

Maximator Test, LLC - White Paper

Autofrettage

Autofrettage – A simple process to enhance the pressure fatigue life of pressure carrying products and pressure vessels.

Autofrettage is a safe, simple, effective process that provides tremendous enhancement to the pressure fatigue life of a pressure carrying product or pressure vessel. Developed in Europe over a century ago, autofrettage has been used by many US and European manufacturers of high pressure vessels to greatly improve their product's pressure fatigue life. The US military (among many other exploiters of this technology) has utilized autofrettage to significantly enhance the pressure fatigue life of products such as most of its gun and cannon barrels. Today, it is used world-wide by a consortium of world-class companies to enhance product pressure fatigue lives - from high pressure fuel and diesel injection systems makers to water-jet equipment manufacturers and developers of other high-pressure delivery equipment (mining, cutting, oil-drilling, polishing, chemicals processing, urea & plastics manufacturing, etc.). In many cases, the pumps, cylinders, control valve bodies, manifolds, high pressure connectors, fittings, adapters and interconnecting lines can all benefit from the autofrettage process.

Autofrettage provides a beneficial compressive stress to the ID surface of any pressure vessel, while allowing the much lower stressed outer surface to act as a band-clamp to prevent failure from occurring at the more vulnerable ID surface. The effects of autofrettage are similar to shot-peening or burnishing the ID surface of the pressure vessel at every possible internal location, without exception. There are few other processes known that can produce such universally beneficial results with such a simple application.

Benefits of Autofrettage

Enhanced product cycle life at elevated pressure cycles

There is more than one way to look at the potential improvement to product cycle life at elevated pressure cycles. The first way to look at it is an increase in product cycles at a given pressure level. Many companies are striving to achieve this benefit these days with minimal investment. The second is an increase in maximum pressure level for a given number of cycles. If your goal is either of these, then autofrettage can help you solve that problem. It is even possible to achieve both an improvement in product life at an elevated pressure cycle. Specific realizable goals are given in a later section entitled "How does autofrettage improve pressure fatigue life?"

Lower cost materials

One of the underestimated benefits of autofrettage is the ability to use lower cost materials to meet high pressure cycle life goals. In cases where higher cost materials with higher strengths and/or lower inclusion levels are specified, often commercially available materials with greater availability at lower cost are more durable at given pressure cycle applications with the use of simple, proper autofrettage procedures.

Less refined surface finish

Another benefit of autofrettage is minimizing the effects of poor surface finish on pressure fatigue life. Every Engineer knows the detrimental effect of rough surface finish on the fatigue life of a product. Autofrettage has the ability to impart a residual compressive stress that is deeper than the worst-case defect of a machined or otherwise as-formed ID surface. This can result in a surface that has very little to no detrimental impact on fatigue life. Engineers also may know that most commercially available processes to improve the surface finish of the inner bore of a product are either very costly or otherwise experimentally prohibitive, but autofrettage may provide a simple, cost-effective solution.

Less sensitivity to stress risers

Either changes in cross-section, cross holes, or irregular ID features can be serious trouble when it comes to pressure fatigue life. Autofrettage can successfully eliminate the concern for many of these unavoidable design features. One of the most advantageous results of autofrettage is that its life-enhancing effects are best realized at ID stress risers. Residual, life-enhancing compressive stresses after autofrettage will be the greatest at these stress riser features.

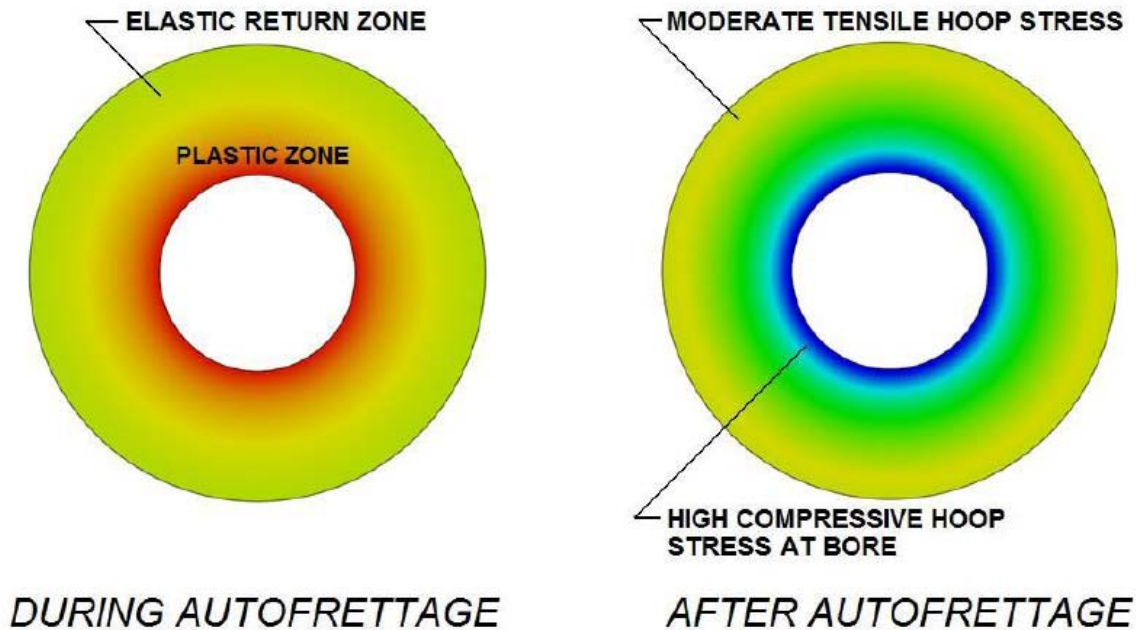
How does autofrettage work?

Autofrettage works by yielding at least a portion of the wall thickness of the material of a high pressure carrying element to eventually produce a beneficial compressive stress on the product's ID surface when the applied pressure is removed.

Essentially, autofrettage works as if the pressure carrying element has a band clamp on its outer circumference, minimizing or eliminating the pressure vessel ID from experiencing the negative effects of pressure pulsations. It's ok to have a tensile band on the outside, since generally all of the fatigue failures will tend to initiate from the ID, where the stresses are highest. Generally, cracks will always tend to initiate from the largest stress riser or the largest defect on the ID surface. The only time this is not the case is when large stress risers with residual tensile stresses are positioned on the outer perimeter of the part.

The following graphic illustrates the process in two steps. In the first step, a very high pressure is applied to the part. The inner most bore will generally experience a small plastic deformation, while the lesser stressed OD will expand elastically. When the pressure is released in step two, the elastic stresses in the

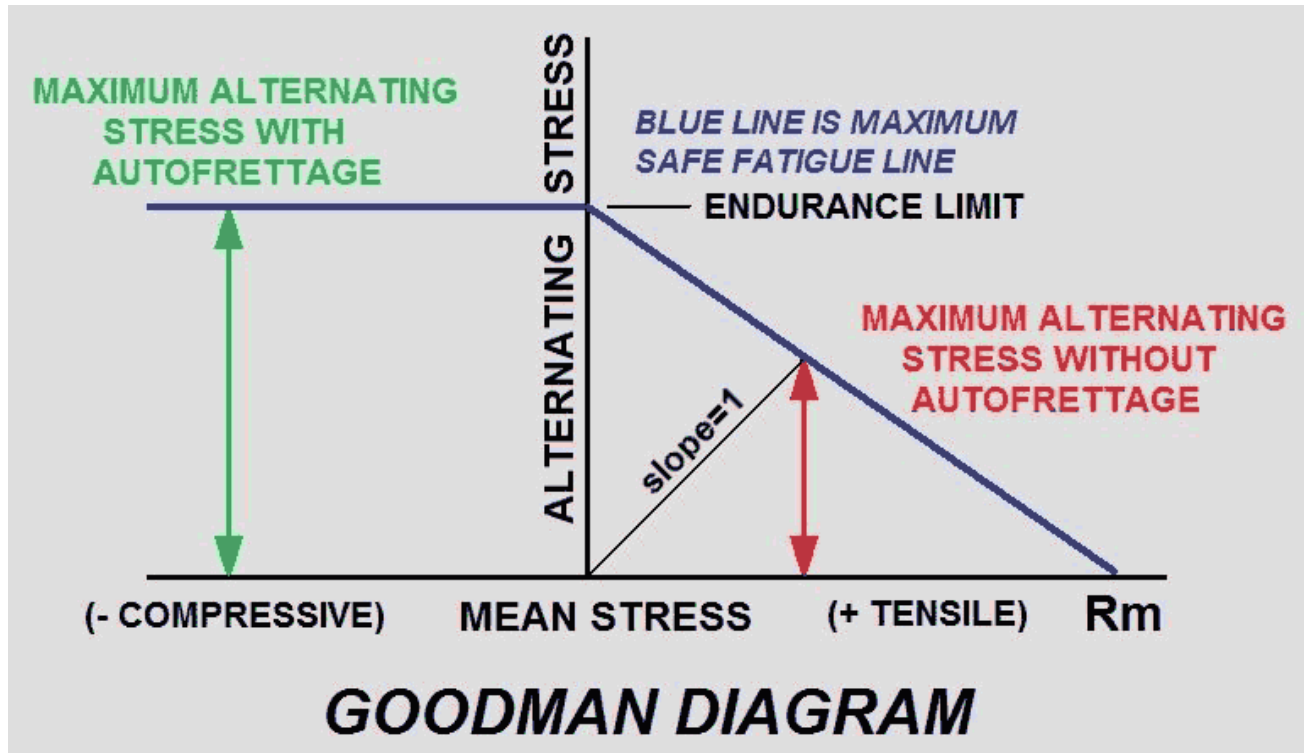
OD of the part overcome the lesser material in the bore and instill a compressive hoop stress which is largest at the inner surface. It is even possible to plastically deform the entire wall of the pressure carrying part and still impart large beneficial compressive stresses at the bore. There is very little measurable dimensional difference between a part that has undergone autofrettage and a part that has not.



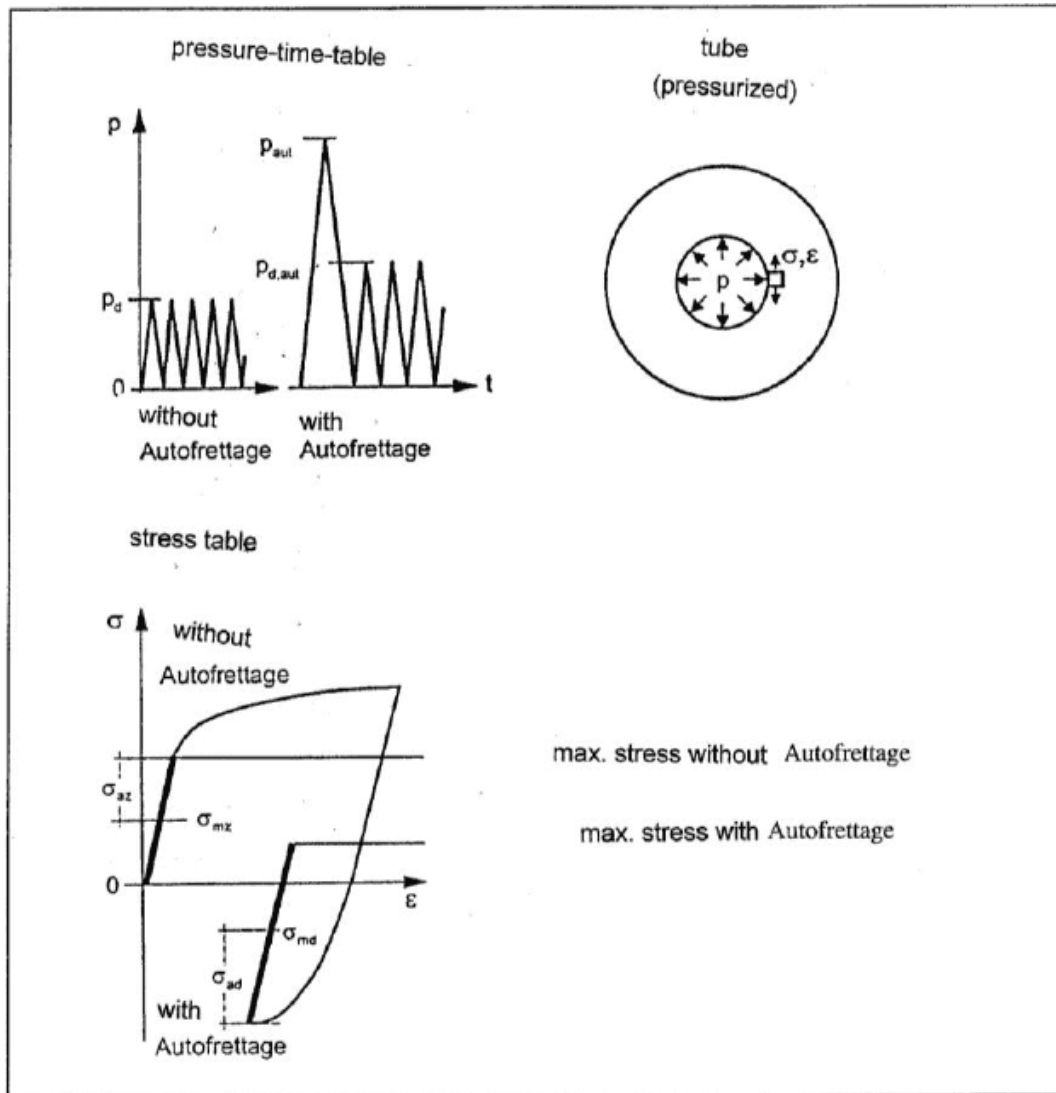
How does autofrettage improve pressure fatigue life?

There are two major beneficial mechanisms at work due to autofrettage. First, there is a hindered or slowed crack initiation phase. In most cases, the crack does not develop due to the lack of sufficient tensile hoop stresses at the bore during peak pressure. In some cases, an already developed crack (or defect acting as a crack) may become arrested and grow no further with repeated cyclic pressure loading.

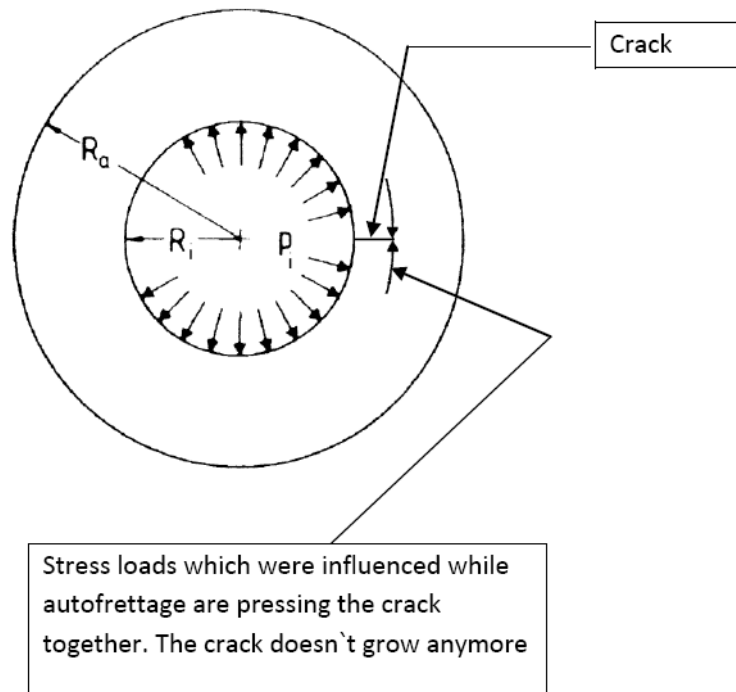
Second, with autofrettage the bore of the pressure vessel experiences alternating stresses with a superimposed mean compressive stress. This means that the oscillating pressure allowed can approach its maximum potential. In the case where there is no autofrettage and the part is exposed to a cyclic pressure which recedes to zero upon the completion of each cycle, the alternating stress will be equal to the mean stress. The second alternative does not promote fatigue longevity. Compare these two scenarios on the following Goodman diagram of acceptable fatigue life.



Proper application of autofrettage can result in an increase in cyclic pressure carrying ability of 30% to 200% depending on initial stress risers and surface finish of your particular product. Looking at this another way, the increase in pressure carrying capability is equivalent to gaining multiple orders of magnitude of operating cycles at a given pressure level.



Under working pressure the stresses inside the component do not move between 0 and a maximal value any more, but start in the pressure area below 0 and end at a much lower maximal value.



Stress load prevents crack growing

The crack will propagate to a certain length and will then be stopped by the pressure internal stresses that are inside the wall where the internal stresses “press” the crack together.

How do you autofrettage?

The best way to get started is to work with experts in the field of autofrettage to develop a simple, low-cost method to autofrettage your product to quickly and easily maximize pressure fatigue life. This can make it effortless to gain the benefits of this highly effective method with very little work and investment on your part.

The first concern becomes “What autofrettage pressure should I use”? The answer to this question is complicated, but it can be answered fairly simply. Generally, higher pressures offer greater benefits, but the designer needs to be cautious to avoid applying pressures sufficient for static burst.

The second concern is to eliminate any deformation to the seals that will be used during the installation of the product during its normal service life. Autofrettage should use fittings designed to seal at locations other than those just mentioned, or they should spread out the load over larger areas to minimize any undesirable deformation. In some cases product design may be influenced.

The following effects can be obtained by the autofrettage process:

- The working pressure of autofrettaged components is increased (with pipes up to 1.8 times higher, with components with cross boring up to 2.5 times higher)
- The deviation of the achievable pressure changing numbers in the time solidity area of the “Wöhler line” decreases. That means the fracture pressure changing numbers on the pressure horizon, where the autofrettage components fail, come next to each other.
The spreading is the proportion of the pressure changing numbers N90% (90% of all parts survive) to N10% (10% of all parts survive).
- Non-autofrettage parts have in general a deviation of $T=1.3$ whereas autofrettage components had in tests a deviation of $T \leq 1.1$
- The notch sensitivity decreases strongly.

Therefore, we achieve the following improvements:

- The working pressure stays the same - the wall thickness can be reduced.
- The working pressure stays the same – more inexpensive material can be used.
- In general there is the possibility to increase the working pressure.
- The finishing of borings and surfaces can be eliminated eventually.
- The life time of a component can be increased at a corresponding working pressure.

For further information, please consult <http://www.maximator-test.com>.