

# NUTS & BOLTS

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## Let's Celebrate!

### New Hampshire Materials Lab Celebrates 25 Great Years

With a focus on problem solving—not simply testing—New Hampshire Materials Lab (NHML) has provided customized cost-effective solutions for manufacturing & insurance companies for over 25 years to more than 1,000 clients.

Recognizing the need for a highly competent laboratory offering a full range of testing and analytical services, NHML was established in 1979 by Professor Fred Hochgraf of UNH and his wife, Sally. Like Hewlett-Packard, the company began in a garage in Durham, NH. The need soon outstripped the available space, resulting in a move to Dover, NH. Larger quarters in Dover housed the growing company for nine years and in 1996, they moved to a modern, 6,000 square foot building in a Somersworth industrial park.

Concurrent with our 25th anniversary, Hochgraf has decided to retire and Tim Kenney has become our new president. Tim has been with NHML since its inception in 1979 and has served as NHML Laboratory Manager. A graduate of UNH, Kenney has nearly 25 years of material investigation experience. Under his leadership, the company will continue to provide the type of excellent service that NHML is noted for and which our customers have come to expect. Mr. Hochgraf will continue to serve us in an advisory capacity and work on special projects.

Conveniently located in southeastern New Hampshire, NHML is within one day's shipment from most areas in New England. With over 1,000 industrial clients and 100 insurance clients throughout the U.S., New Hampshire Materials Laboratory looks forward to the next 25 years.

## High Cycle Fatigue

### Background

#### And You Thought That All Residual Stress Was Bad!

Having a layer of compressive stress on the surface can be very beneficial to fatigue life in the high cycle regime. While the high cycle fatigue regime covers all failures beyond a few thousand load cycles, in practical terms, compressive residual stress makes its benefits available beyond lives of maybe ten thousand load cycles. In high cycle fatigue, tensile stress at the surface is a very bad thing. Why?

#### How tensile static stress works to reduce cyclic stress...

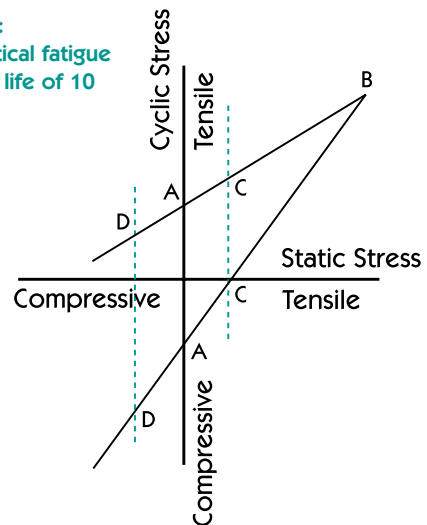
**Question:** At what value of static tensile stress will a part break in a single load cycle? **Answer:** The ultimate tensile stress.

**Question:** During cyclic loading, when will a part break if there is zero static stress? **Answer:** Both the material's S-N curve (cyclic stress vs log N) and log cyclic strain vs log N curves give us the life in cycles to failure. More correctly, they give us a line for which half of all samples fail sooner and half fail later. That's the line published by most metal suppliers. The more useful line for us metal

users is the line for which maybe 2% fail sooner and 98% fail later, but of course, those data are harder to find in the literature.

**Linear Averages** In between these extremes of *all* or *no* static stress, linear averages work well enough as shown in Figure 1. Suppose you know the cyclic stress that gives a specific life when there is zero static stress, say  $10^7$  cycles. (1A) Then suppose that you have determined that in your particular problem the static tension is 1/4 of the ultimate. (1C) Then the cyclic load that can be super-

FIGURE 1:  
Hypothetical fatigue curve for life of 10 cycles





imposed on that static load for a life of  $10^7$  cycles is 3/4 of the cyclic load with no static stress.

So far, this exercise has shown you how tensile static stress works to reduce the cyclic stress the part can withstand for equivalent life. Compressive residual stress increases allowable cycle stress (1D).

Recall that in high cycle fatigue, with a polished part and no stress raisers, 90% of the life is spent in fracture initiation. If the surface has flaws or stress raisers, then you start to chew into that 90% life. However, if the surface is always in compression then fracture initiation never starts! That rule holds even if the surface is scruffy and even if there are stress raisers!

While the linear averaging of static tensile stress and cyclic stress works well enough, it isn't quite so simple on the compressive side, but there is some very good news. That's because fracture initiation stops when the maximum reached by the cyclic stress falls below some value. No fracture initiation, no high cycle fatigue failures! Practically speaking, that is something less than 2/5 of the yield for polished workpieces—less with poor surface finish and stress raisers.

### As usual there is a limit to all good things.

On the compressive side of the load cycles, when the minimum reaches some substantial fraction of the compressive yield strength, a tiny amount of yielding occurs. Then, with each compressive stress cycle, that yielding reverses the metal stress so it becomes tensile. That's bad for high cycle fatigue life.

### How do we get beneficial compressive residual stress?

Keep in mind that Newton's Laws require that equilibrium be maintained. For every compressive area there has to be a tensile area and the moments have to balance. Therefore, every method for producing compressive stress unavoidably introduces tensile stress.

### Carburizing

Providing one doesn't mess up the heat treatment subsequent to carburizing, the parts get a surface layer with

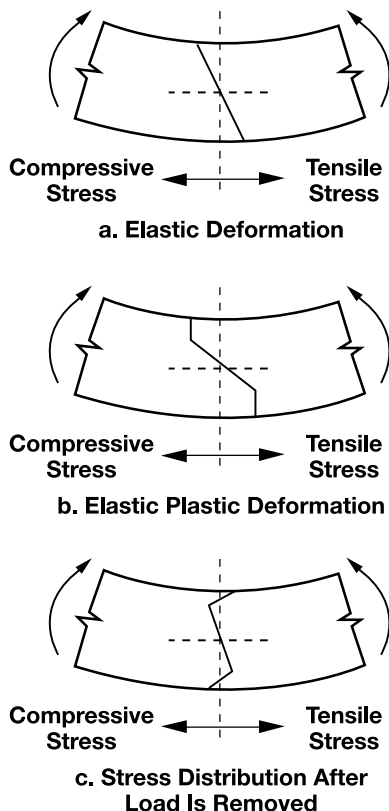


FIGURE 2: Stress distribution after elastic-plastic deformation

compressive stress and a core that is strong enough to support the case against cyclic loading. Too abrupt a transition between the case and core leads to spalling. Best carburizing is done in three steps: first, put in the carbon; next, reduce the furnace's carbon potential and let diffusion spread out the transition. Normalize, then rehard- en, and finally temper as appropriate for the particular case and core chemistries.

Specifications need to call out a high hardness value through a certain depth, a mid- value at some greater depth, and a lower, core hardness not closer to, nor farther from, the surface than a specified depth range.

### Remember Newton?

Don't cut into the core after carburizing. That area is in tension and fatigue failures can get started. I have seen an exception in an automatic transmission main shaft where a centerline oil hole was bored after carburizing. They got away with it by putting the surface of the hole into compression by pushing a slightly oversize steel ball through the hole.

### Nitriding

Nitriding is a subcritical heat treatment. Wear resistance can be wonderful and fatigue crack initiation is largely prevented. However, the layer is thin and has an abrupt transition to the core. Even the best load capacity of a nitrided part is therefore less than a good job of carburizing. If the load is too great the nitrided surface spalls off from the core.

### Shot Peening

Round shot, hammered into the work hard enough to dimple the metal, cold works a thin layer into compression. That improves the fatigue strength. The compressive layer is thin so that it doesn't take a lot of load stress to overcome the compression and throw the surface into tension. Lots of things can go wrong in this process such as having the shot fracture, not throwing the shot at the part with enough energy, or having shadowing. Almen strips are essential for QC.

### Bending, Simple Bends

Now this offers great opportunities, real cheap! Bend a strip of metal until the surface just starts to yield and hold



it (for now). What does the stress distribution look like? (Figure 2b) On the convex side there is a layer having tensile stress equal to the yield strength. On the concave side there is compressive stress equal to the compressive yield strength that also forms a layer that extends a short distance. Remember that the compressive yield is usually numerically higher than the tensile yield. Accordingly, the neutral axis moves off center towards the tensile side. Remember that shifting of the neutral axis when you are doing bending calculations. (I have yet to see a finite element stress analysis program that can reflect this shifting of the neutral axis, even if the program purports to be able to deal with a little plastic deformation.) The stress pattern involves both elastic and plastic deformation. (Figure 2b)

Now, remove the applied bending moments. Recall that plastically deformed metal "springs back" elastically. So every element of the bent metal unloads elastically according to its distance from the original neutral axis (not the offset neutral axis from the original bending.) Now here's the surprise: the extreme fiber that was in tension goes into compression as it springs back! (Figure 2c) And the extreme fiber that was in compression springs back to be in tension!

Newton will be satisfied. There is now a band of residual compressive stress on the convex side. The residual stress transitions into a band of residual tension on the concave side per the attached sketch.

### Prebending the Spring

How can that help us? A truck's leaf spring is bent upward by force applied by the axle. That force is resisted by downward forces at both ends of the spring. On which side do fatigue cracks initiate? On the top. So clever practice is to prebend the spring in the same direction that it will see in service. The prebend is just enough so the spring takes a small set. While bending, there is tension on the top and compression on the bottom. When the bending is released, the top goes into compression. Presto! The fatigue life is vastly improved.

### Torsion

Coil springs experience cyclic torsion stress. I am told that the coil springs in railroad car suspensions are pre-stressed by being compressed until they take a slight set.

*While the part is being bent, Newton is satisfied since the net moments within the piece of metal are exactly opposed by the externally applied moments.*

Just as in the bending case cited above, when the applied force is removed, the surface residual stress takes on the opposite sign from the cyclic stress imposed in service. Result: the fatigue life is tremendously improved. And because the sign of the residual stress from the prebend is the opposite of the applied stress in service, the steel is able to tolerate the total neglect in this application. Most notably, rusting does

not give fatigue crack initiation sites until the rust extends below the prestressed thickness.

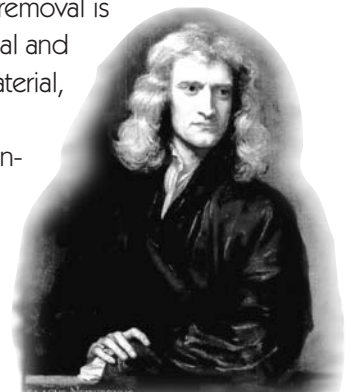
There is a second reason for this prebend. Believe it or not, these heavy railroad car springs are wound cold from heat treated bar stock. Coming out of the coiling machine there is an undesirable pattern of residual stress. That undesirable stress pattern is undone by prebending so that only the desirable residual stress pattern remains.

### Straightening

Lots of folks use an arbor press and a pair of V blocks to straighten parts. The resulting residual stress pattern is just what I described above under "Bending". Whether there is "just a little tweaking" or a lot, the arbor press side goes into compressive yielding. When the part springs back it will be in tension. Fatigue failure, here we come!

If it is warpage from heat treating, much better to heat uniformly and design a quench fixture that keeps the part straight during the quench. High energy quenches can help. And we can't neglect keeping the part straight during tempering through uniform heating and clever fixturing. If the warpage is from recovery after you machined away layers that had residual stress, then you can fixture the part during the stress relief cycle.

The up side is that less stock removal is required. That reduces material and machining costs. With less material, you may even be able to get equal performance with a leaner alloy steel.



Sir Isaac Newton

## Our Philosophy

*New Hampshire Materials Laboratory has one goal—to help you solve your technical problems at a reasonable cost. Tests help, but are not always enough. Our team of dedicated and experienced professionals has both the skills and the backup facilities to serve in the following:*

- Failure Analysis
- Material Certification/Compliance
- New Product Testing
- Mechanical Properties
- Tensile/Compression Testing
- Heat Treat Problems/Verification
- Reverse Engineering
- Weld & Life Testing
- SEM & EDS



## High Cycle Fatigue

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