

Synopsis. Identified key facts about dislocations and used this knowledge to understand the underlying mechanisms behind alloying, work hardening and the effect of grain size on increasing strength. Briefly introduced Tresca and Von Mises multiaxial yield criteria, which utilize the empirical observation that yield is controlled by the maximum shear stresses.

**Important things to remember: How to strengthen materials – alloy, reduce grain size, harden, anything else?** No that is it for metals.

**Carbon nano-tubes are made with perfect single crystal structure. Do they have high strength? Why or why not?** This is a current research topic and it is important to note that it is difficult to perform a tensile test on a carbon nano-tube, so there is a lack of good experimental data. Even so, I think that there is a good chance that an individual nano-tube may have a very high strength. A defect free structure at a small scale is likely to be strong. The small scale is important here, free surfaces tend to pin dislocations, so even a fine whisker (1  $\mu\text{m}$  diameter) of a metal can have a very high strength compared to the bulk material.

**In 3.091 we learned that crystals are ductile because of the presence of slip planes, and glasses are brittle because there's no built in mechanism for deforming. So, how is it that making more boundaries and making it harder to transmit distortions makes metals stronger? Isn't this just going to make them more glassy and more brittle? Hmmm... This is completely consistent.** We will examine this in M18. Generally stronger materials are more brittle.

**Tough vs. Strong vs. Stiff.** We have not talked about toughness yet (but we will tomorrow in M18). But strength and stiffness are fundamentally different. The response below is reproduced from M16: **I'm a little confused by what the difference is between stiffness and strength.** Stiffness is the constant of proportionality between a force and a displacement (at the structural level) or a stress and a strain (at the material level). A strength is the maximum load that a structure can carry or the maximum stress than a material can carry (without yielding (yield strength) or failing (ultimate tensile strength)).

**Also I don't understand the concept of work-hardening. Is the idea basically that making dislocations tangled with each other and less linear will make a material stronger? How is this achieved by rolling out the metal? What are other means of doing this?** Your idea about work hardening is correct (at least at the level of understanding we are aiming for in Unified). As more dislocations accumulate in the material they become entangled and their motion becomes restricted. Given that plasticity is all about dislocation motion, then this results in a higher yield stress. Rolling deforms the material past its yield point and therefore causes it to work-harden. Other cold working processes include deep-drawing (used to make soda cans), shot peening (used to harden surfaces) peen-forming (used to create complex shapes, such as wing skins) and stamping operations (used to make car bodies). I hope that this helps.

**Mud: What does the burger vector describe and in which way is it pointing.** It represents the smallest unit of displacement of the vector and represents the magnitude and direction of displacement. As far as we are concerned it is just a length, but people working on dislocations in more depth need to be able to describe dislocation displacements as a vector quantity and to relate it to the crystallographic directions. There is a very sophisticated and mathematical field of mechanics associated with dislocations and Burger was apparently an early contributor to this.

**What is an interstitial defect?** This is not very important to our discussion of yield. The most common form is when an extra (usually small) atom can fit in the gaps between the atoms of a regular crystal lattice. This will usually have the effect of distorting the lattice slightly, which may result in hardening or embrittlement. Hydrogen can diffuse interstitially in many metals, although hydrogen atoms are so small they do not provide much hardening effect.

**What are the constraints on what kinds of junk you dump in a material? Similar size? Want to adopt the same type of crystal structure? Or do things “just work out”** I should be careful here. Alloy development has become very sophisticated and bears no relation to alchemy whatsoever. Also I should probably not have used the term “junk” Solid solution alloying almost always involves elements that adopt the same crystal structure. Precipitate hardening involves the formation of a hard compound between two or more of the alloying elements ( $\text{CuAl}_2$  in the case of 2000 series Al alloys). Thus crystallography, and the chemistry (thermodynamics) of the alloying elements are very important. Simulation techniques are becoming available that can guide the alloy development process.

**With the precipitation impurities how are these aligned with the crystal structure?** They are not necessarily aligned in any way with the crystal structure. It is important to note that the precipitate particles typically contain 1000-100000 atoms and so are large compared to the individual atoms of the lattice. See Ashby and Jones book 2 chapter 10 has a nice description of  $\text{CuAl}_2$  formation in an aluminum alloy.

**Why are pure metals so soft?** Without alloying the resistance to dislocation motion is low, so dislocations can move more easily and so the yield stress is low.

**Didn't understand how a material with a low dislocation density is soft!.** See comment above. In addition there are mechanisms by which dislocations can nucleate (e.g. Frank-Read sources) as stress is applied. Thus the number of dislocations will rapidly increase as stress is applied, and the movement of these dislocations will cause plasticity to occur.

**The diagrams of dislocations through the microscope – they were of finite length, I thought that they extended through the entire length of the crystal (one dimensional).** Good question. This is an artefact of the imaging technique. The picture was taken via transmission electron microscopy. This is restricted to looking at very thin layers of material (~100 nm thick). In addition the dislocations are being viewed end on – so they are foreshortened by the imaging technique.

What exactly was the picture of the dislocations showing? In what plane do you see a line defect relative to the typical dislocation drawn? In the figures I was using from Ashby and Jones the line of the dislocation is perpendicular to the page (board/screen). I.e. the long direction is perpendicular to the plane of the image. See the relevant picture from Ashby and

Jones below.

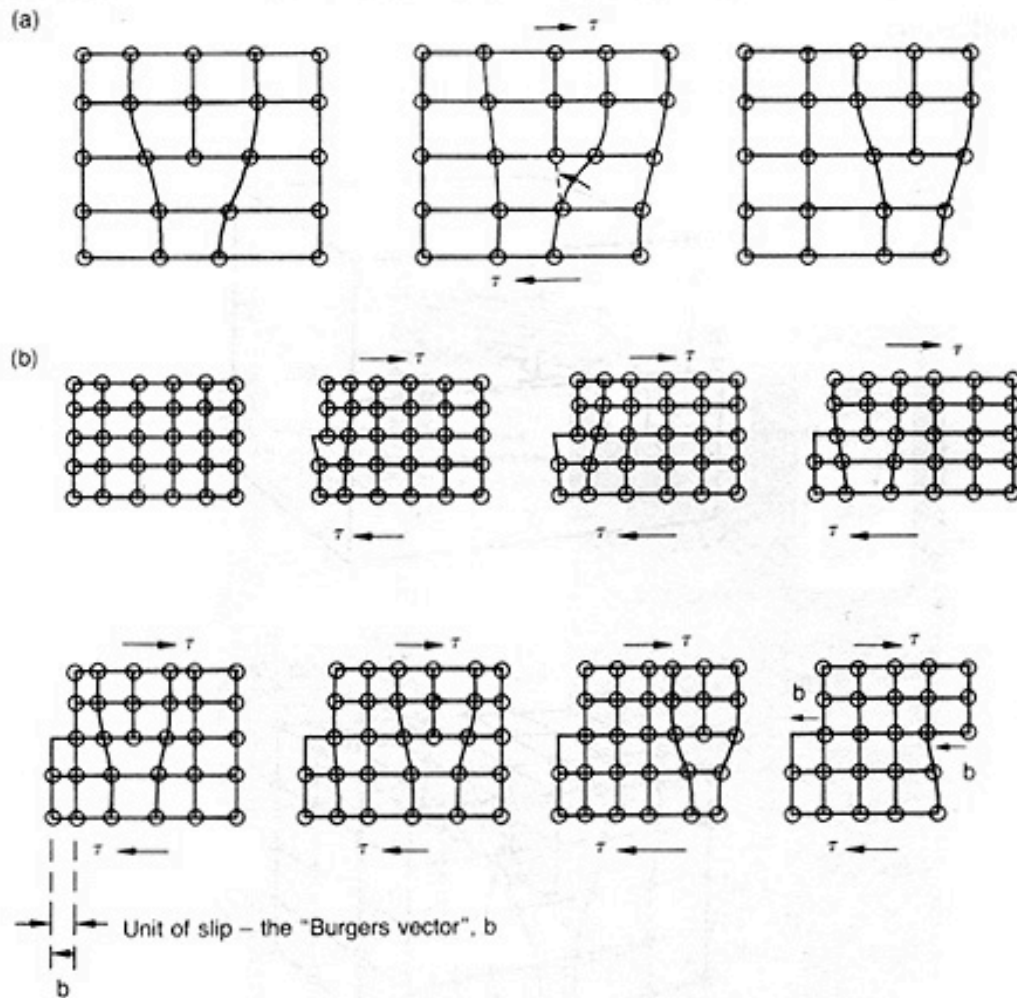


Fig. 9.4. How an edge dislocation moves through a crystal. (a) Shows how the atomic bonds at the centre of the dislocation break and reform to allow the dislocation to move. (b) Shows a complete sequence for the introduction of a dislocation into a crystal from the left-hand side, its migration through the crystal, and its expulsion on the right-hand side; this process causes the lower half of the crystal to slip by a distance  $b$  under the upper half.

**I keep getting distracted so I don't know where the mud starts to set in...That's why I do not write mud. Maybe lectures should be videotaped! They're so good, whenever I am paying attention that is.** I appreciate your honesty in performing this self-analysis. Here are some thoughts. For the rest of your career you will be participating in meetings in which people will be delivering information in a less structured way than a lecture. Figuring out how to assimilate this information and be able to evaluate it in a real time is a very important skill. Avoiding distraction is a key. One way to do this is to pose some questions to yourself at the start of the class –based on the notes, or just on the title of the lecture. Listen to the lecture

with these questions in mind and see if you can answer them by the end. Secondly, just being mentally prepared to learn (rested!!, up to speed with the material from the previous lecture) is very important. Secondly, videotaping is all very well, it has the unfortunate consequence of denying you the opportunity to ask questions, or to interact with me and the rest of the class. I am not sure that having all videotaped classes would actually improve the quality of your learning experience.

There were 7 muddy cards with no mud, or positive responses. Thank you