens is compared with data on base material using local strain analysis. Damage mechanisms are studied and used to propose a fatigue criterion. Finally thermal-mechanical fatigue tests were completed on welded specimens to reproduce the typical loading seen by welds on exhaust manifolds. The fatigue criterion is extended to cover non isothermal loadings in a large range of temperatures. This criterion and the junction model are used then to predict the lifetime of welds subjected to thermal-mechanical loadings.

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