Fatigue stress failures caused by pressure fluctuations.

What Is Material Fatigue?

Material fatigue is a phenomenon where structures fail when subjected to a cyclic load. This type of structural damage occurs even when the experienced stress range is far below the static material strength (substantially less than those that would cause plastic deformation). Fatigue was initially recognized as a problem in the early 19th century when investigators in Europe observed that bridge and railroad components were cracking when subjected to repeated loading. Fatigue stress failures occurs as well in metals as in polymers.

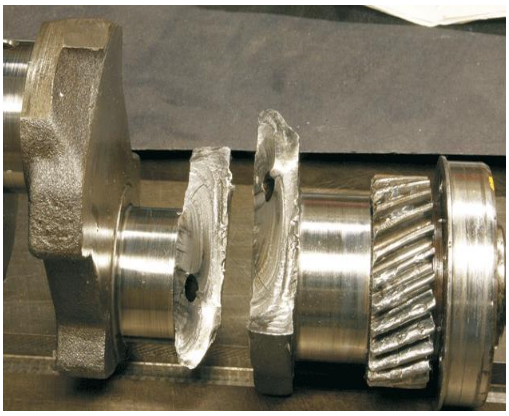
Some examples of fatigue stress failures:

Fatigue stress failure in an aircraft engine.

Fatigue cracking in a bridge girder.

Figure 3. Fatigue Crack in Gear Tooth Root Fillet.

High cycle fatigue failure in gear tooth.



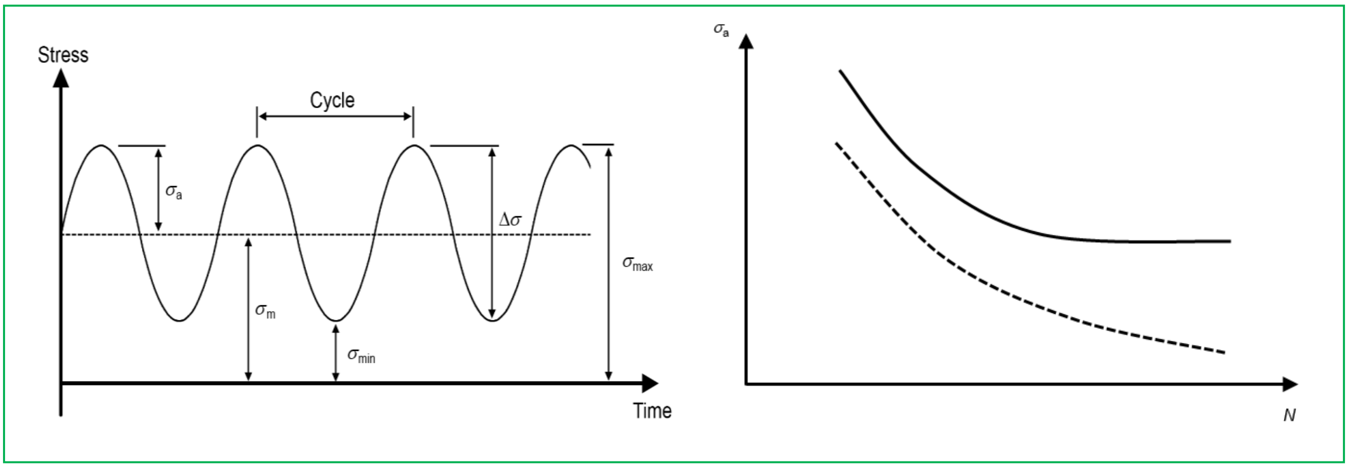
Crankshaft fatigue failure.

Part of aircraft fuselage blown away due to fatigue.

Fatigue stress caused by waves.

The most important parameters for fatigue damage are the **stress amplitude [σ_a]** and the **frequency** of the **stress cycles.**

The number of cycles required to cause fatigue failure at a particular peak stress is generally quite large but it decreases as the mean stress **[σ_m]** or stress amplitude **[σ_a]** is increased.



Research in the field of fatigue first began in the 19th century and has resulted in a number of methods for fatigue prediction. One of the classical models is the so-called *S-N* curve.

This *S-N* curve relates the number of cycles until failure (i.e. lifetime *N*), to the stress amplitude *S*.

The general trend is that a longer lifetime is obtained with a decrease in stress amplitude *S* or [σ_a].

For example a decrease of the stress amplitude [σ_a] by 10% can increase the lifetime by 50%.

Some materials exhibit a stress threshold, known as the endurance limit (solid line in the *S-N* curve). At stresses below this threshold, no fatigue damage is observed and components can operate for an infinite lifetime.

There is very little, if any, warning before failure if the crack is not noticed.
The process until a component finally fails under repeated loading can be divided into **3 stages**:

1) During a large number of cycles, the damage develops on the microscopic level and grows until a macroscopic crack is formed (slow crack growth).
2) The macroscopic crack grows for each cycle until it reaches a critical length (slow crack zone).
3) The cracked component breaks (fast fracture) because it can no longer sustain the peak load.

A good example of fatigue failure is breaking a thin metal rod or wire with your hands after bending it back and forth several times in the same place.

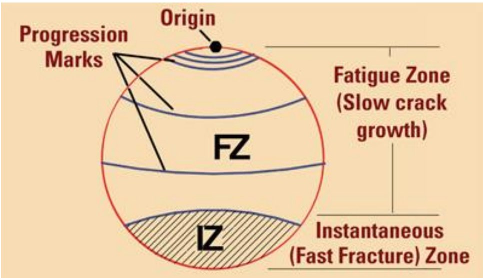
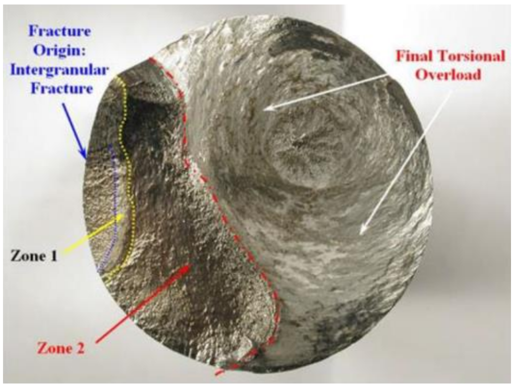


Fig. 3. This typical plane bending fatigue failure shows how a crack starts at the origin and slowly grows across the Fatigue Zone. When the crack reaches the boundary of the Instantaneous Zone, its growth rate increases significantly.



Fatigue stress failures can be caused by 4 common fatigue forces:

1. Internal pressure fluctuations.
2. Repetitive bending.
3. Repetitive torsion.
4. Repetitive tension.

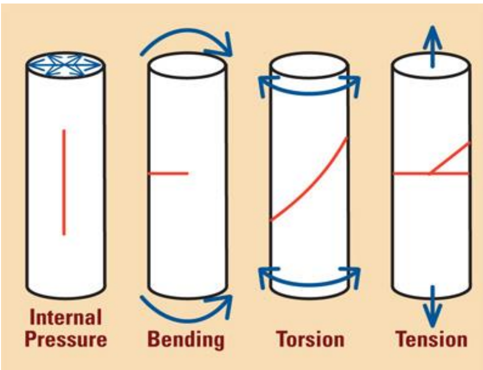


Fig. 2. Fracture planes caused by four common fatigue forces: Because the section properties will change as the crack grows, it's important to look carefully at the point where the failure starts to determine the direction of the forces.

Each fatigue force/moment shows its own specific fracture planes.

Fatigue failure prevention starts with good design practice. As mentioned before, fatigue stress failures can be caused by internal pressure fluctuations.

For example select a proper (booster) pump for your pipe system. By not selecting the right pump for your pipe system can result in severe pressure fluctuations in your whole system.

Fixed or **single speed pumps** operate by delivering a band of pressure between a pre-set minimum and maximum pressure. The pressure at the outlets is likely to vary depending on the amount of water being used.
Some pumps are able to deliver water at a constant pressure by controlling the speed of the pump. That means that the pump has a controller that automatically adjusts the pumps speed to deliver constant water pressure to the outlets, regardless of the demand or the inlet pressure. A **variable speed pump** changes the speed by the controller adjusting the Frequency (Hz) of the power supplied to the motor. This is why some call constant pressure pumps Variable Frequency pumps.

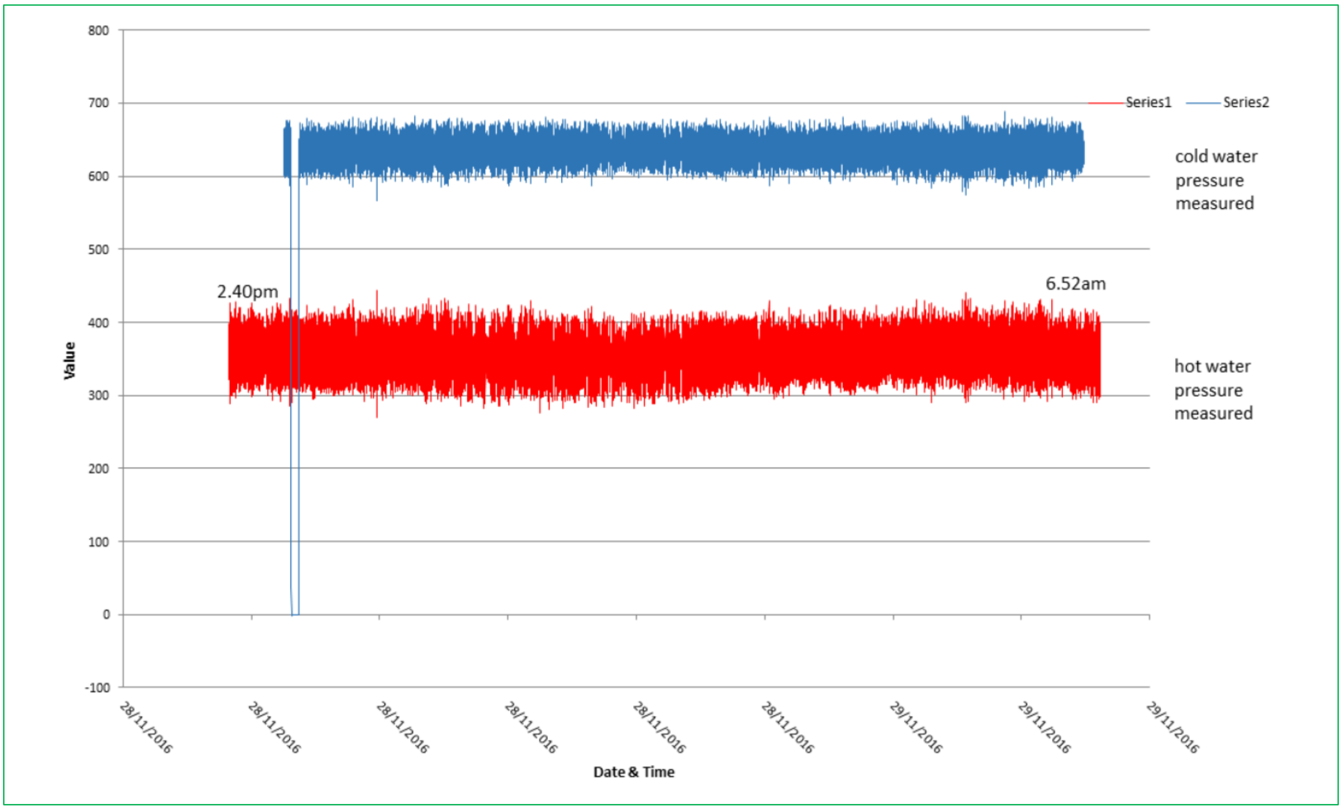
Click on below link to view a video about **single speed** vs **variable speed pumps**. YouTube

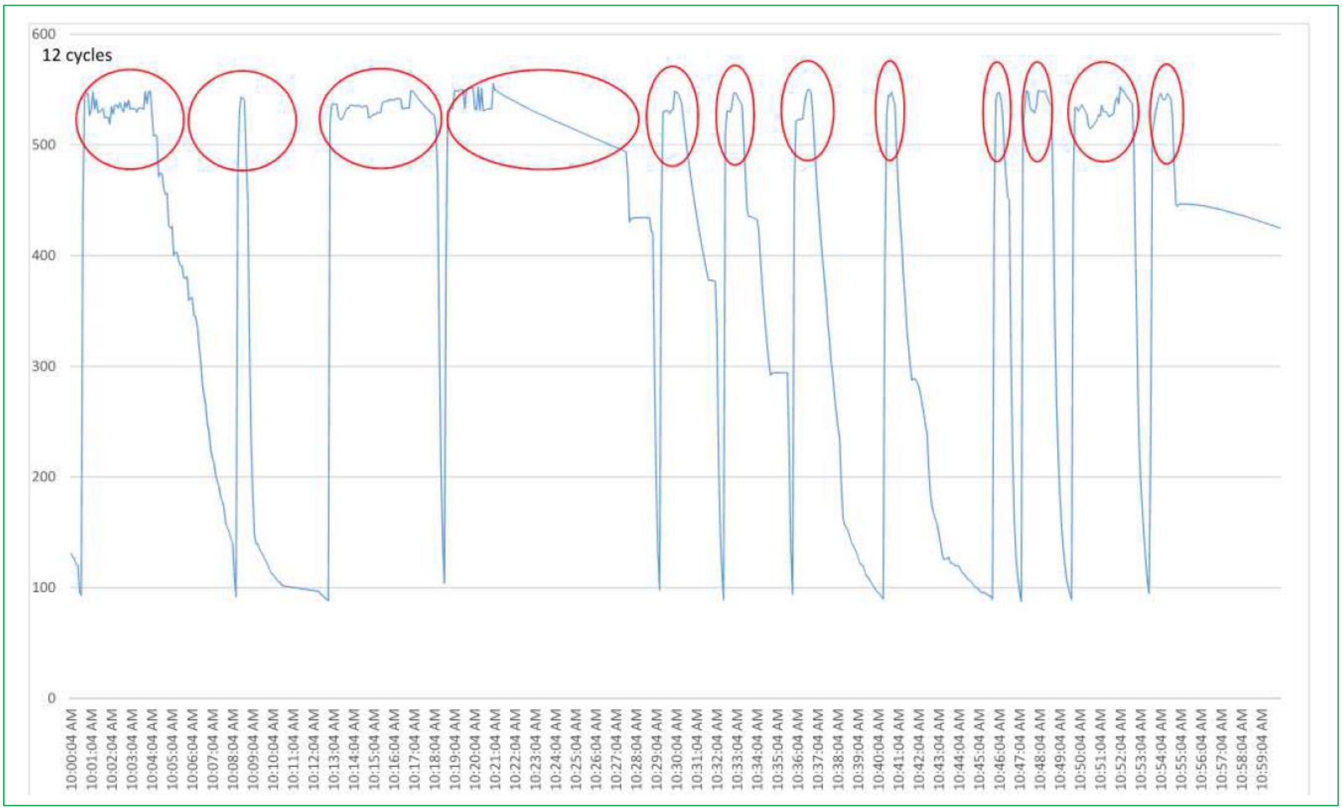
https://www.youtube.com/watch?v=xc6Qrswlgxg

Below you will find some videos showing pressure gauges installed in mixed Copper/PP-R Hot Potable Water Reticulation Systems (HWRS) around Australia, showing frequent pressure fluctuations in the whole HWRS, caused by fixed or single speed cold water booster pumps.

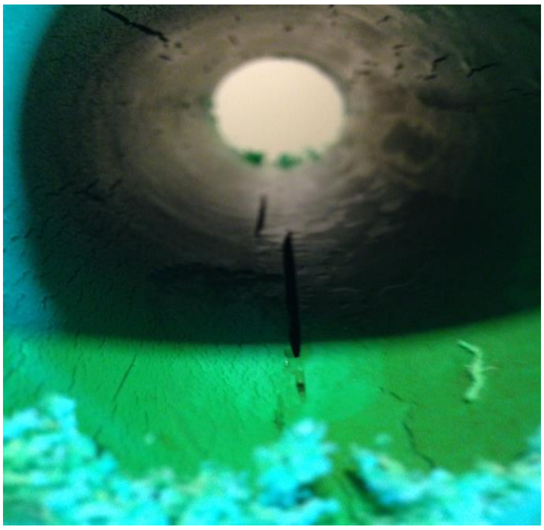
The pressure fluctuations vary from **100 kPa** till almost **300 kPa every 10-30 seconds!**
These pressure fluctuations occur **24 hours a day and 7 days a week**.

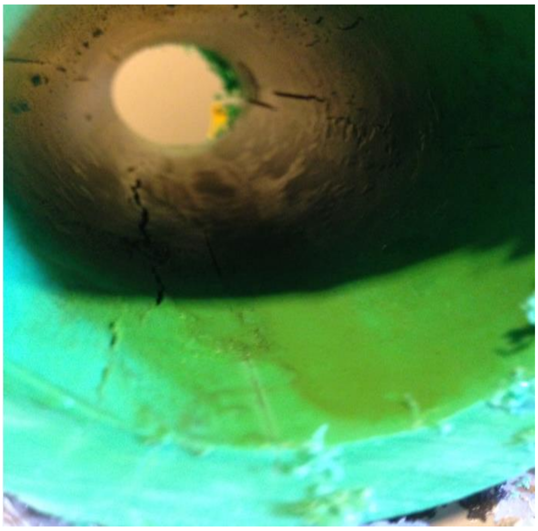
Click on below pictures to view these videos. YouTube





These graphs show you constant pressure fluctuations [kPa] measured in HWRS around Australia.





This is what those constant pressure fluctuations caused to hot potable water PP-R and Copper pipes and other components in the Hot potable Water Reticulation Systems (HWRS).

Fatigue *Just as the human body can break down if exposed too long to an adverse environment or repeated stress, so also can materials fail due to fatigue. A material can fail by repeated exposure to a stress well below its normal breaking point purely by cycling the stress on and off.*
Water heaters can be exposed to repeated pressure fluctuations during their life and must be designed to resist the effects of fatigue. (**Extract from Rheem Hot Water Manual 2006 page 356**).

How would you feel if you had to dive to the bottom of a 10-30 meter swimming pool and back to the surface every 10-20 seconds for the rest of your life?

There is a lot of (International) literature available about fatigue stress and fatigue stress prevention.

Fatigue stress prevention could save you a lot of money!