15th International Conference on Fracture (ICF15)
June 11-16, 2023 Atlanta, GA USA

MICROSTRUCTURE-PROPERTY PREDICTIONS AND MULTISTAGE FATIGUE LIFE PREDICTION OF HOLE RESTORATION COUPONS USING AFSD

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Abstract

Military aircrafts operate frequently in a highly corrosive environment. Corrosion in aluminum aircraft structures with holes and adhesive-bonded lap joints promotes multi-site cracking, which can lead to failure of major aircraft components. To expedite and facilitate the corrosion repair process, an emerging *solid-state* process, additive friction stir deposition (i.e. AFSD) is applied for the hole restoration followed by the fatigue performance evaluation. Because of the friction stir induced material flow of the deposited and substrate materials, the resulting microstructure and its associated properties are position-dependent. The weak metallurgical bond at the bottom of the repaired hole coupon can promote a crack initiation under cyclic loading and the total life consists of crack initiation, short crack growth, and long crack propagation. This paper describes the use of a multiphysics modeling approach to characterize the process-driven properties evolution and to evaluate the effects of a kissing bond on the total life of hole restoration coupons.

1. Introduction

Structural repair, which aims to restore the original geometry while enabling good mechanical performance post-repair, can offset the costs dramatically. Given the promising experimental results on AFSD-based repair, a critical question arises: how can we control the repair quality and post-repair fatigue performance by controlling the process conditions? This necessitates critical modeling efforts and prediction capability of the process-microstructure-fatigue performance linkage for AFSD-repaired AA7050 coupons. The problem is challenging because of the incomplete understanding on tailoring of AFSD process to improve fatigue performance with limited test data, less knowledge on the characterization of material properties under the combination of temperature, strain rate, and pressure, and no conclusive results for the direct correlation between the AFSD process parameters and the resulting fatigue performance. To reduce the technology gap, our multiphysics modeling approach includes: 1) the CFD-based process model for characterization of the AFSD-induced temperature and the resulting material flow, 2) grain and precipitation kinetics modeling to correlate the microstructure with thermal-mechanical field, zone partitioning and assignment of heterogeneous material properties, and 3) crack initiation, small crack, and long crack growth models for the total life prediction. This paper describes the multi-stage fatigue life prediction for AFSD-repaired hole coupons and assessment of the effect of the presence of a kissing bond on the fatigue performance for the given microstructure-driven properties.

2. Results

The microstructure in an AFSD-repaired hole coupon is heterogeneous with four distinct zones: the dynamically recrystallization zone (SZ) where the plastic deformation from the AFSD tool causes the formation of equiaxed recrystallized fine grains, the thermal-mechanically affected zone (TMAZ) where the plastic deformation introduces a high dislocation density, the heat affected zone (HAZ) where no plastic deformation occurs but the thermal exposure causes the overaging of precipitation, and the base material zone (BM). The constituent properties in each zone depend on the grain size, precipitation hardening, and dislocation hardening. A multi-stage fatigue life (MSF) model was developed to incorporate the effects of microstructural features. The fatigue life of the AFSD-repaired Al7xxx can be described by three distinct stages, fatigue crack incubation, small crack growth, and long crack growth. The MSF model considers all stages as separate regimes and then sums the three stages to capture the total fatigue life.

Given the process-dependent deposition zones in a hole restoration coupon, a parameterized model was created via the customization of Abaqus CAE. An automated model generation approach was developed, as shown in Figure 1. Boolean operation is performed on the hole restoration coupon using 3D ellipsoids to generate zone partitions, and then each zone is assigned with the corresponding material properties as shown in Figure 1. Fatigue performance evaluation was performed for the good repair without the kissing bond. The crack initiation and propagation life is 9k and 9.6k cycles, respectively. The predicted total life is 18,651 cycles, which is within the data range of fatigue cycles between 12,787 cycles and 24,878 cycles.

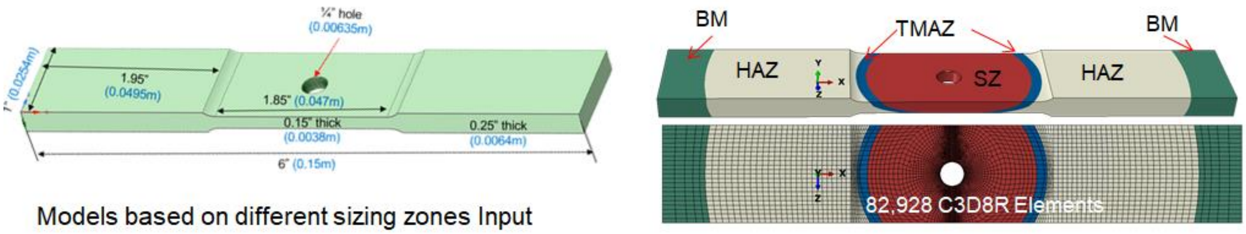

Fig.1 – Illustration of a repaired hole geometry and its associated FEM-based performance model.

To evaluate the detrimental effect of the kissing bond on the fatigue performance, an observed kissing bond at the bottom of the hole-repaired coupon was introduced as shown in Figure 2. Using our extended finite element toolkit (XFA3D), multiple crack propagations can be simulated without local remeshing. Due to the presence of the kissing bond, the crack growth on the left side is much faster resulting in the reduced fatigue life of 7,616 cycles.

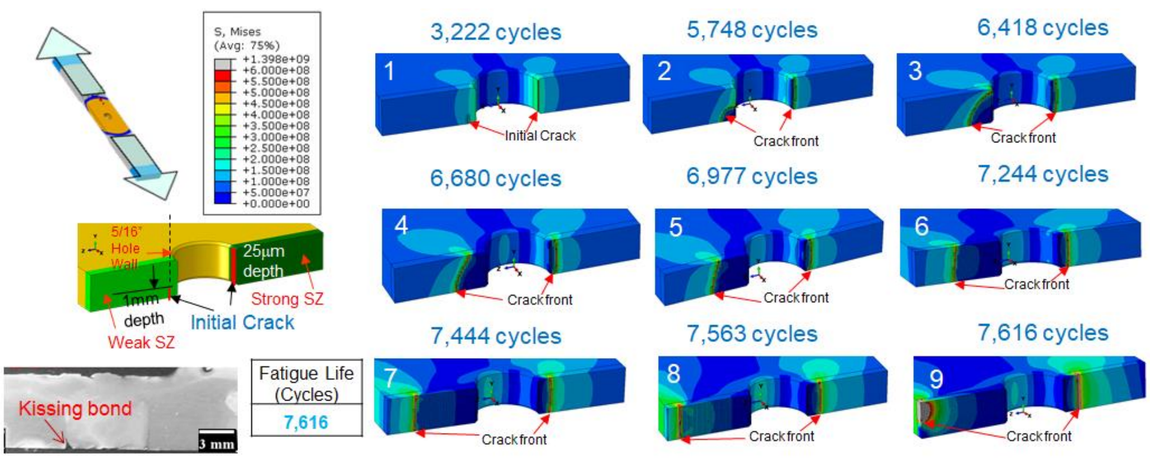

Fig.2 – Summary of fatigue performance results for a repaired hole with a kissing bond.

3. Conclusions

A modeling framework has been established for the high-fidelity simulation of the AFSD repair using the process-driven property evolution and the multi-stage total life prediction model. In addition to including the material heterogeneity in the performance model, the process-induced defect such as a kissing bond has been considered to evaluate its impact on the total life of the repaired coupon.

Acknowledgements

The work is funded by Naval Air Warfare Center, Aircraft Division under the Contract of N68335-21-C-0834.