TECHNICAL TIDBITS

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What Happens During Yielding?

Are your connectors feeling a bit dislocated? – A discussion on the causes of yielding and how to best avoid it.

- **Dendrites**
- **Grains**
- **Grain Boundaries**
- **Slip Planes**
- **Dislocations**

The next issue of Technical Tidbits will focus on the control of grain size as a material strengthening mechanism.

Electrical contacts must be designed to supply adequate contact force without yielding. Material yielding occurs if the amount of force (stress) on a contact exceeds the material's elastic limit, which causes permanent deformation. Any amount of permanent deformation of the contact will reduce the contact force, thus reducing the integrity of the electrical interface. Materials must be able to withstand the high stresses of contact, even after exposure to elevated temperatures for long periods of time. In order to understand from where a material's strength comes, it is necessary to examine the mechanism of permanent deformation.

When metal solidifies from the molten state, millions of tiny crystals start to grow into a tree-like network of crystals called **dendrites**. When the material is subsequently hot worked, these dendrites reorganize into grains in the solid metal. Each **grain** is a distinct crystal with its own orientation. The areas between the grains are known as **grain boundaries**. Figure 1 shows a two-dimensional representation of grains and their boundaries within a metal.

Within each grain, the individual atoms form a crystalline lattice. Each atom will have a certain number (depending on the structure of the lattice) of close neighbors with which it shares loose bonds. When stress is applied to the metal, the atoms will start to spread apart. The atomic bonds stretch, and the attractive forces between the atoms will oppose the applied stress, like millions of tiny springs (see Figure 2). If the metal has not yielded, the interatomic forces will pull the metal back into its original shape when the stress is removed.

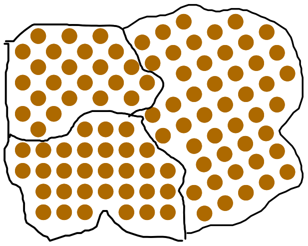

Figure 1. Crystalline Grain Structure

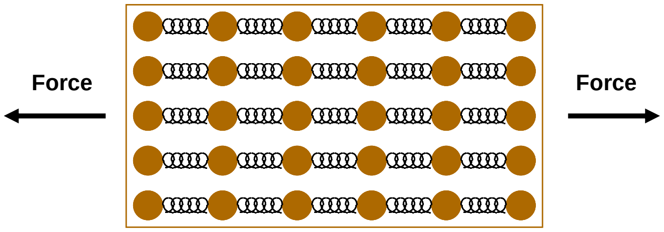

Figure 2. Stress Representation

In order for the metal to permanently deform, an opposing force must overcome the attractive force between the atoms. Within each crystal, there are certain planes where atoms are free to slide across each other (see Figure 3). These are known as **slip planes**. Deformation is possible if the slip planes can slide across each other. The theoretical shear stress required to break all the bonds across the plane is around 1,500,000 psi. However, even the strongest metals yield at a fraction of the theoretical stress level. Therefore, something else must be happening when metals yield.

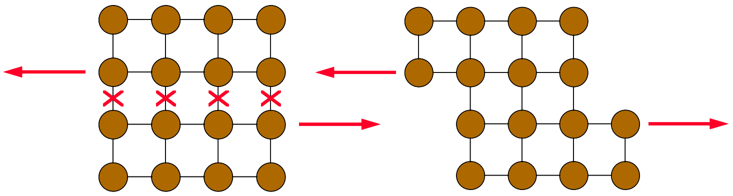

Figure 3. Slip Plane Representation

What Happens During Yielding (continued)

When the crystals first start to form during casting and hot working, there will always be small imperfections in the crystal structure. The crystals tend to grow in spiral-shaped patterns, leaving discontinuities between the layers. These discontinuities are known as **dislocations**. Seen from an edge view, these look like extra planes of atoms in the crystal lattice, as shown in Figure 4.

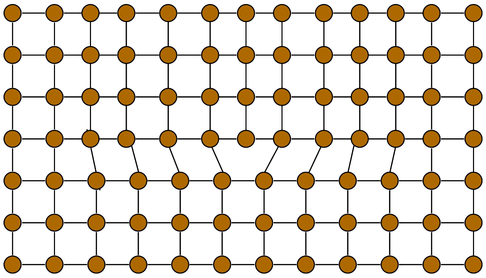

Figure 4. Representation of Edge Dislocation in Crystalline Structure

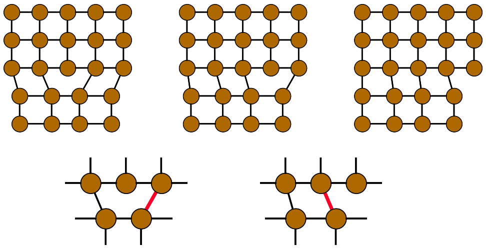

Figure 5. Movement of Dislocation through the Crystalline Structure of the Grain

When metals yield, it is the dislocations that move, not entire atomic planes. Figure 5 shows a representation of a dislocation moving across a slip plane through a grain. This allows the crystal to deform easily. Notice that only one atomic bond is broken and reestablished for each step the dislocation takes through the grain. This requires much less energy than having to break every atomic bond on the same slip plane. Since every grain will have millions of dislocations, permanent deformation of the metal becomes relatively easy.

At elevated temperatures, there is more energy available for dislocations to move. This is why the strength of most materials falls when the temperature increases. This is also the mechanism that enables creep and stress relaxation. A slightly elevated temperature may be all that is needed to give the dislocations enough energy to move, even when the stress is well below the yield strength at room temperature.

A material's strength comes from its ability to slow down or stop the movement of dislocations. The highest performance, strongest metals such as copper beryllium have the most effective means of stopping dislocations. Additionally, these dislocation-stopping mechanisms will also increase a material's resistance to creep and stress relaxation, further improving a connector's end of life performance. In the next few months, Technical Tidbits will take an in-depth look at several different strengthening methods.

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