Two-Insert Assembly for High-Throughput Vibration-Based Fatigue Testing

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Motivation

Turbine, engine, and aircraft design must account for fatigue from high-cycle vibrations, resulting in microscopic cracks and failure below yield strength. S-N curves, found experimentally, predict material fatigue strengths.

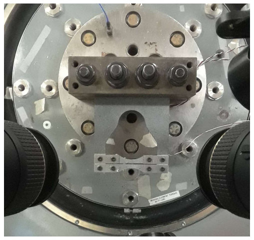
With traditional testing methods, high-cycle fatigue (HCF) measurements can be costly, time-consuming, and not representative of multiaxial high-speed fatigue.

Vibration Based Fatigue

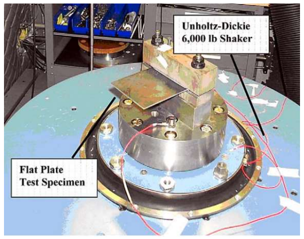
- More representative of in-situ fatigue
- Fast testing

Equipment

- Electrodynamic Shaker
- Cantilevered Specimen
- Strain Gauge
- Laser Vibrometer
- Photron SA-Z High Speed Cameras for DIC Measurement



Top down view of plate.

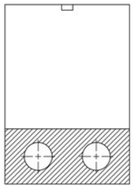


Cantilevered plate for fatigue testing [1].

Comparison of Testing Times

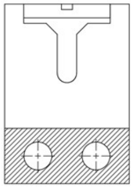
Testing Method	Frequency	Time per Sample 10^7 cycles
Servo-Hydraulic	40-60 Hz	46 – 70 hours
Rotating Beam	160 Hz	17 hours
Vibration-Based	1000-1600 Hz	1.5 - 2.5 hours

Insert Plate Designs



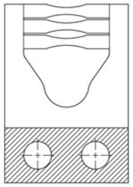
George et. Al [1]

- Peak stress at free edge
- Strain gage applied to monitor sample



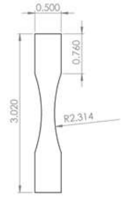
Bruns, Zearly et. Al [2]

- Specimen insert placed in carrier plate
- Reduces material waste



Initial Multi-Insert

- Three specimens fatigued simultaneously
- Decreases overall testing time

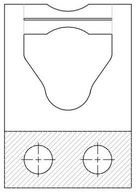


Scott-Emuakpor et. al [3]

- Hourglass specimen insert
- Improved repeatability

Half-Dogbone Specimen

- Closer strain measurements between specimens



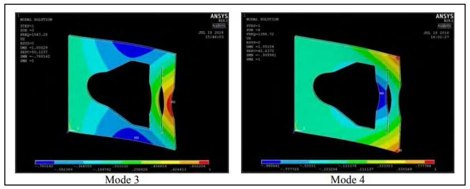
Double Insert Design

- Closer strain measurements between specimens

Test Setup

- Samples speckled for DIC strain measurement.
- Apply strain gauges to inserts.
- Laser vibrometer used for control after strain gauge fails.
- Load plate in Mode 3. When the outer specimen breaks, replace it.
- Replace strain gauges and load in Mode 4. Decrease shaker force to match previous inner specimen strain. Cycle to inner specimen failure.
- Replace inner specimen and strain gauges. Switch to Mode 3 and decrease shaker force.

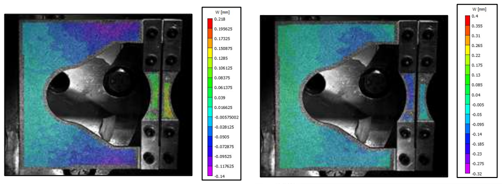
	Mode Shape	Outer Specimen ε	Inner Specimen ε
Stage 1	Mode 3: (860 Hz)	3000 με	2520 με
Stage 2	Mode 4: (1000 Hz)	2126 με	2520 με
Stage 3	Mode 3: (860 Hz)	2126 με	1790 με



ANSYS analysis of plate mode shape.

Mode 3 – 1040 Hz
Mode 4 – 1417 Hz

Initial Results

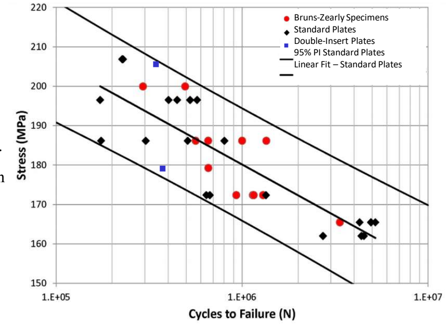


DIC measurement of plate mode shape.

84% strain ratio between inserts.

S-N curve for Aluminum Plates

Two samples successfully fractured. Testing was halted to replace broken and stripped bolts.



Next Steps

- Populate curve with 12 datapoints
- Modify base geometry to improve testing method
- Apply induction coil heating for high-temperature testing

[1] George, T., et al. "Development of a Novel Vibration-Based Fatigue Testing Methodology." International Journal of Fatigue, vol. 26, no. 5, 2004, pp. 477–486.
[2] Bruns, J., et al. "Vibration-Based Bending Fatigue of a Hybrid Insert-Plate System." Experimental Mechanics, vol. 55, no. 6, 2015, pp. 1067–1080.
[3] Scott-Emuakpor, O., et al. "Improved Hybrid Specimen for Vibration Bending Fatigue." Fracture, Fatigue, Failure and Damage Evolution, vol. 8, 2017, pp. 21–30.