Welded austenitic steel pipes were fatigue tested in bending.

Constant amplitude and three different variable amplitude loads were applied.
Problem to study

Pressure vessel components are designed for long life of spectrum loading but reference data is often based on LCF constant amplitude tests of small specimens.

This results in uncertain predictions demanding large safety factors.

Here, we investigate component strength closer to the interesting long life region, where fatigue limit mechanisms influence the life.

For life prediction, we study three different models for fatigue damage development, all used with the Palmgren-Miner damage sum hypothesis.

- the simple Basquin model *neglecting* the fatigue limit,
- a model including an *asymptotic* fatigue limit (in accordance with the pressure vessel code ASME), and
- a Basquin model including a *decreasing* fatigue limit.
Test set up

The tests were performed in a servo-hydraulic test machine, using a specially designed fixture to achieve fully reversed bending of the pipes.

- \( R = -1 \)
- displacement control
- strain gage monitoring
- 10-15 Hz
- Run out: 5 million
- Internal pressure: 70 bar
- Failure criterion: detected leakage.
Level crossing spectra

Four different loading types were used:

1) constant amplitude,
2) a synthetic Gaussian load,
3) a user specified spectrum of loads,
4) a specially designed two level block load.

The variable amplitude loads were applied in blocks of 400-450 cycles, repeated until failure or run out.
The results suggest a similar slope for the different types of loading and large scatter.
We next use a *norm* that would put the test results on a single line if the Palmgren-Miner rule is valid.

\[ \| \epsilon \|_{Basquin} = \left( \frac{1}{m} \sum_{i=1}^{m} \Delta \epsilon_i^\beta \right)^{1/\beta} \]

The diagram suggests that constant amplitude tends to give longer life than predicted from the Palmgren-Miner rule, **BUT** the two variable amplitude types cannot be distinguished!
Three models for prediction

The Basquin model without fatigue limit

\[ N = \alpha \cdot \Delta \epsilon^{-\beta} \]

A model with asymptotic fatigue limit (from the ASME code)

\[ N = A \cdot (\Delta \epsilon - C)^{-B} \]

A Basquin model with decreasing fatigue limit

\[ N = \alpha \cdot \Delta \epsilon^{-\beta} \quad \text{if} \quad \Delta \epsilon > \Delta \epsilon_0(d) \]

\[ N = \infty \quad \text{if} \quad \Delta \epsilon \leq \Delta \epsilon_0(d), \]

where \( \Delta \epsilon_0(d) \) decreases for each applied cycle in sequence that exceeds the limit.
Model fits to the variable amplitude results

Differences are significant for long lives. What model should be used?

We now constructed a special spectrum that should distinguish the three models at long lives.
The scatter is too large to distinguish between the three models. More tests are needed, preferably at longer lives. Variable amplitude tests in resonance machines would be a possibility.

Predictions from constant amplitude reference tests tend to be un-conservative.
Welded components for pressure vessel applications were investigated with focus on the fatigue limit influence at variable amplitude.

The results suggest that the Palmgren-Miner rule for damage evolution is un-conservative if it is based on constant amplitude reference data.

However, the results also suggest that using the Palmgren-Miner rule based on a synthetic reference spectrum may give good predictions.

Prediction of long life behaviour is highly sensitive to the choice of prediction model and therefore demands a lot of reference tests performed at long life.
A hypothesis based on the idea of crack growth and arrest is used:

Before the load is applied there is a crack with potential to be the cause of failure.

The stress intensity threshold for this crack represents an initial fatigue limit.

The first cycle in an applied load spectrum that exceeds this limit will cause a crack growth and the new longer crack will have a lower fatigue limit.

Each subsequent load cycle that exceeds the actual fatigue limit will further lower the limit.

This theory of damage evolution can be used to predict fatigue life for a stationary random process of loads.

Reference:

Gaussian sequence
Sequence from user specified spectrum