**Fatigue Crack Growth in Aluminum Lap-Joint Data Set**

Data challenge of the 11th Annual Conference of the PHM Society 2019

Scottsdale, AZ

|  |  |
| --- | --- |
| **Data Brief** | Fatigue experiments were conducted on aluminum lap-joint specimens, and lamb wave signals were recorded for each specimen at several time points (i.e., defined as number of cycles in fatigue testing). Signals from piezo actuator-receiver sensor pairs were reported and it was observed that these signals were directly related to the crack lengths developed during fatigue testing. Optical measurements of surface crack lengths are also provided as the ground truth. The dataset is split in training and validation to facilitate the application of data-driven methods.  |
| **Format** | The data is organized by folder structures. The parent folder contains one file and two folders. The file is named “Read Me.docx” (this file) and has all the information for the testing description and data explanation. One folder is named “training” and contains all training data sets. The other folder is named “validation” and contains all validation data set. The folders are organized by specimens, named T1-T6 in the training folder and T7-T8 in the validation folder. All formatting is explained in detail this file. |
| **Credits**(Please see relevant publications below) | Prof. Yongming Liu, Arizona State UniversityDr. Tishun Peng, Gas Technology Institute |

|  |
| --- |
| **Citations:****If you use this dataset to publish your research, cite the following papers:** |
| * He J, Guan X, Peng T, Liu Y, Saxena A, Celaya J, Goebel K. **A multi-feature integration method for fatigue crack detection and crack length estimation in riveted lap joints using Lamb waves.** *Smart Materials and Structures*. 2013 Sep 4;22(10):105007.
* Peng T, He J, Xiang Y, Liu Y, Saxena A, Celaya J, Goebel K. **Probabilistic fatigue damage prognosis of lap joint using Bayesian updating.** *Journal of Intelligent Material Systems and Structures*. 2015 May;26(8):965-79.
 |
| **Other relevant publications using this dataset:** |
| * Peng T, He J, Xiang Y, Liu Y, Saxena A, Celaya J, Goebel K. **Probabilistic fatigue damage prognosis of lap joint using Bayesian updating.** *Journal of Intelligent Material Systems and Structures*. 2015 May;26(8):965-79.
* He J, Guan X, Peng T, Liu Y, Saxena A, Celaya J, Goebel K. **A multi-feature integration method for fatigue crack detection and crack length estimation in riveted lap joints using Lamb waves.** *Smart Materials and Structures*. 2013 Sep 4;22(10):105007.
* Yang J, He J, Guan X, Wang D, Chen H, Zhang W, Liu Y. **A probabilistic crack size quantification method using in-situ Lamb wave test and Bayesian updating.** *Mechanical Systems and Signal Processing.* 2016 Oct 1;78:118-33.

**Publications from the PHM Data Challenge 2019 – Best Teams:*** Youn M, Kim Y, Lee D, Cho M. **A Fatigue Crack Length Estimation and Prediction using Trans-fitting with Support Vector Regression.** In *Proceedings of the Annual Conference of the PHM Society 2019* Sep 26 (Vol. 11, No. 1).
* Kong HB, Jo SH, Jung JH, Ha JM, Shin YC, Yoon H, Sun KH, Seo YH, Jeon BC. **A Hybrid Approach of Data-Driven and Physics-based Methods for Estimation and Prediction of Fatigue Crack Growth.** In *Proceedings of the Annual Conference of the PHM Society 2019* Sep 26 (Vol. 11, No. 1).
* Zuo MJ. **Ensemble Linear Regression and Paris’ Law Based Methods for Structure Fatigue Crack Length Estimation and Prediction Using Ultrasonic Wave Data.** In *Proceedings of the Annual Conference of the PHM Society 2019* Sep 26 (Vol. 11, No. 1).
 |

**1. Introduction**

This data set consists of measurement from piezeoelectric (PZT) sensors that are mounted on aluminum specimen that were tested to fatigue conditions. Failure occurred due to formation of cracking (see Fig. 1).

The specimens consisting of two aluminum panels and they are joined by three rivet rows by five rivets. The riveted panels are made of 1.6mm-thickness aircraft grade 2024-T3 aluminum sheets. Surface-bonded piezoelectric (PZT) ceramic wafers are used as actuators to generate Lamb waves as well as sensors to receive Lamb signal. The pitch-catch configuration is used for Lamb wave damage detection. According to the existing experimental data, the crack usually initiates at the countersunk hole in the first row, it will connect these holes and finally break the specimen. Therefore, only the countersunk holes in the first row are chosen for inspection. The geometry of the lap joint component and sensor network configuration is shown in Fig. 1. The sensors (green dots, NO. 6-10) and the actuators (red dots, NO.1-5) are shown in Fig. 1 and the dashed lines are the sensor pair paths in testing. The data acquisition is repeated two times to reduce the measurement uncertainty. Details on the experimental testing description and data organization is shown below. For more information about the data generation process and measurement details, please refer to the relevant publications listed earlier in this document.



**Fig. 1. Lap joint: sensors and actuators**

**2. Testing description and organization of files**

Eight specimens (named T1 through T8) have been utilized. Among them, T1-T6 are used for training and T7-T8 are used for validation. A hydraulic material testing machine working at 5Hz at room temperature conducts the fatigue testing. Both constant amplitude loading and variable amplitude loading cases are studied. T1-T7 are under the constant amplitude fatigue loading and T8 is under the variable amplitude loading. During the testing, the optical microscope is used to identify the location of the crack appearance. It should be noted that the crack locations differ for each specimen. The locations are described using the intersection of the first row of countersink holes and the sensor pair paths (see Fig. 1). In the reported data, only signals for the sensor pair path with crack observation are included. Other sensor pair path signals are excluded in this data set for simplicity.

A summary of all eight specimens are shown in Table .1

|  |
| --- |
| **Table 1. Riveted lap joints fatigue testing results summary** |
| Specimen NO. | Crack initiation location | Loading Spectrum |
| T1 | Sensor pair 6-1 | Constant |
| T2 | Sensor pair 9-4 | Constant |
| T3 | Sensor pair 8-3 | Constant |
| T4 | Sensor pair 9-4 | Constant |
| T5 | Sensor pair 10-5 | Constant |
| T6 | Sensor pair 6-1 | Constant |
| T7 | Sensor pair 9-4 | Constant |
| T8 | Sensor pair 6-1 | variable  |

**2.1 Training data set organization**

All training data set for specimens T1-T6 are organized in the folder of “training” using 6 sub-folders. Within each sub-folder corresponding to a specimen, there is a specimen-specific description excel file (for example, “Description\_T1”) corresponding to that specimen. The crack propagation details and loading spectrum for that specimen is explained in that excel file. For example, in the case of T1, an example of this reported crack lengths is shown in Table. 2 (as shown in the file “Description\_T1”).

|  |
| --- |
| **Table 2. Example of fatigue crack growth data for specimen T1**  |
| Number of cycles | Crack length (mm) |
| 0 | 0 |
| 60000 | 2.18 |
| 62500 | 2.76 |
| 65500 | 3.51 |
| 69025 | 4.51 |
| 70026 | 4.9 |
| 70766 | 7.46 |

The loading profiles is also included in the folder for each specimen and the file name is “Constant Loading Profile-5 cycles.csv”. Since all specimens in the training data set have the same loading profile, the file is the same for specimen T1-T6. Time history for the applied force for the first 5 cycles are reported in the file. The first column is the time and the second column is the stress value (unit: MPa).

Piezo sensor signals are reported in the sub-folder within each specimen folder and is organized corresponding to the measurement time (i.e., number of cycles). An additional folder “Baseline” contains the ultrasonic data collected right before the fatigue testing (i.e. number of cycles=0). Within each folder, there are two files “signal\_1” and “signal\_2”, which corresponds to two repetitions for the same measurement. Each data-file contains three variables "time", "ch1", and "ch2". While the first is self-explanatory, "ch1" and "ch2" correspond to the actuation/excitation signal and received signal, both of which are measured in Volts.

The total numbers of data-files available for each specimen at each cycle-number are tabulated in Table 2.

**Table 3. List of Data-Files**

|  |  |  |
| --- | --- | --- |
| ***Specimen*** | ***Cycle Number*** | ***Number of Data-Files (including repetitions)*** |
| T1 | Baseline | 2 |
|  | 60000 | 2 |
|  | 62500 | 2 |
|  | 65500 | 2 |
|  | 69025 | 2 |
|  | 70026 | 2 |
|  | 70766 | 2 |
| T2 | Baseline | 2 |
|  | 50000 | 2 |
|  | 70033 | 2 |
|  | 72000 | 2 |
| T3 | Baseline | 2 |
|  | 14000 | 2 |
|  | 50000 | 2 |
|  | 55391 | 2 |
|  | 57038 | 2 |
|  | 60035 | 2 |
|  | 62017 | 2 |
|  | 64019 | 2 |
|  | 65029 | 2 |
|  | 66012 | 2 |
|  | 66510 | 2 |
| T4 | Baseline | 2 |
|  | 55900 | 2 |
|  | 60200 | 2 |
|  | 65001 | 2 |
|  | 67054 | 2 |
|  | 70016 | 2 |
|  | 71130 | 2 |
|  | 73210 | 2 |
|  | 75045 | 2 |
| T5 | Baseline | 2 |
|  | 42000 | 2 |
|  | 46000 | 2 |
|  | 51000 | 2 |
|  | 56000 | 2 |
| T6 | Baseline | 2 |
|  | 55000 | 2 |
|  | 60078 | 2 |
|  | 68091 | 2 |
|  | 69018 | 2 |
|  | 72516 | 2 |
|  | 73211 | 2 |

**2.2 Validation data set organization**

Experimental data for specimen T7 and T8 are organized in the validation folder. The loading file for specimen T8 is variable-amplitude loading. The file name is “Variable Loading Profile-1 block-1000 cycles” and contains a block of loading for 1000 cycles. The load will repeat this block until the specimen breaks.

The total numbers of data-files available for each specimen at each cycle-number are tabulated in Table 5.

**Table 5. List of Data-Files**

|  |  |  |
| --- | --- | --- |
| ***Specimen*** | ***Cycle Number*** | ***Number of Data-Files (including repetitions)*** |
| T7 | Baseline | 2 |
|  | 36001 | 2 |
|  | 40167 | 2 |
|  | 44054 | 2 |
|  | 47022 | 2 |
| T8 | Baseline | 2 |
|  | 40000 | 2 |
|  | 50000 | 2 |
|  | 70000 | 2 |
|  | 74883 | 2 |
|  | 76931 | 2 |