Hardness

Advanced

- All people, without exception, have a pretty good idea of what "hardness" means in the context of materials properties. Extremely few people, however, have a decent notion of what the terms "yield stress" or "maximum elongation" tells us about materials properties.
  - Ironically, while the two latter properties are well-defined, hardness is not!
  - *Yield stress*, as *we* know, can be measured in precisely defined ways, and can be expressed in terms of basic material properties.
  - *Hardness* is different. It is not uniquely defined, and that means there is no unambitious way of measuring it. There are only some *recipes* - that's why we have several hardness scales in parallel.
- Essentially, there are two types of basic hardness measurement set-ups (plus some more unusual principles).
  - **1.** Measure the *size* of an indentation made by some indenter under a known load. The following hardness tests use this principle:
    - **Vickers**
    - **Brinell**
    - Knoop
  - **2.** Measure the *depth* to which an indenter penetrates under specified conditions. The following hardness tests use this principle:
    - **Rockwell B**
    - **Rockwell C**
    - **Shore A**
  - More unusual or outdated are
    - **Mohs** hardness scale (the first one), defined via "what scratches what".
    - Shore scleroscope principle: measure the rebound of a ball or hammer.
- In the "Materials in Action" series, "Structural Materials", page **100**, the scales are compared (which is not easy).
  - Here we usually use the **Vickers scale**. It runs from **0** to about **3000**; the unit is essentially that of stress (**Pa**); but the numbers are given in outdated units:
  - In the "Materials in Action" series you will find an unusual unit: "**kgf**", which is *kilogram-force*, which is something different from a "**kg**", because that was and is a mass. Nevertheless, the unit for the hardness is **kg/mm^2**; what is meant is the force that a mass of one **kg** experiences in the gravitational field of the earth. In German the unit "kilopond" (**kp**) was used; it's the same thing. Of course we have $\mathbf{1 kg/mm^2 \approx 10 N/10^{-6}\,m^2 = 10^{-5}\,Pa}$
- Here is a table with some *Vickers hardness* data:

Material	Vickers hardness		Material	Vickers hardness		Material	Vickers hardness
Sn	5		Limestone	250		Polypropylene	7
Al	25		MgO	500		Polycarbonate	14
Au	35		Window glas	550		PVC	16
Cu	40		granite	850		Epoxy	45
Fe	80		quartz	1200			
Mild steel	140		Al_2O_3	2500			
Hardened steel	900		WC	2500			

- Hardness measures in some lumped way a combination of elastic, plastic, and fracture properties, i.e. it combines somehow Yield stress, Youngs modulus and fracture parameters.
  - There is, however, no unique formula giving the hardness number as a function of the primary parameters.
- The best one can do is to provide some approximate relations for certain classes of materials.

- For relatively soft metals and for steel, respectively, there is a very simple relation between the Vickers Hardness H_V and the yield stress R_P or the tensile strength R_M

$$H_V \approx \begin{matrix} 3 \; R_P & \text{"soft" metals} \\ 3.2 \; R_M & \text{steel} \end{matrix}$$

- Of course, you have to express the strength parameters in **kg/mm^2**, too

This makes life easier and explains why we have not much dealt with hardness here: For our materials of interest, it is essentially the same as the much better defined parameters governing plastic deformation.

- Life would be even more easier, if most scientists would use the same hardness scale. Of course, they don't, so here is an approximate conversion, adopted form the "Materials in Action " Series already mentioned.