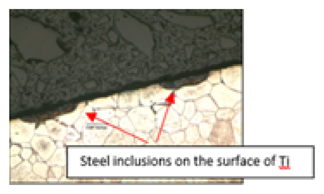
Effect of Embedded dissimilar materials on fatigue life of Honeycomb Panels

Siqi Chen, Tim Gormley, Shida Xu
Prof. M. Salviato - UWAA A. Clinton - GKN Aerospace

GKN AEROSPACE

UNIVERSITY of WASHINGTON

Introduction



Background:

Certification of new parts requires prediction of fatigue life of the component. GKN Aerospace currently uses an overly conservative method to assess certain manufacturing defects and seeks a more reliable tool.

Motivation:

GKN Aerospace produces engine exhausts (Titanium Honeycomb formed at elevated temperatures). As part of this process, inclusions of dissimilar materials can be experienced. GKN seeks more efficient method to predict reliability of parts with embedment of dissimilar metals

Problem Statement:

Obtain understanding of effect of embedded dissimilar materials observed in GKN Aerospace manufacturing process, and *deliver an analytical method for its prediction on fatigue life.*

Customer Specification:

- Based on existing regulatory guidelines, develop analytic methodology to predict life capability impact of embedded defects on component performance
- Primary focus on tensile loading
- The methodology should be easy to use and reasonably accurate for design purposes.
- Material specified as Ti-CP-Gde4

Analysis

Considerations:

After reviewing 14.CFR.25/14.CFR.33, considering material features and damage tolerance guidelines, it is concluded regulatory agencies place more restrictive requirements on fatigue loading and fatigue life, hence this should be the primary focus

Use a analytic method to produce reliable results at low computational complexity for design purposes

After reviewing NASA papers and consulting faculty advisor Prof. M. Salviato, it is determined this method has merit, could be adopted to solving the problem, and could produce result with greatest computational efficiency of all methods considered

Decision:

- Primary focus on fatigue life under cyclic loading
- Use finite element analysis (FEA)
- Validate P.Lazzrin proposed method on given problem

Budget

On budget, with surplus

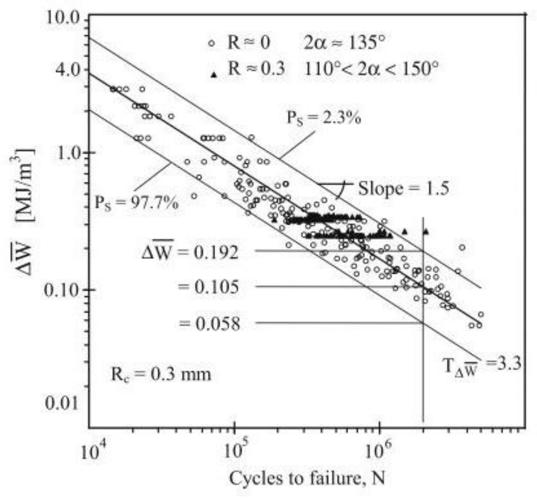
Item	Planned	Actual
Additional Testing Material / Buffer	$760-$2200	$2,600
Commercial Testing Service / Buffer	$1,440	$0
Specimen Manufacture	$1,800	$1,100
Total Budget	Actual Spent	Remaining
$4,000	$3,700	$300

Detail Design & Workflow

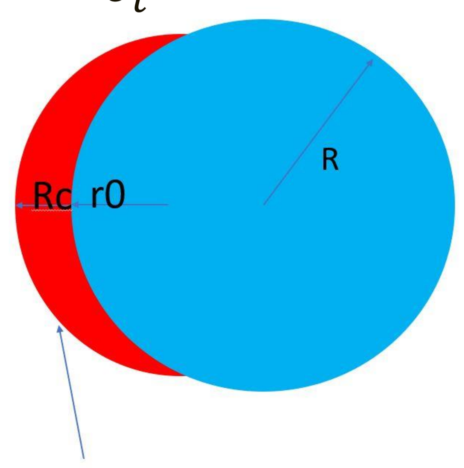
Lazzrin Method:[1,2]

- Control volume determined by R_C
- Calculated entirely from material properties
- Average Strain Energy Density linearly related to cycles in log-log domain
- Works with geometries where stress varies throughout material

$$R_C = \frac{(1+\vartheta)(5-8\vartheta)}{4\pi}\left(\frac{K_{IC}}{\sigma_t}\right)^2$$

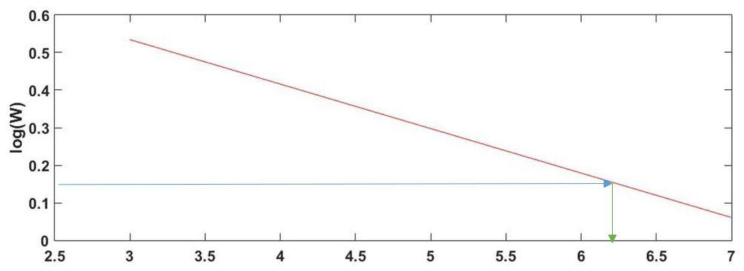


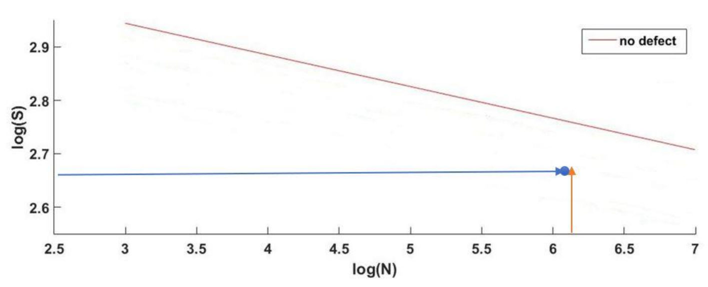
Sample W-N Curve with Nominal Scatter Factor

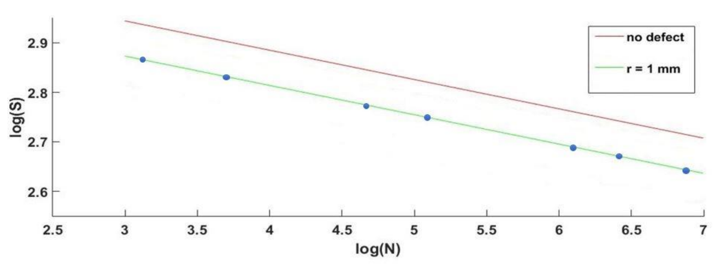


Characteristic volume

- For a given loading and geometry, FEA can be used to derive average strain energy density, W, throughout plate
- W*V summed for elements in control volume, divided by volume of control volume
- W then used to get N from W-N curve
- Can then be used to construct an S-N curve for the geometry

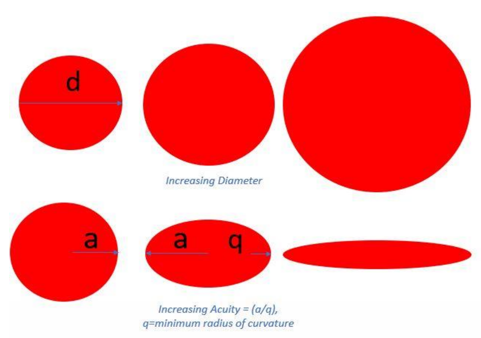




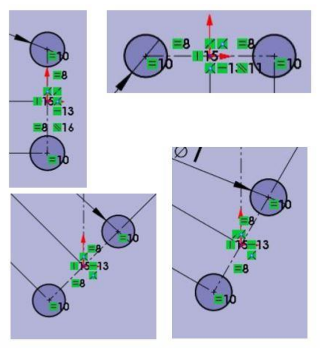


Validation:

- Perform tests to determine GKN material prosperities
  - ASTM E8, E466, E1820
- Utilize material property to determine critical defect size
- Engineer through-all defects to specimens
  - Size, Acuity, Relation
- Compare FE model prediction and actual testing result and resolve discrepancies
- Validate calibrated model with real defect

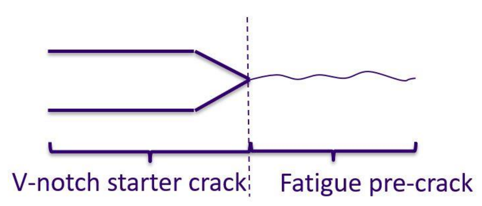


Acuity Defect Arrangement Design



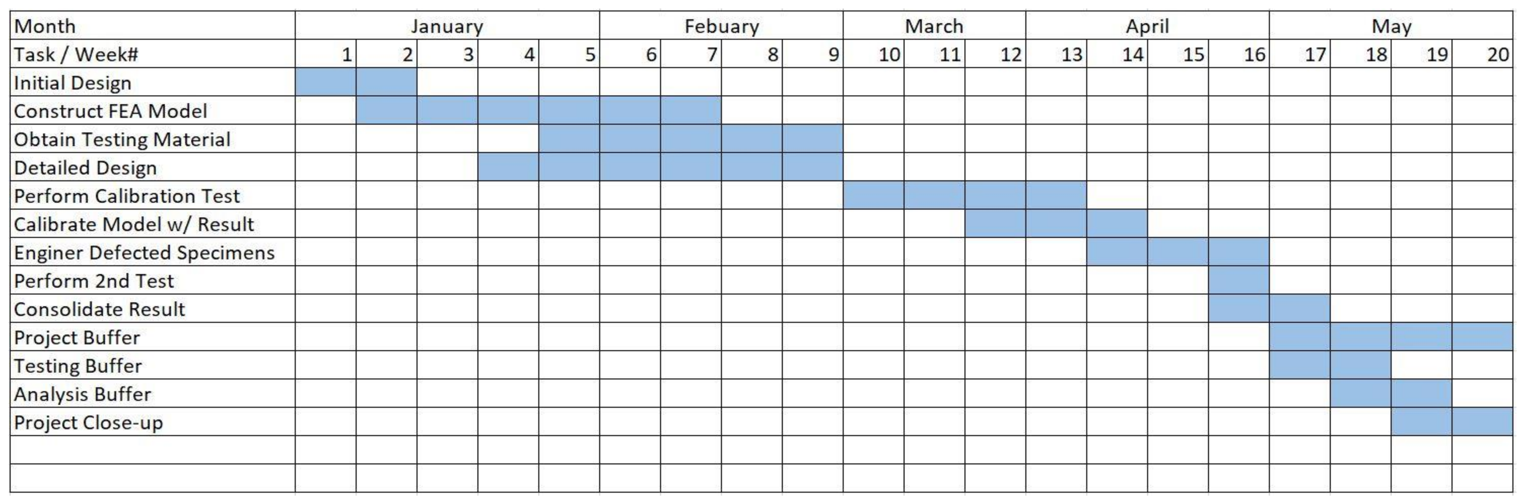
Relationship Defect Arrangement Design

DIC Fracture Testing Specimen



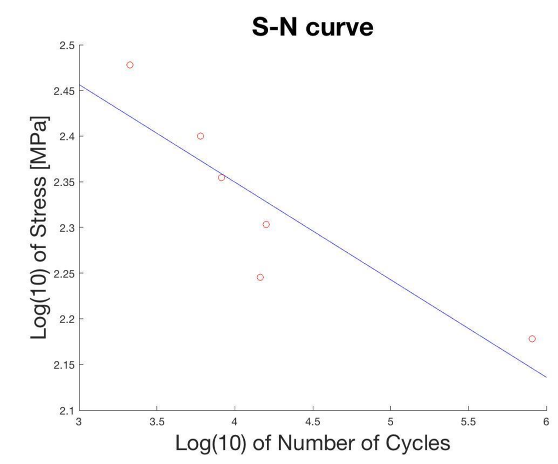
Fracture Test Notch Design

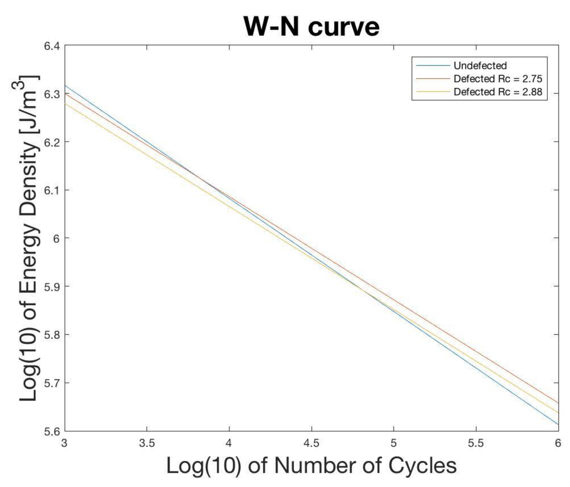
Schedule



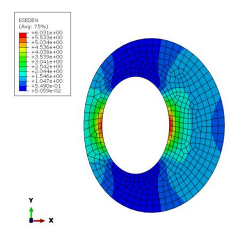
Key Results

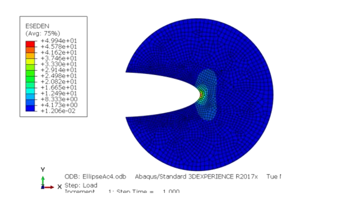
- Lazzrin Method uses quasi-static tests to obtain R_C and is only thus far validated on brittle metals. When applying the method to ductile material such as Ti-CP-Gde4, the model prediction offers a median error of 42% comparing to experimental method.

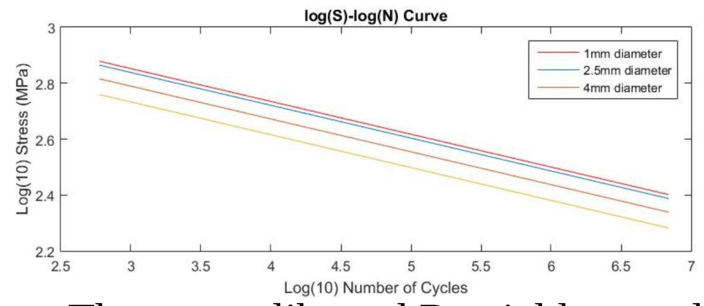


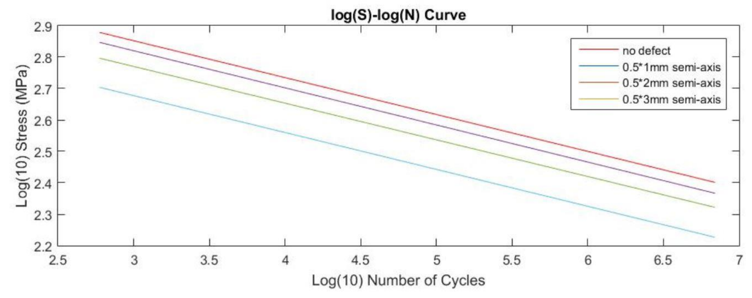


- Further research indicates using quasi-static method to predict fatigue behavior tend to yield erroneous results, and Rc was recalibrated with another method recommended by Prof. M. Salviato.

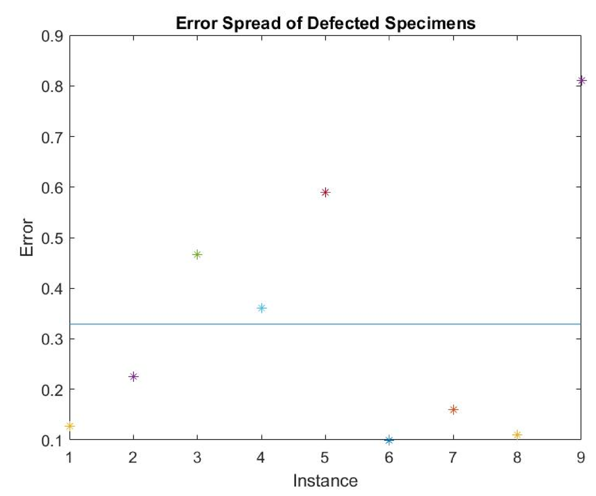


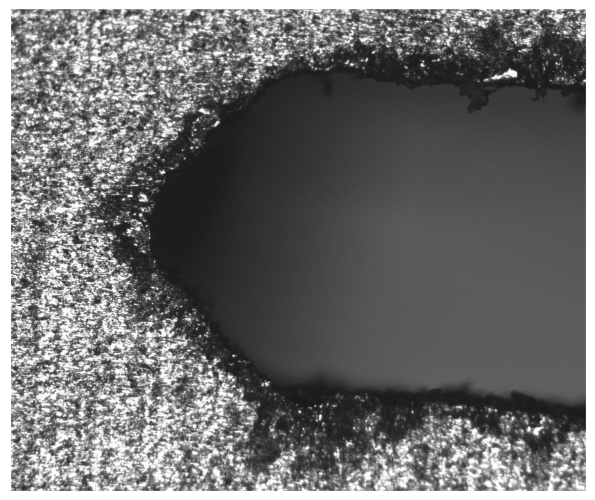






- The new calibrated R_C yield around 32% error, considering the scatter factor, spread pattern of data, defects possibly introduced to the specimen during defect manufacture, and nature of fatigue testing, the result indicate Lazzrin Method could be reasonably adopted for this research.
- The project developed and delivered a Finite Element model that shows promisingly accurate and less conservative result then current practice produced at higher computational efficiency.





Microscopic Inspection of Defected Specimen

Future Work

- Perform more test with the same material and same procedures to establish statistical significance
- Extend verification of the Lazzrin method to a wider range of metal kinds and specimen parameters
  - Ductility, depth, metal bound (Unable to investigate since no proprietary specimens provided by GKN)
- Compare extended verification results with industry records, make adjustments accordingly and promote the final result for wider adoption

Acknowledgement

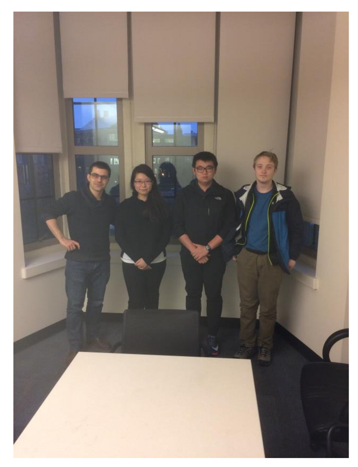
Special thanks to:

Industry Sponsor GKN Aerospace for providing this opportunity of an industry leading topic for capsone class

Mr. A. Clinton for continuous support from customer perspective

Prof. M. Salviato, for guiding the team with exceptional theoretical knowledge technical knowhow

Prof. Morgansen, Prof. Waas, ME shop, Physics shop, and PhD candidate Yao Qiao for facilitating the development of the project



- [1] *Lazzarin, Paolo, and F. Berto. "Some expressions for the strain energy in a finite volume surrounding the root of blunt V-notches." International Journal of Fracture 135.1-4 (2005): 161-185.*
- [2] *Atzori, B., P. Lazzarin, and G. Meneghetti. "Fracture mechanics and notch sensitivity." Fatigue & Fracture of Engineering Materials & Structures 26.3 (2003): 257-267.*
- GKN informational materials
- ASTM, E8. "8M. Standard test methods of tension testing of metallic materials [metric]." *Annual book of ASTM standards* 3 (2003).
- Norma, A. S. T. M. "E466-96 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials." *Filadelfia (EE. UU.): American Society for Testing and Materials* (1996).
- Standard, A. S. T. M. "Standard test method for measurement of fracture toughness." *ASTM, E1820-01* (2001): 1-46.
- Standard, A. S. T. M. "E606-92,“." *Standard Practice for Strain-Controlled Fatigue Testing,” Annual Book of ASTM Standards* 3 (2004).
- 14.CFR.Part 25 Airworthiness Standards: Transport Category Aircraft
- 14.CFR.Part 33 Airworthiness Standards: Aircraft Engines
- Newman Jr, J. C., Edward P. Phillips, and R. A. Everett Jr. "Fatigue analyses under constant-and variable-amplitude loading using small-crack theory." (1999).
- Bozek, J. E., et al. "A geometric approach to modeling microstructurally small fatigue crack formation: I. Probabilistic simulation of constituent particle cracking in AA 7075-T651." *Modelling and Simulation in Materials Science and Engineering* 16.6 (2008): 065007.
- Phillips, D., Erin Iesulauro, and E. Glaessgen. "Multiscale modeling of metallic materials containing embedded particles." *45th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference*. 2004.
- Bonacuse, Peter J. "Geometric modeling of inclusions as ellipsoids." (2008).
- Standard, A. S. T. M. "E1681-03,“Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials,”." *Annual Book of ASTM Standards* 3 (2003).
- Wells, Doug, and Phillip A. Allen. "ASTM Committee Meeting E08. 07.03 Surface Cracks-E2899 Business." (2014).
- Lazzarin, Paolo, and R. Zambardi. "A finite-volume-energy based approach to predict the static and fatigue behavior of components with sharp V-shaped notches." *International journal of fracture* 112.3 (2001): 275-298.
- Lazzarin, Paolo, Filippo Berto, and Michele Zappalorto. "Rapid calculations of notch stress intensity factors based on averaged strain energy density from coarse meshes: Theoretical bases and applications." *International Journal of Fatigue* 32.10 (2010): 1559-1567.
- Kotousov, Andrei, et al. "Three dimensional finite element mixed fracture mode under anti-plane loading of a crack." *Theoretical and Applied Fracture Mechanics* 62 (2012): 26-33.
- Zappalorto, Michele, and Paolo Lazzarin. "In-plane and out-of-plane stress field solutions for V-notches with end holes." *International journal of fracture* 168.2 (2011): 167-180.
- Berto, Filippo, Paolo Lazzarin, and Chun Hui Wang. "Three-dimensional linear elastic distributions of stress and strain energy density ahead of V-shaped notches in plates of arbitrary thickness." *International Journal of Fracture* 127.3 (2004): 265-282.