3.2 Fracture Toughness

3.2.1 A Few Basics about Fracture

- It's time to introduce the **first law of materials science**:

You can break anything if you're brutal enough

  - Just kidding, of course. Or am I?

- The first law of Materials Science states that everything will break if sufficient force is applied. It certainly applies to swords.
  - With a tensile test you can always fracture your specimen if your machine is powerful enough. If we keep on pulling, the specimen will be broken in the end.
    The stress-strain curve gives us quantitative data (meaning *numbers*) about the maximum stress a material can take, the maximum strain or elongation it suffers before breaking, and the work we have to do (the fracture energy) to deform it up to the final fracture.
    The picture below gives an idea of what machines look like that can break almost everything. It also shows that a lot of effort and money is going into tensile testing. We simply need the data.

Monster machine for breaking things

- Data from tensile testing are sufficient for describing all kinds of material deformations. Unfortunately they are not good enough by far to tell you everything about *fracturing* your material. After all, you and I know that things, including all metal things and thus sword blades, don't just fracture by being slowly and lovingly, if forcefully, being pulled apart.
  If a sword fractures, it is almost always a violent and fast affair resulting from sudden and violent stress applied to just a small part of the blade.
  - Let's look at few examples. Even "tough" sword blades might fracture and not bend if deformed very quickly. The sword of an officer who was dishonorably discharged was often ceremonially broken by bending it rapidly over your knee. Bending slowly may not have done the trick.
  - If you press a somewhat dull chisel slowly into a metal sheet, you will get a dent. If you do it rapidly (bang on the chisel with a hammer) you get a dent *and* a hole = fracture.

- Things are even worse than that. Metal constructions that stood stable under some load for many years sometimes suddenly collapse without any outside influence like a big storm. Whenever metals break by fracture for no apparent reason, we call that **failure**.
  I don't know if old swords that were very good at their times fracture more easily when tried some hundred years later, but I would not be surprised. Things like that happen more often than we like with other steel objects.
  - The roof of the rather big **congress hall** in **Berlin** suddenly collapsed in 1980 after it stood there for 23 years. That disaster was due to **stress corrosion cracking** in the steel beams, an especially treacherous failure mechanism.

    Another creepy mechanism for things that are under steady mechanical load but otherwise do nothing is aptly called "**creep** ". Creep, given time, will lead to slow deformation and sudden fracture.

    On top of all that we have **fatigue**, causing sudden fracture of metals after some time of *active* service. Fatigue may occur if some parts experience low-level oscillating forces. In other words, fatigue might occur if the metal vibrates to

some small extent for some time
The most spectacular example of this kind of fracture you can find in the Internet, looking under "Boeing roofless" where you will find an airplane that converted itself into a convertible in mid-flight. Parts of the cabin just flew off, due to fatigue, and the passengers found themselves suddenly in a roofless airplane but did not really enjoy the fresh air.
I need to say a lot more to creep and fatigue, answering the obvious "why" questions you must have by now. But before we get there, we need to do some work first.

- It is true, we don't care all that much about slow processes on time scales of many years in connection with sword blades; I just thought I let you know that *fracture* has man facets. Nowadays we understand them quite well, but not as well as we would like. Otherwise major disasters concerning sudden and unexpected fracture of metal things would not happen as they do.
  - By the way, if I claim we "understood" something, I mean that the science of that topic has reached a point where we can *predict* what will happen under certain circumstances with great confidence. I do *not* mean that we can only explain retrospectively what has happened (like your stock broker).
  - Understanding fracture, however, means understanding structural *changes* in materials. Understand structural changes in materials means understanding the structure of materials first. That will take a few chapters; after that we will return to the subject.
- For the remainder, let's look at fracture only in an experimental way and see how one can do some useful fracture tests besides uniaxial pulling and pushing. What we need, for example, are experimental assessments of how fracture prone a given piece of steel like a sword blade would be.
  - One simple way of doing this is to fracture a sample under conditions reminiscent of a sword fight. We will look at that in the next sub-chapter.