Long-term deterioration of liners from fatigue damage (pressure transient or external loading)

Introduction

The following fact sheet gives some preliminary results of tensile-tensile fatigue tests conducted on a GFRP (glass fibre reinforced polymer) CIPP and polyurethane (PU) spray liner.

The main objectives were to evaluate the long-term performance of these liners under fatigue conditions, such as pressure transients and external traffic loading. The test can be used as an accelerated deterioration test of a liner by providing S-N (stress vs. number of cycles to failure) curves for fatigue strength of liners, and provide a cut-off value where fatigue may be an issue.

Methodology

Tensile tests

Tensile coupons were CNC cut (for polymers) and water jet cut (for CIPP) from flat sample plates from manufacturers.

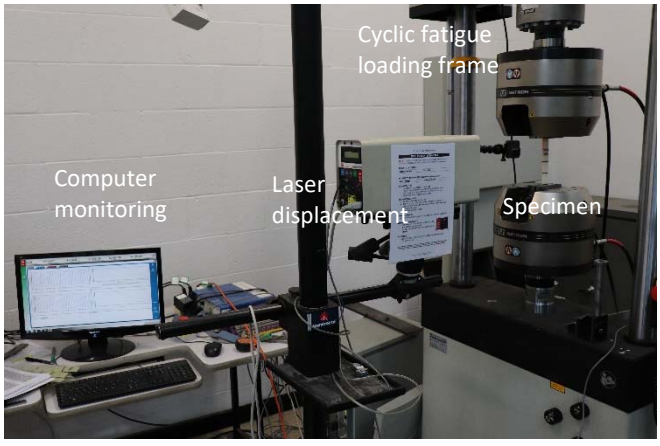

Figure 1: Tensile-tensile fatigue test specimen apparatus

Over 12 tensile-tensile fatigue tests were conducted for each liner according to the ISO 13003 (2003) standard (Figure 1). The testing followed a stress ratio of 0.9 (minimum stress was 10% of maximum stress, e.g. 30 MPa to 3 MPa).

Test parameters are as follows:

- Specimen direction: 2 directions for CIPP and 1 direction for PU spray
- Test speed: 2 Hz for CIPP and 0.5 Hz for PU spray

Specimens were monitored for heat throughout the test.

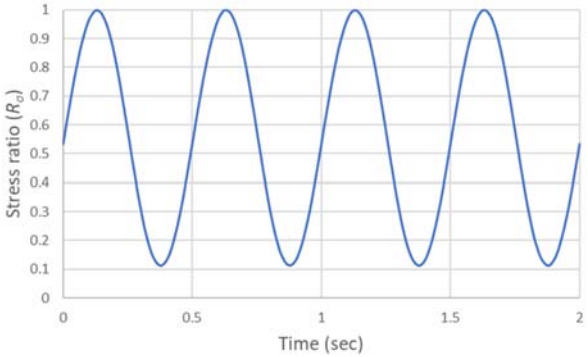

Figure 2: Example stress ratio curve during testing of CIPP

Results

CIPP

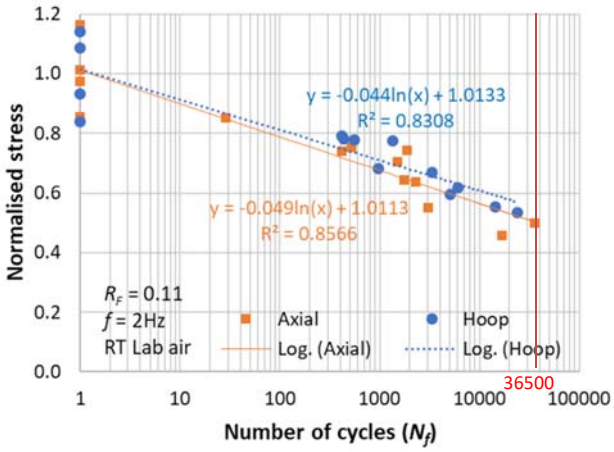

Figure 3: Normalised stress (maximum tensile stress applied / average short-term tensile strength) vs. number of cycles until failure for CIPP (in axial and hoop direction).

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PU spray liner

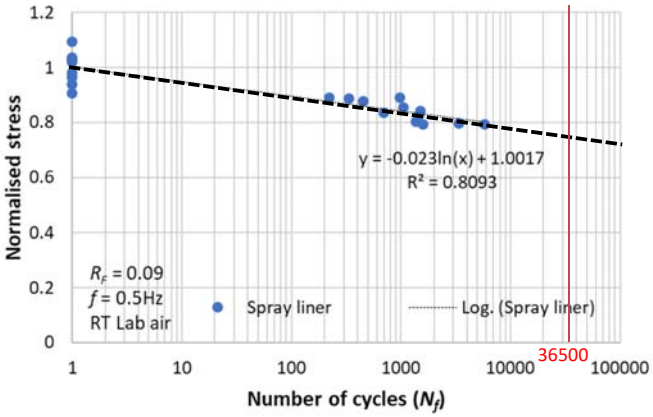

Figure 4: Normalised stress (maximum tensile stress applied / average short-term tensile strength) vs. number of cycles until failure for PU spray liner.

Discussion

The S-N curve shows that CIPP with GFRP (Figure 3) is susceptible to fatigue damage. Results in both the axial and hoop direction show similar normalised stress gradient declines with increasing number of cycles to failure. Therefore, examining fatigue from either pressure transients or external loading may be an issue.

The S-N curve for PU spray liner (Figure 4) has less reduction in stress ratio with increasing number of cycles compared with the GFRP CIPP tested.

Examining both cases, the stress ratio in CIPP reduces with number of cycles to failure. If we know the approximate number of pressure transients per day, we can use this as an estimate for fatigue life due to pressure transients. Table 1 provides the number of pressure transients that may be experienced by a liner.

If we assume that a minimum of two pressure transient cycles occur during a day (pump start-up and pump shutdown) the minimum pressure transient cycles to be experienced by a liner in a 50-year life would be 36,500. Therefore, if a known range of pressure transient increase in pressure is known for the pipe, a check for fatigue damage could be examined in the liner.

Table 1: Number of pressure transients that may be experienced for a pipe based on how many years in service

	Number of pressure transients per day			
Years	1	2	4	10
1	365	730	1460	3650
10	3650	7300	14600	36500
20	7300	14600	29200	73000
50	18250	36500	73000	182500
100	36500	73000	146000	365000

Examining both Figure 3 and Figure 4 for 36500 cycles (50 year assuming 2 pressure transients per day), a 50% and 75% normalised stress is observed for the GFRP CIPP and PU spray liners examined respectively. These values can be multiplied by the average short-term tensile strength value to determine a degraded strength due to fatigue. The liner should be designed in such that the stress experienced in the liner is below the degraded strength due to fatigue.

Note: This is an extreme case of fatigue as cycles are varying considerably more than what may be expected due to a typical pressure transient or traffic load. In designing liners, the design-relevant stress should be much lower than that experienced due to fatigue. Also, these curves should be examined for all liner material types and products as the S-N curves may vary depending on material type.

Conclusions

A decrease in normalised stress was observed in the GFRP CIPP and PU spray liner tested. PU spray lining showed a smaller impact due to fatigue than GFRP CIPP. An example on how to apply strength degradation due to fatigue loading was given.

References

ISO 13003 (2003). Fibre-reinforced plastics - Determination of fatigue properties under cyclic loading conditions, Switzerland, pp. 1-17.