Crack Tip Plastic Zone Measurement in Austenitic Stainless Steel Using Thermoelastic Stress Analysis

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Abstract
Thermoelastic stress analysis (TSA) has been used to measure the crack tip plastic zone radius and mode I stress intensity factor ΔK_I during fatigue loading in austenitic stainless steel grade 304 compact tension (CT) specimens.

Introduction
Austenitic stainless steels are commonly used in nuclear power applications such as the pressure vessel cladding and core internals where they are subjected to cyclic stresses due to thermal transients during operation. These stresses cause low cycle fatigue as they are high enough to cause plastic strain and the number of cycles is unlikely to exceed 10^5 over the design lifetime [1] .
In aerospace alloys, the plastic deformation ahead of a fatigue crack has been identified by the local changes from a spatially uniform value in the phase component of data from thermoelastic stress analysis [2], whilst the stress intensity factors can be measured from the corresponding magnitude data [3]; however, neither of these techniques have been applied to steel.

Method
Compact Tension (CT) specimens (ASTM E647, w=20mm, b = 0.7mm) of 304 grade austenitic stainless steel were produced by Electrical Discharge Machining (EDM) and one side was polished and painted matt black. These were then subject to a fatigue load at 20Hz with R=0.5 and images captured regularly using a Thermoelastic Stress Analysis (TSA) camera system (Deltatherm 1750, Stress Photonics, Maddison, WI, USA).

Post-processing in MATLAB of the phase data from the thermoelastic data was used to locate the crack tip and plastic zone by locating the regions of non-zero phase associated with the crack tip. The plastic zone radius was measured as the horizontal distance from crack tip to the furthest extent of the plastic zone. Additionally, the FATCAT algorithm [3] was used to evaluate ΔK_I. The specimens were of non-standard thickness, and therefore the analytical formula for the stress intensity factor provided in E647[4] was not suitable.

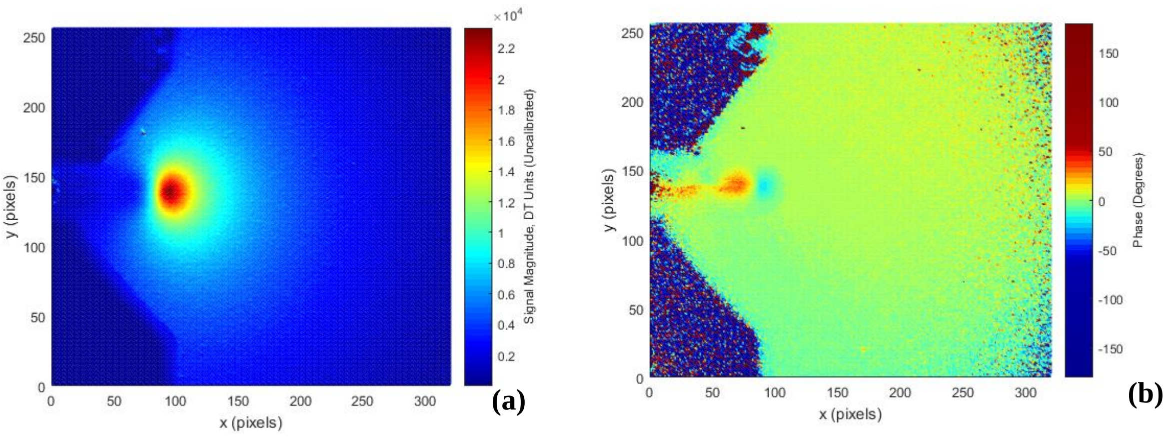

Figure 1 TSA data showing **a)** magnitude of the signal, used to measure ΔK_I **b)** phase map with plastic zone ahead of the crack in turquoise and the plastic wake on the crack flanks in red. The grips are visible in the left-hand corners.

Results

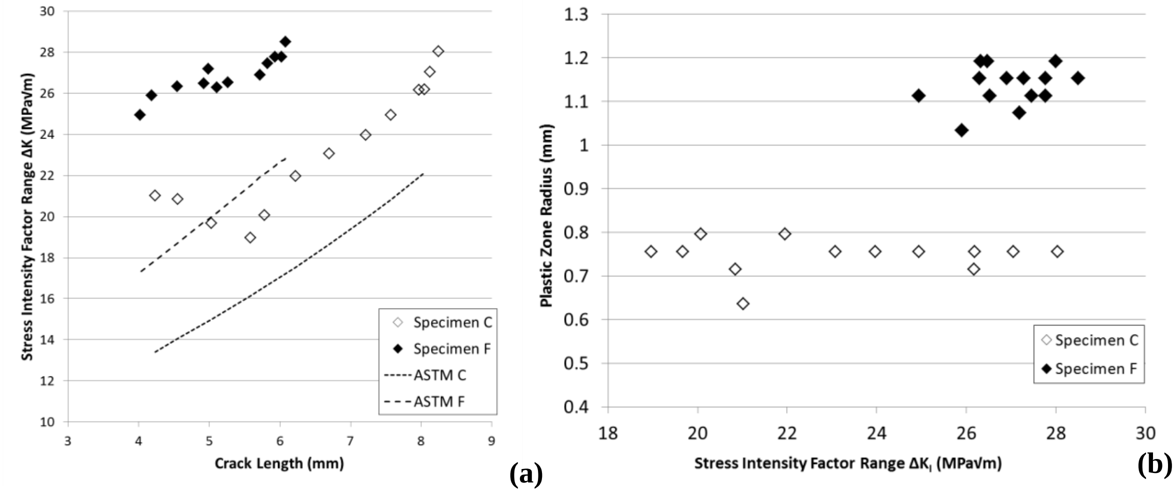

Figure 2 Plots showing results of two specimens both loaded at R = 0.5, C at *P* = 450±150N and F at *P* = 600±200N. **a)** ΔK_I vs crack length shows that the measured ΔK_I is in poor agreement with ASTM E647 analytical solution, possibly due to the reduced specimen thickness, C behaviour up to 5.5mm due to prior overload. **b)** Plastic zone radius vs ΔK_I shows no dependence on ΔK_I, but shows a larger mean stress creating a larger plastic zone radius.

The results in Fig. 2 indicate little correlation between stress intensity factor range and plastic zone radius in this material; however, a potential effect of mean stress on plastic zone radius has been observed. An overload was applied to specimen C at a crack length of 4.5mm, which caused temporary shielding of the crack tip and reduced the effective stress intensity factor amplitude. Further specimens will be tested using a high magnification lens to measure plastic zone radius with a greater accuracy and will be reported

Conclusions

Thermoelastic Stress Analysis has been used to measure plastic zone radius and ΔK_I simultaneously during stable fatigue crack growth in 304 austenitic stainless steel CT specimens for the first time.

Acknowledgements

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References

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