Assignment 1 – NGUYEN XUAN BINH – 887799

Problem 1

Select an article form Engineering Failure Analysis journal and write a summary of the paper. The summary report should be short (1-2 page with the most relevant picture) and it should include the description of the following issues:
- Analyzed structure and failure location
- Fatigue mechanics (crack initiation, propagation, final failure)
- Possible reasons for the failure and main affecting factors
You can find Engineering Failure Analysis journal here:
https://www.sciencedirect.com/search?qs=&pub=Engineering%20Failure%20Analysis&cid=271094

The chosen article that I decided to analyse is titled

Thermal corrosion fatigue crack growth behavior and life prediction of 304SS pipeline structures in high temperature pressurized water

https://www.semanticscholar.org/paper/Thermal-corrosion-fatigue-crack-growth-behavior-and-Li-Han/f916fd6e23a4e877e2c16c4ec042baaabc3256af

- **Structure**: The research focused on 304 stainless steel (304SS) pipeline structures commonly used in nuclear power plants, specifically targeting both base materials and welded joints. The examined pipelines were in a stepped tubular form, where specimens were fabricated to simulate typical defects experienced in service conditions.
- **Failure Location**: Fatigue crack growth and eventual failure were most significant at the prefabricated defect sites in the welded joints compared to the base material. These defects were placed strategically to observe the initiation and propagation of cracks under thermal fatigue conditions, and failure analysis revealed that welds were more susceptible due to their microstructural characteristics.

Fatigue Mechanics

1. **Crack Initiation**:
    - Cracks typically initiated at prefabricated defects in both the base material and the welded joints. In the welded joints, crack initiation was due to higher residual stresses and larger grain sizes.
    - The initiation mechanism was largely driven by thermal cycling between high (325°C) and low (38°C) temperatures. This causes significant thermal strains that stressed the material.
2. **Crack Propagation**:
    - The study observed transgranular crack propagation, where cracks moved through the grains of the material rather than around grain boundaries. This mode of propagation was influenced by the slip-oxidation mechanism

- Crack growth was observed to occur faster in the welded joints, and the growth rate decreased exponentially as the cooling rate decreased.

3. **Final Failure**:

    - The final failure occurred when the propagated cracks reached a critical length. The failure mode was predominantly influenced by the stress concentration around defect sites, which led to catastrophic rupture when the material could not carry the thermal cyclic loads.

Possible Reasons for Failure and Main Affecting Factors

1. **Material Properties**: The coarse grain structure in welded joints and the residual strains due to welding processes were significant factors that increased crack growth rates
2. **Thermal Stresses**: The alternating exposure to hot (325°C) and cold (38°C) water created large thermal stresses in the pipeline
3. **Cooling Rate**: The cooling rate was also a critical factor influencing crack growth. The study showed an exponential relationship between the cooling rate and the fatigue crack growth rate, which means that higher cooling rates led to faster crack propagation.
4. **Microstructure**: The slip-oxidation mechanism was predominant, where repeated cyclic stresses and oxidation accelerated crack growth.
5. **Residual Stresses**: Welding caused significant residual stresses in the joints, making them more prone to crack growth and eventual failure.

Problem 2
Perform a Rainflow counting for the following load history (see Figure 1).

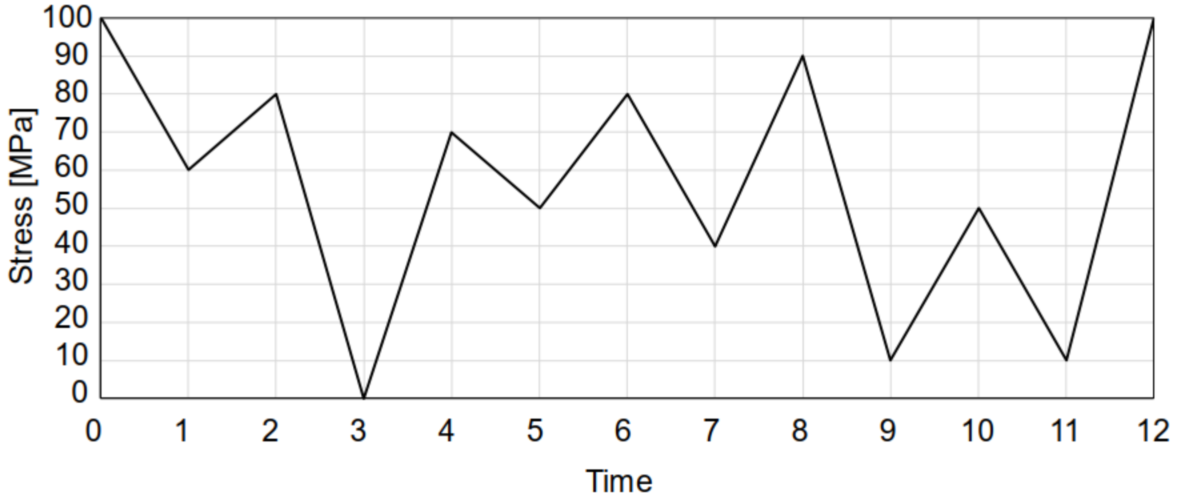
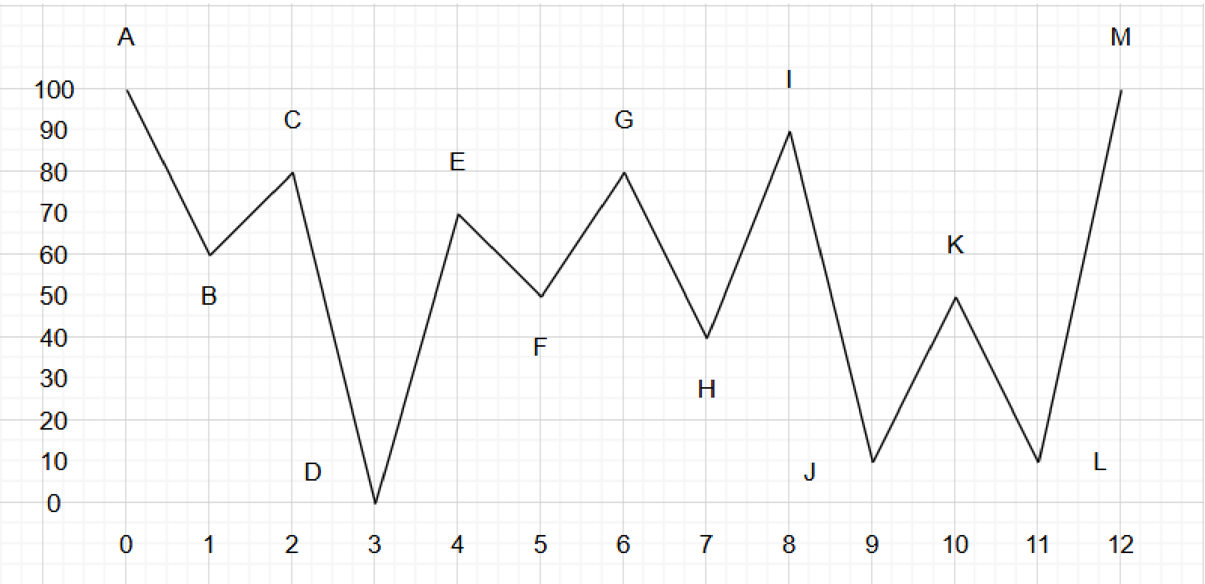
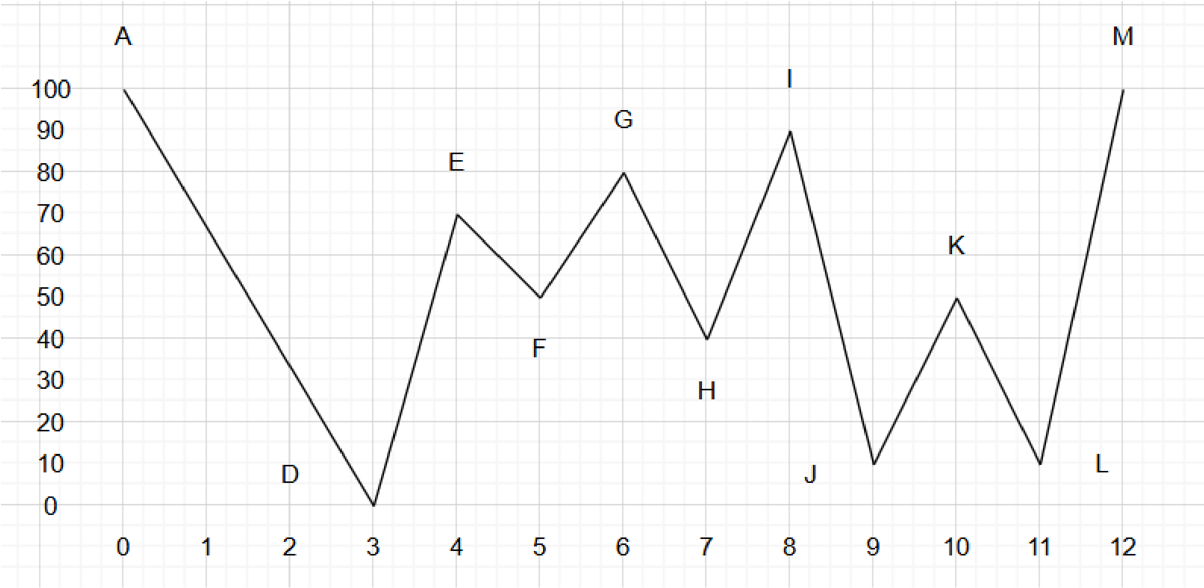


Figure 1 Load history for one repetition

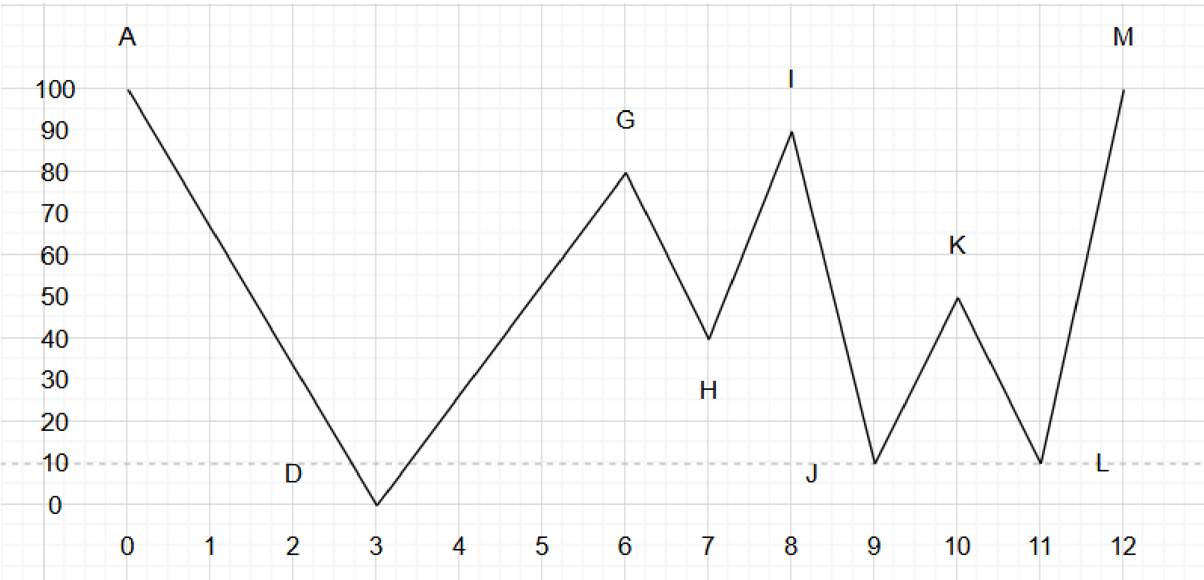
Firstly, we do not need to rearrange the history, since the sequence has already started with the highest magnitude. Now, we can name the points on the graphs as follows:



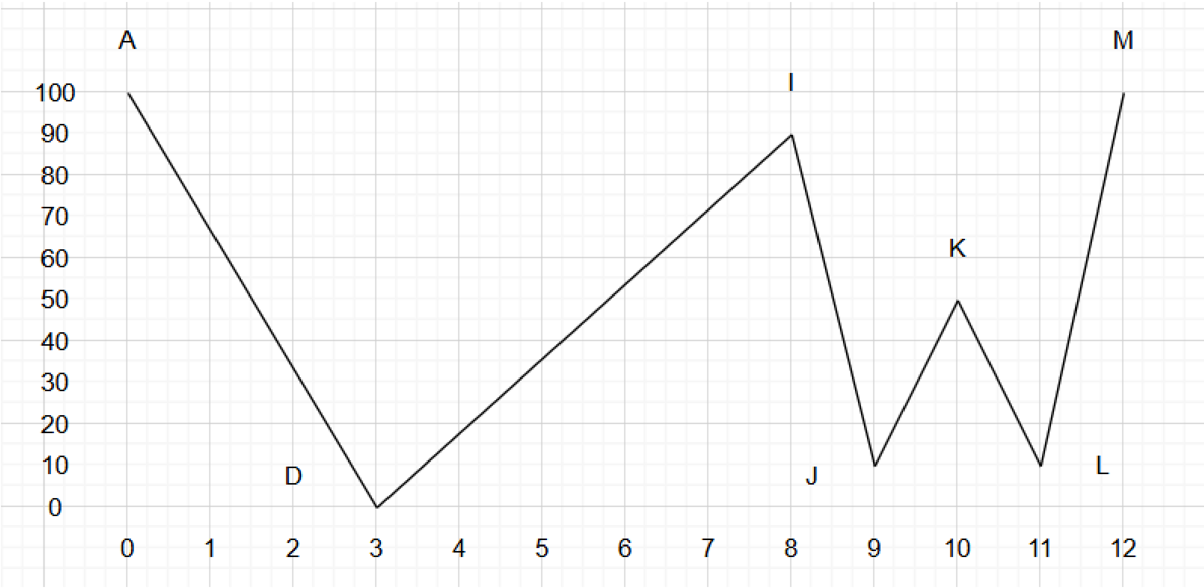
The next cycle where the change is smaller than or equal to the next change is cycle B-C
Range: 80 – 60 = 20
Mean: (80 + 60)/2 = 70
Then we remove B-C cycle. The load history now becomes



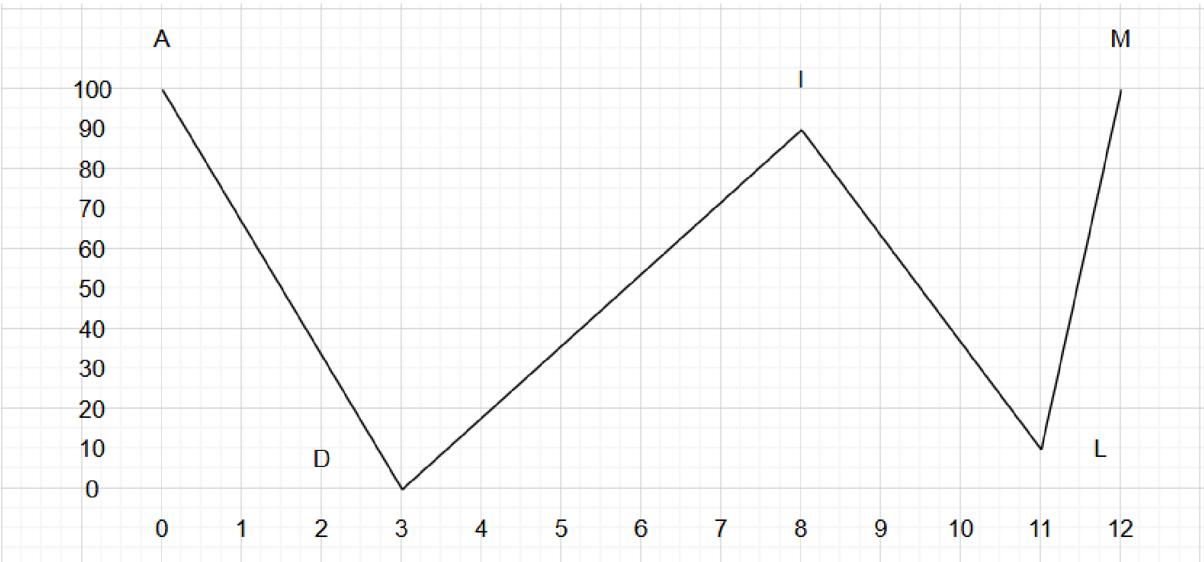
The next cycle where the change is smaller than or equal to the next change is cycle E-F
Range: 70 – 50 = 20
Mean: (70 + 50)/2 = 60
Then we remove E-F cycle. The load history now becomes



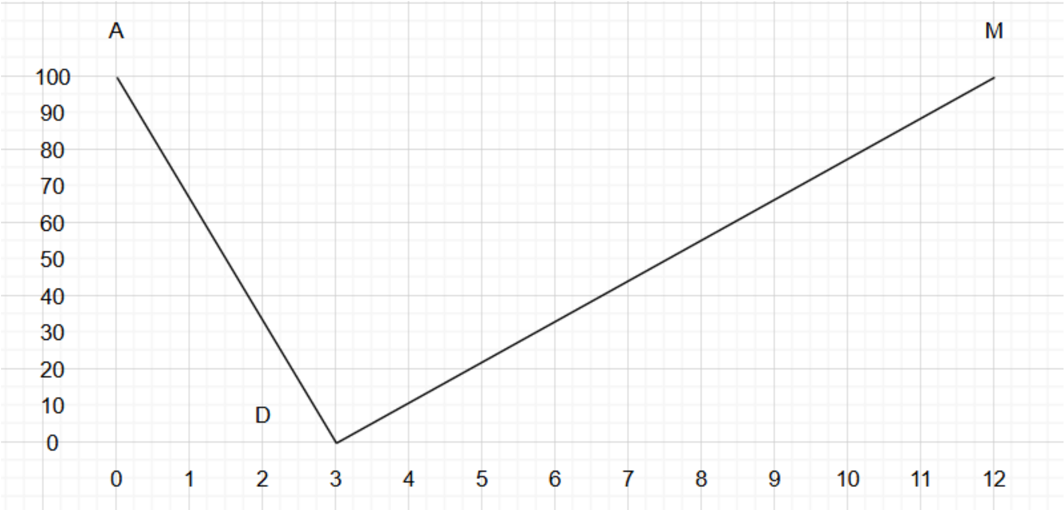
The next cycle where the change is smaller than or equal to the next change is cycle G-H
Range: 80 – 40 = 40
Mean: (80 + 40)/2 = 60
Then we remove G-H cycle. The load history now becomes



The next cycle where the change is smaller than or equal to the next change is cycle J-K
Range: 50 – 10 = 40
Mean: (50 + 10)/2 = 30
Then we remove J-K cycle. The load history now becomes



The next cycle where the change is smaller than or equal to the next change is cycle I-L
Range: 90 – 10 = 80
Mean: (90 + 10)/2 = 50
Then we remove I-L cycle. The load history now becomes



The next cycle where the change is smaller than or equal to the next change is cycle A-D
Range: 100 – 0 = 100
Mean: (100 + 0)/2 = 50

Finally, we can summarize Rainflow counting for this load history as

Cycle	Range	Mean
B-C	20 MPa	70 MPa
E-F	20 MPa	60 MPa
G-H	40 MPa	60 MPa
J-K	40 MPa	30 MPa
I-L	80 MPa	50 MPa
A-D	100 MPa	50 MPa

Problem 3
An unnotched member fabricated from AISI 4142 (see Table 1) is subjected to the load history shown below.

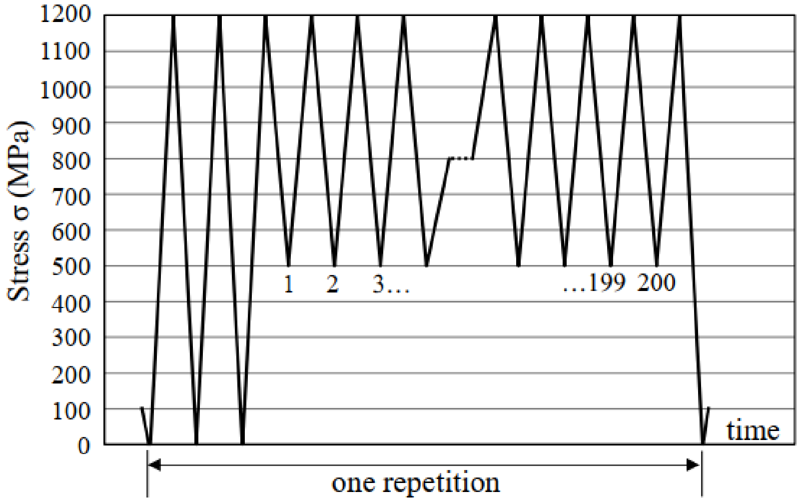


Figure 2 Load history for one repetition

a) Perform a Rainflow counting of the following load history (see Figure 2).

At first glance, the cycle does not start with the maximum value yet. Therefore, it would be nice if we can shift this load history one cycle ahead, bringing half cycle from the end of one repetition and combine it with the start of the loading history

If we do this, we can see that at the beginning, there are 3 cycles.

First series of cycles: 3, max stress is 1200 MPa and min stress is 0 MPa

Their range: 1200 – 0 = 1200 MPa

Their amplitude: (1200 + 0) / 2 = 600 MPa

Their mean: (1200 + 0) / 2 = 600 MPa

After these 3 cycles, we have 200 cycles.

Their max stress is 1200 MPa and min stress is 500 MPa

Their range: 1200 – 500 = 700 MPa

Their amplitude: (1200 - 500) / 2 = 350

Their mean: (1200 + 500) / 2 = 850 MPa

b) Estimate the number of repetitions and the number of cycles to failure (Miner rule). Use the Goodman equation (see Dowling book section 9.7 and Lecture 2 slides):

$$\boldsymbol{\sigma_a} = \left(\mathbf{1} - \frac{\boldsymbol{\sigma_m}}{\boldsymbol{\sigma_u}}\right) \cdot \boldsymbol{A} \cdot \boldsymbol{N_f^b}$$

Suggestions: Constants for Goodman equation from Table 1.

Table 1 Constraints for stress-life curves: tests at zero mean stress on unnotched axial specimen

Material	Yield Strength σ_o	Ultimate Strength σ_u	True Fracture Strength $\tilde{\sigma}_{fB}$	$\sigma_a = \sigma_f'(2N_f)^b = AN_f^B$ σ_f'	A	$b = B$
(a) Steels						
AISI 1015 (normalized)	227 (33)	415 (60.2)	725 (105)	976 (142)	886 (128)	−0.14
Man-Ten (hot rolled)	322 (46.7)	557 (80.8)	990 (144)	1089 (158)	1006 (146)	−0.115
RQC-100 (roller Q & T)	683 (99.0)	758 (110)	1186 (172)	938 (136)	897 (131)	−0.0648
AISI 4142 (Q & T, 450 HB)	1584 (230)	1757 (255)	1998 (290)	1937 (281)	1837 (266)	−0.0762
AISI 4340 (aircraft quality)	1103 (160)	1172 (170)	1634 (237)	1758 (255)	1643 (238)	−0.0977

Notes: The tabulated values have units of MPa(ksi) except for dimensionless $b = B$. See Table 14.1 for sources and additional properties.

Based on the information from table 1, the properties of AISI 4142 steel are

$$\sigma_u = 1757MPa, \qquad A = 1837MPa, \qquad b = -0.0762$$

The Goodman mean stress correction formula is

$$\sigma_a = \left(1 - \frac{\sigma_m}{\sigma_u}\right) A N_f^b$$

Where σ_a is stress amplitude, σ_m is mean stress and N_f is the number of cycles until failure. However, since we have two kinds of cycles, we need to inverse calibrate the cycles until failure for both cases

$$\sigma_a = \left(1 - \frac{\sigma_m}{\sigma_u}\right) A N_f^b \Rightarrow N_f = \left(\frac{\sigma_a}{\left(1 - \frac{\sigma_m}{\sigma_u}\right) A}\right)^{1/b}$$

For first series of cycles

$$N_{f1} = \left(\frac{\sigma_a}{\left(1 - \frac{\sigma_m}{\sigma_u}\right) A}\right)^{1/b} = \left(\frac{600MPa}{\left(1 - \frac{600MPa}{1757MPa}\right) 1837MPa}\right)^{1/-0.0762} = 9916$$

For second series of cycles

$$N_{f2} = \left(\frac{\sigma_a}{\left(1 - \frac{\sigma_m}{\sigma_u}\right) A}\right)^{1/b} = \left(\frac{350MPa}{\left(1 - \frac{850MPa}{1757MPa}\right) 1837MPa}\right)^{1/-0.0762} = 479508$$

Finally, we can apply the Miner's rule to obtain the number of repetitions until failure

$$B_f \sum \frac{N_i}{N_{fi}} = 1 \Rightarrow B_f = \frac{1}{\sum \frac{N_i}{N_{fi}}} = \frac{1}{\frac{N_1}{N_{f1}} + \frac{N_2}{N_{f2}}} = \frac{1}{\frac{3}{9916} + \frac{200}{479508}} = 1390$$

Therefore, the notched specimen will break in failure after **1390** repetition. We also know that each repetition have 3 + 200 = 203 cycles, so it will take 1390 x 203 = **282170** cycles until failure (cycles here can have varying mean stress, stress magnitude and range)