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BY

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THESIS

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Abstract

To my parents, for their love and support.

Acknowledgments

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LIST OF ABBREVIATIONS

Chapter 1

Introduction

Remanufacturing has been considered an important role in reducing energy consumption and environmental pollution, and

Chapter 2

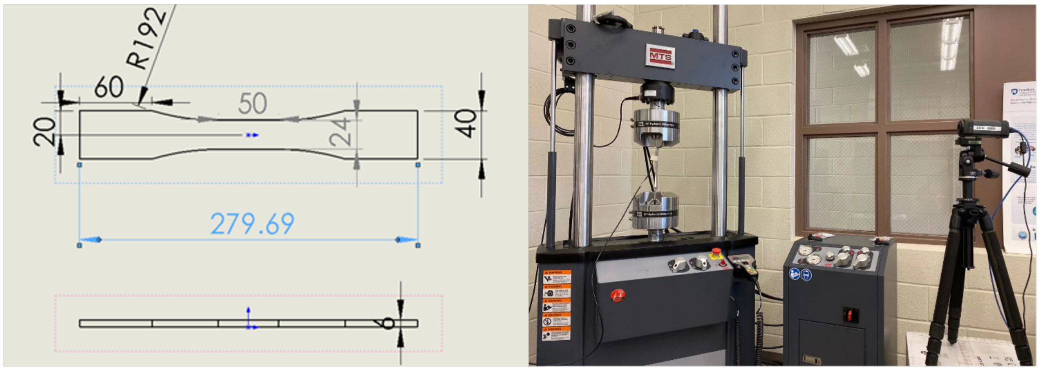
Experimental Dataset

This chapter describes the dataset and the experimental procedure used in this research for developing machine learning applications. First, the cyclic fatigue testing was conducted till the fracture of a material to acquire the fatigue characteristics of a material. Second, to mimic the scenarios in the remanufacturing industry, interrupted fatigue testing was utilized to produce specimens at different fatigue levels as a representation of end-of-life products. Linear and nonlinear ultrasound measurements are used to evaluate the fatigue damage of those specimens stopped at the predetermined number of cycles in the interrupted fatigue test. Besides, the residual stress and full width at half maximum data from X-ray diffraction are also presented.

2.1 Life cycle fatigue testing

The life cycle fatigue testing aims to collect the fatigue life data to understand the fatigue behavior of our targeted material. The fatigue life of a material is defined as the total number of cycles that a material can sustain under a specified loading condition. In order to develop the S-N curve of a material, the material is tested at different loading stress amplitudes, and the fatigue test is repeated multiple times for each loading stress amplitude to account for the variance of fatigue life.

The fatigue testing in this research is led by Prof. Li's group at the Penn State University. The targeted material is 5052-H32 aluminum alloy which is widely used for car body construction in the automotive industry. Figure 2.1 shows the dimension of the specimen and the test machine. Three loading amplitudes, 11.7, 12.7, and 14.7 kN for the cyclic fatigue testing are selected to develop the S-N curve which is shown in Figure 2.2.



(a) Schematic of the 5052-H32 aluminum alloy specimen

(b) MTS 100KN Landmark fatigue testing system at Prof. Jingjing li's lab

Figure 2.1: Life cycle fatigue testing setup

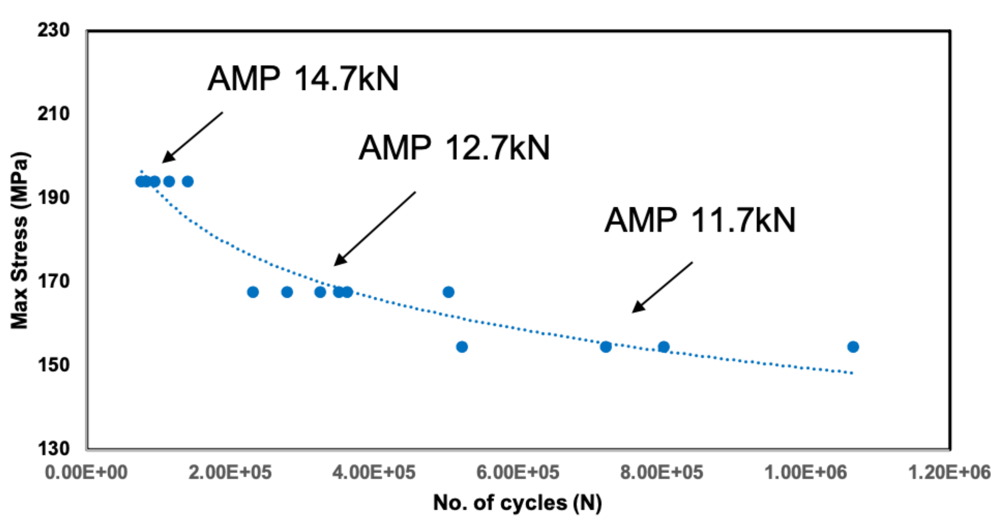


Figure 2.2: S-N curve for 5052-H32 aluminum alloy

2.2 Interrupted fatigue testing

The purpose of performing interrupted fatigue testing is to produce specimens at various fatigue levels by stopping the testing at several predetermined number of cycles. Considering the material cost and the time spent, the number of cycles applied to the specimens is set to be two levels, 33% and 67% fatigue life corresponding to the three loading amplitudes, 11.7, 12.7, and 14.7 kN. These specimens are used to represent the end-of-life products having different fatigue damage levels in the remanufacturing industry. Besides, three specimens without going through fatigue testing, i.e., 0% fatigue life, are included as specimens at the healthy state. The summary of the

Table 2.1: Summary of the interrupted fatigue testing specimens

Specimen ID	Loading Amplitude (kN)	Percentage of Fatigue Life (%)	Max Stress Applied (MPa)
1	11.7	33	176
2	11.7	33	176
3	11.7	67	176
4	11.7	67	176
5	12.7	33	195
6	12.7	33	195
7	12.7	67	195
8	12.7	67	195
9	14.7	33	221
10	14.7	33	221
11	14.7	67	221
12	14.7	67	221
13	–	0	–
14	–	0	–
15	–	0	–

interrupted fatigue testing specimens is presented in Table 2.1

2.3 Linear and nonlinear ultrasound measurements

Linear ultrasonic (LU) and nonlinear ultrasonic (NLU) testing serve as the two main NDE methods for measuring the accumulated fatigue damage in the specimens. The ultrasonic testing is led by Prof. Matlack's group, and the ultrasound testing system is shown in Figure 2.3. The LU and NLU measurements are both 1-D time domain signals, but the two approaches differ based on the different theories and parameters, e.g., excitation wave shape, frequency, amplitude, etc. Examples of LU and NLU signals are presented in Figure 2.4.

LU and NLU measurements were collected at nine locations in a specimen as illustrated in Figure 2.5, and each location was measured three times to ensure the measurement repeatability. As a result, for each specimen, there are $9 \times 3 = 27$ signal profiles produced.

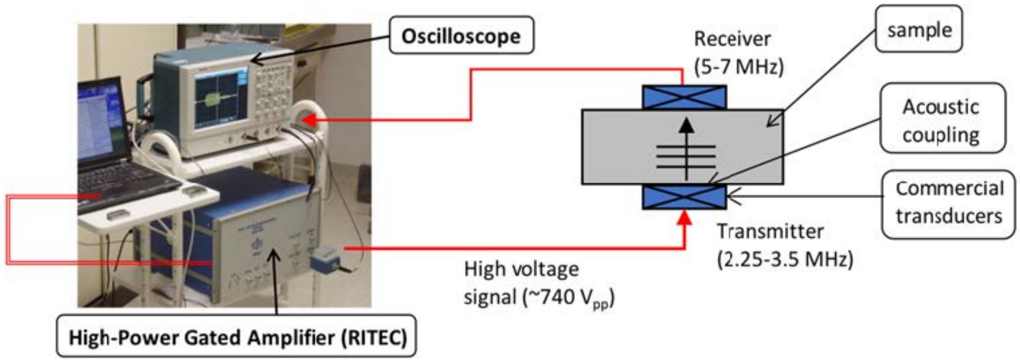
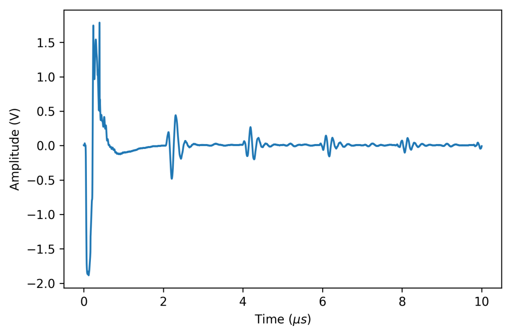
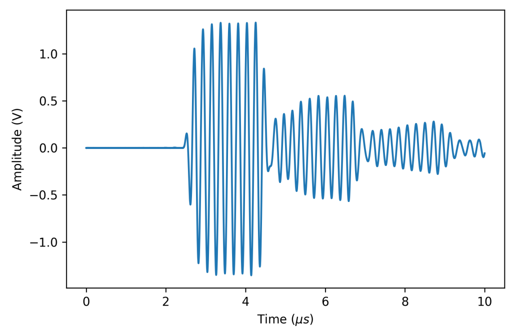


Figure 2.3: Experimental setup for LU and NLU at Prof. Matlack's Lab



(a) Linear ultrasonic signal



(b) Nonlinear ultrasonic signal

Figure 2.4: Examples of linear and nonlinear ultrasonic signals

2.4 X-ray diffraction measurement

Another quantity of interest, residual stress, is measured by X-ray diffraction (XRD) in this research. Residual stress is known to be associated with fatigue behaviors such as crack initiation and propagation. Besides, the full width at half maximum height (FWHM) of the diffraction peak in XRD is also calculated. Prof. Li's group performed the XRD measurements for a subset of specimens in the interrupted fatigue testing specimens. The XRD data is used in the regression tasks in Chapter 5.

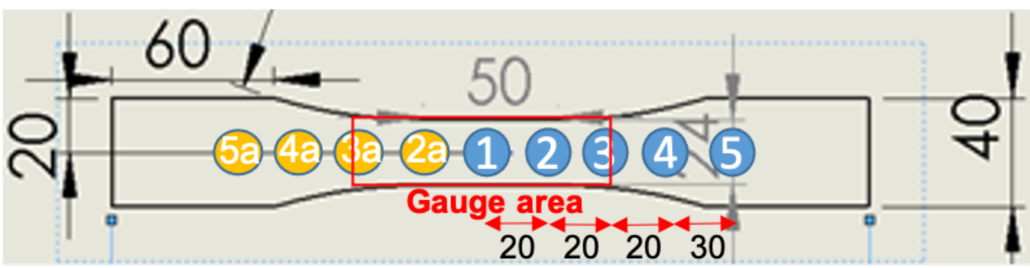


Figure 2.5: Schematic of the measurement locations for LU and NLU measurements. (The unit of length is in mm)

Chapter 3

Model Development

Chapter 4

Remaining Useful Life Prediction Framework

Chapter 5

Residual Stress & FWHM Prediction

Chapter 6

Conclusion

References