8.3.3 Bang it!

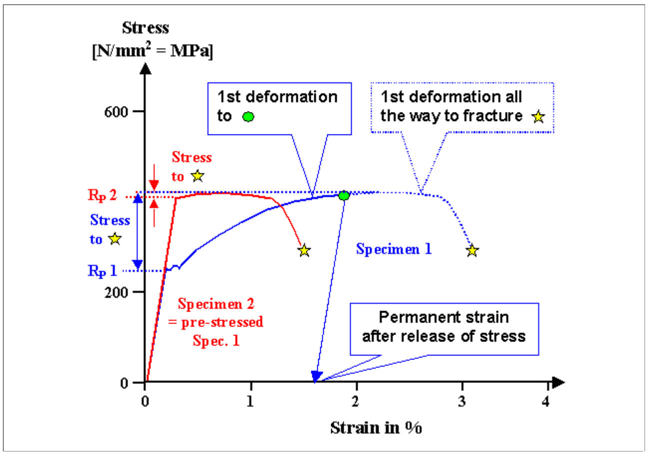
When you "bang" your steel or induce plastic deformation or strain by some other means, you produce and move dislocations. A lot of the dislocations produced will get stuck in your crystal and then act as obstacles to the ones that are still moving. Your crystal gets harder and we have called that effect strain hardening; it is also known as **work hardening**

Strain hardening thus means that your obstacles for dislocation movement are other dislocations.

- In the invading soldier metaphor, it is clear from recent experiments along that line in Iraq, Afghanistan and so on, that you actually can impede the advance of your own soldiers by "stuck" soldiers from some other parts of your military. If, for example, your military bureaucracy grows faster than your fighting troops, you can be sure that it will be a major obstacle for the guys out there.
  We also have what is known as "friendly fire", not to mention basic stupidity—but that analogy becomes too painful to pursue.
- Strain hardening is an every-day phenomena. Bend a metal paper clip back and forth a few times and it *strain hardens*, becoming more difficult to bend. Eventually it fractures.
  You can see that effect rather nicely in the stress-strain diagrams I made for you. The steel gets much harder after it was somewhat deformed and "strain hardening" was named as the reason. At that point, however, that was just descriptive and not explanatory.

The measure for what can be achieved with strain hardening is not so much R_P, the yield stress, but rather R_m, the ultimate tensile strength. This is clear. You simply cannot get effects of strain hardening before you did some serious straining.

- So should I now make some steel, deform it until it reaches R_m, and then use it for a sword blade? After all, it is now as hard as it ever can get from strain hardening?
  Don't. There is no such thing as a free lunch and the prize you have to pay for excessive strain hardening is clear: your steel will now break at the slightest provocation.
  Think about your paper clip or look at the stress-strain curves again.



Stress - strain curves showing the effect of strain hardening

- We have a piece of C15 steel (whatever that means). If we do a tensile test until the bitter end we would get the blue curve. The specimen yields at **R_P 1** and that defines its hardness. For fracturing it, you need to go up to its ultimate tensile strength and for that you must almost double the stress needed to induce first plastic deformation.
  Now you deform your C 15 steel only up to the green point; almost at the ultimate tensile strength (the maximum of the curve). You give the deformed steel to your smith and tell him to make a sword out of it. Your smith will find that he was given rather hard steel and makes a sword with a hard blade that will fracture at the slightest impact. Why?
- Easy to see, If you don't give the pre-deformed steel to your smith, but to your tensile-test engineer, she will find the red stress strain curve. The specimen now yields at **R_P 2**, exactly the stress where you finished the first tensile test. it is no much harder. After yielding occurred, the curve continues exactly as it would have in the first tests if you hadn't stopped the machine. It takes only a tiny bit of more stress after **R_P 2** has been reached and your specimen fails (after first deforming rapidly a bit more than 1%)

So beware. Banging your steel a lot at *low* temperature is sure to induce strain hardening. At the same time, ductility decreases.

- Banging a lot at high temperatures *well above* the austenite transition temperature will do not much good for strain hardening, though, because now you work with a *different* material (austenite) that changes completely upon (slowly) cooling down. It will not "remember" your banging.

- Banging a lot at high temperature just a *little bit* above the austenite transition temperature and cooling down *not too slowly* might do all kinds of things including *some* strain hardening because you make it difficult for your steel to achieve nirvana and to rid itself of the defects around at high temperature.

At that point we can start to appreciate a basic problem that you, the *ancient* smith, faces when you forge a sword blade.

How do you know how far away from the transition temperature you are?

- You didn't have a thermometer, for God's sake! You didn't even know the meaning of temperature; you only had some vague notion of pleasant, hot, very hot and cold.
  The standard thermometers from today, by the way, couldn't take the heat either. Look up how you would measure high temperatures *today*.
- And no! Don't deceive yourself:. Being able to distinguish between hot, very hot, and unbelievably hot was not good enough. *Precise* temperature control matters a lot in blade forging! I will come back to that later again.