2.3.2 What Makes Steel so Special?

Before we tackle all those "why" questions, we must look a bit deeper into the "what" questions. *What* properties, exactly, make steel so special?
Let's first look at a world *without* iron and steel, to see what's it all about.

- The **Iron Age** started about 3.000 years ago and lasts until this very day. Before that we had the **Bronze Age** that succeeded the **Copper age**, and way back we had the **Stone Age**. Before that we had Ages with names like "Jurassic Age", but "we" weren't there.
  It's of course a bit silly to keep track of time that way, and one should note that the Bronze Age overlapped with the Iron Age for 1000 years or so. We still have bronze for many applications, come to think of it.
  Are we entering the **Silicon (Si) age** now? I doubt it, despite the fact that I earn my living by advancing silicon technology and not by writing popular science books.

Misc. Link **The "Ages"**

  We certainly have plenty of fun (and aggravations) with **semiconductor products** like personal computers, radio, TV, cell phones, video and the Internet, not to mention solar cells and instant financial crashes. My children do not believe that human life without Internet and cell phones is actually possible but I know it is. I was there.

  Nevertheless, you didn't need silicon or other semiconductors to run big ships, airplanes, cars, railroads and, quite important, elevators. You didn't need semiconductors either to conquer half the world as the Germans tried and the British did.

You needed steel products.

- If you are not convinced, ask yourself two questions:

  1. What would you rather miss? Your car or your cell phone?
  2. What would be that one object you would take to that desolate island, if you are given a choice?

In our age, whatever its name will be in hindsight, we not only have steel and silicon, we also have aluminum, titanium, and many other metals and alloys; Teflon and many other polymers; carbon fiber composites (***CFC***) and glass fiber composites (***GFC***); and above all, we have **electricity**.

- We have a plethora of high-tech materials enabling wonderful things like artificial knee and hip joints (wait until you need one to appreciate this), lightweight bicycles and airplanes, Lasers and the possibility to send e-mails all over the globe in bulk, but we still would make a *sword from steel*. Or, if you like that better: a knife, a pair of scissors, sewing needles, an axe, saw blades, car bodies, ships, high risers and their elevator cables, machines of all kinds, and so on, are still made from steel.
  If you think about it, not all that much that was made from steel some time ago, is now made from something else. Steel is just a great material!
- It's the *properties* that count, of course. Whenever we look at a product, we must ask ourselves: what kind of material properties do I need for my sword, my rails, my turbine blades, my sewing machine needle, my gear wheels in the sewing machine, my hip transplant, my wheel chair?
  Note that in Materials Science and *Engineering*, properties of materials include banal things like: availability of the material, ease of recycling after use, aging / longevity, and, of course, the **costs**.

As far as your sword is concerned, the first important property is:

It must not break!

- If it does, you give your opponent a break he is certain to use.

Making an unbreakable sword is easy, of course. You could even make the blade from brittle cast iron and it won't break—as long as you make it rather thick.

- It also won't break because now you can't swing it anymore - it is too heavy. This is trivial but makes clear that we need to consider **specific properties** that are tied to weight or size.

Making an unbreakable *lightweight* sword is also easy too: just make it from some tough wood like ash or yew. It could be rather light but won't break easily. Needless to say, your customer will still not be satisfied.
You need just the right weight for the right length, and your sword should certainly be *harder* than wood.

As hard as possible, come to think of it. You want it to cut through armor and bone, at least in principle, and this is not possible with swords made from soft materials. A glass sword meets these requirements. Quite hard, sharp, and easily adjusted to the right length and weight.

- Aha - it should be hard but definitely not *brittle*. Glass is lightweight and hard but will break on first impact for sure. So it should be the opposite of brittle, which is: ???

Is "*tough*" the right word, maybe? Yes, tough could be the right word, but leather is also quite tough and so is my wife on some occasions. We need a better word.

- The opposite of brittle is "**ductile**". A material is ductile if it does not *break* when overloaded by *mechanical stress*, like glass, china or concrete, but just *deforms* somewhat. Ductile materials are also called **malleable**; you can change their shape with a mallet or hammer.
  That's why the body of your car twists and bends when you hit a tree, or your sword suffers a notch if you hit a hard object like the blade of another good sword. We don't like this bending or notching, to be sure. If you look at your car after you hit a tree, you are inclined to use four letter words.
  Now imagine that your car body would have been made from a brittle material like glass, and you will be grateful that steel (or any other metal) is ductile. The same goes for your sword. A notch is preferable by far to fracture.
  We need to compromise here. You can't have a cake and eat it any more than you can have a perfect undamaged sword and use it.

Here we have the central problem of sword making. The blade should be hard but not brittle. It must have the right weight and length.
And the only way to meet these criteria is to use an *optimized* ductile material. A metal in other words.

- The sword smith of old came up with an amazing variety of ways to deal with the "optimized" in the sentence above. Combining two or more kinds of iron or steel was quite prominent all over the planet. Hard but rather brittle steel was combined with soft and ductile wrought iron, for example. Let's call such swords "**composite swords**" for starters. **Pattern welded swords** or **Japanese swords** belong to that category.
  Another approach was to start with hard and fairly brittle "**wootz steel**" but to work it in such a way that the result is hard but no longer brittle. **Wootz blades**, sometimes also called "**true damascene swords**" belong to that category.
  Good swords made with incredibly complex technologies thus existed almost 2000 years ago. But after roughly 800 AD, some smiths in the West stopped to make elaborate pattern welded swords and in essence just laminated harder steel on a softer core. Why? What was wrong with those beautiful patern welded swords?
  Whatever their reason was, they still banged their steel into shape with a hammer. Not before around - roughly - 1850 mankind was able to cast steel. Casting steel is our major technology today. All knives, scythes, cutting tools, submarine bodies, and so on (not to mention swords, wherever they are still used) are made from uniform cast steel.
  There is one last important optimization used on top of all the techniques described above: harden only the important part, the *cutting edge* of the blade in a special process called "**case hardening**".
- We have a non-trivial "*why*" question here: Why did sword blade forging develop from an extremely complex process to an apparently quite simple one?

Is there anything else we need to consider with regards to important properties of a sword? Of course; the list goes on:

- You want a specific **shape**: straight and double-edged, bent like a *sabre*, or the other way around like a *yagatan*.
  You want a specific **cross section** of the blade: elliptical like a Celtic sword, wedge-shaped like a Japanese *katana*; with one, two or three **fullers** or grooves. Maybe your blade should be hollow?
  You may want the blade to be extremely sharp and stay this way.
  You would like your sword not to rust like crazy, and it shouldn't turn dull with age.
  You sword should be affordable, and a smith should be able to repair some minor damage it suffered in battle.
  Very important: the blade should be *flexible* or *elastic*. In other words, it should be able to bend if forced, but it should snap right back to being perfectly straight if the force is off.

  Basic Link

  Sword types

  Old sword lore praised swords that could be bend into a semicircle around the body of its bearer without breaking or staying bent.
  We call that an **elastic deformation**, a deformation that is not permanent but allows the material to regain its original shape. Springs or rubber bands deform elastically and with ease, your sword, however, should be able to deform elastically but *not* with ease. So **elasticity** or **stiffness** as a property needs more thoughts, too.
- We are still not done. So far we only looked at the blade. But you also need a **hilt** with a *cross guard*, a *pommel*, and so on.
  Your complete sword—blade plus hilt—now has a center of gravity that should be not too far from the hilt. The location of the **center of gravity** together with its weight defines its **moment of inertia** (we come to that). All of that together with the kind of grip your hilt provides determines how it "**handles**".
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How a sword handles depends on the sword and you, of course. One size doesn't fit all, for sure. Handling as a property is only important for swords intended for actual battle—but then it is extremely important. The best steel doesn't do you much good if you can't swing your sword like it is a part of your arm.

Basic Link
Sword parts

- The last point is: Your sword should have all the properties described above but it should also be a *work of art*. That's especially true in our enlightened age, where we don't own a sword as a tool for our jobs anymore but only for what it symbolizes.
  But even in times when you actually used your sword, you liked it to have some aesthetic value. I use my car for moving from A to B but I also like it to be aesthetically pleasing. You use your wife - ouch that really hurt (my wife was looking over my shoulder).
  - **Theodoric**, the famous Ostrogoth king was raving about the beauty of the swords he obtained as a gift from **Thrasamond**, King of the Vandals in most of his one-page "Thank You" letter. In comparison, the gift of "pageboys of noble birth and fair complexion" rated exactly the 7 words quoted here.
- Let's have a quick look at ancient **bronze swords**. They are usually not very long. Too long, and they break or bend severely - if not, they are too heavy. There isn't much one could do about that 4000 years ago, and there isn't much one could do about it today either.
  - You could change the properties of your bronze to some extent with exactly the same basic mechanism that work so well with iron and steel. But there are limits one cannot overcome. We are going to look at bronze swords in greater detail later
  - Iron with a little bit of carbon—steel or cast-iron in other words—is a far more complex material than bronze. It can have extremely good or extremely bad properties, and that makes it difficult to master this material by trial and error. But for exactly the same reason it also offers many opportunities for coming up with many different kinds of steel, one of which might be what you are looking for.
    You can't have your cake and eat it and you can't have a material that is easy to understand and use it for all kinds of different things either.
- It is clear what we need to do next. We must get a better grip on the key properties described by words like *hard*, *brittle*, *ductile*, *stiff*, *elastic* and so on. In order to do this we must first define these properties in a way that allows us to *measure* them and thus to describe these properties by cold hard *numbers*. This will be the topic in the next chapter.