TECHNICAL TIDBITS

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Strain Hardening & Strength

Permanent Deformation Can be Your Friend – A discussion on mechanism of material strengthening by permanently deforming materials through work hardening.

- **Cold Work**
- **Strain Hardening**
- **Work Hardening**
- **Temper**
- **Dislocation Entanglement**
- **Annealing**
- **Recrystallize**

The next issue of Technical Tidbits will focus on thermal strengthening mechanism.

The August 2000 edition of Technical Tidbits (issue 14) covered the topics of dislocations and plastic strain. It was discussed that all permanent deformation of the metal comes from the movement of crystalline imperfections known as dislocations through the grains in the metal. This month's edition will examine how strain hardening uses deformation as a method of adding strength to a metal.

Strain hardening is one of the most commonly used means of adding strength to an alloy. It is simply the use of permanent deformation to increase the strength of the metal. Other names for strain hardening are **cold work** and **work hardening**. No discussion of strain hardening would be complete without mention of the term "temper". **Temper** is a description of the amount and type of processing done to a material at the mill, including cold work and thermal treatments. This is what is meant when an alloy is described as half hard, full hard, spring temper, etc.

When a material is permanently deformed, the dislocations move until they are stopped by something else in the crystalline lattice. In Issues 14 and 15 of Technical Tidbits it was described how grain boundaries and alloying elements interfere with the movement of dislocations. However, one of the most effective dislocation stoppers is another dislocation. Where dislocations run on different planes and intersect, they cannot pass through each other. The dislocations pile up against each other, and can become intertwined. This **dislocation entanglement** prevents any further permanent deformation of that particular grain, without the use significantly greater energy. This greatly increases the strength of the material under any subsequent loading.

Figure 1 shows what theoretically happens during strain hardening. A certain amount of strain (deformation) is put into the material (gray line). When the load is removed, the material returns to a state of zero stress along a path perpendicular to the elastic loading line (purple squares). When the material is reloaded, it follows the same path up to the original stress-strain curve (blue line). However, the material's elastic limit has been increased by a certain amount. The new yield strength (green dotted line) is now substantially higher than the old yield strength (dashed red line). However, the total elongation available has now diminished. This increase in strength will therefore diminish ductility and formability.

Figure 2 shows the cold rolling process used to increase the temper of strip materials. The strip is passed between two rollers that exert heavy pressure. The strip is compressed through the gap and becomes much longer and thinner. The grains in the metal also become elongated. This permanent deformation causes the dislocations to pile up, which increases the strength of the material. Additionally, the larger grain boundary area serves as an inhibitor to subsequent dislocations.

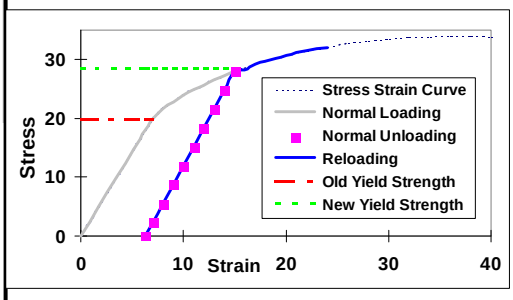


Figure 1. Stress-Strain Curve with Strain Hardening Illustrated

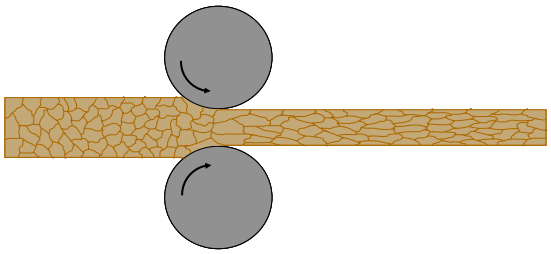


Figure 2. Representation of Cold Work Being Rolled into Copper Alloy Strip

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Strain Hardening and Strength (continued)

The degree of cold reduction determines the strength of a metal. As the percent cold work increases, so does the strength. Conversely, the total elongation decreases as cold work increases. Figure 3 shows the relationship between strength, elongation, and cold work for yellow brass. As the percent cold work increases, there are diminishing returns on strength. This is due to the fact that at higher reductions, there are fewer free dislocations to become entangled. Also, the elongation (ductility, formability) decreases rapidly with cold work. Since the material is less able to plastically deform, fracture becomes much more likely

At high levels of cold work, the material becomes very difficult to further process or form. If it must be formed, or reduced further in thickness, then **annealing** becomes necessary. This is a high temperature soak, which causes the grains to **recrystallize**. Old grains are obliterated, and new grains, complete with new dislocations, start to grow. All effects of the prior cold work disappear. This returns the strength and elongation of the material to the starting (no cold work) value. The material is then ready for any further cold work that may be necessary. The final temper of a strain-hardened material is actually the amount of cold work applied to it after the final anneal. Annealing must be done at a high enough temperature and at a long enough time to destroy the old grains. Still, the time must be short enough and the temperature low enough to prevent new grains from growing too large.

Cold work is one of the most important means of improving the strength of metals. However, a balance must be struck between the amount of strength imparted to the metal and the amount of ductility lost. Harder tempers like spring and superspring have high strength and low ductility (bad formability), whereas softer tempers like annealed and 1/4 hard have low strength and high ductility (very good formability). When choosing a material for a connector, it is best to use the highest strength material that still meets the formability requirements of the design.

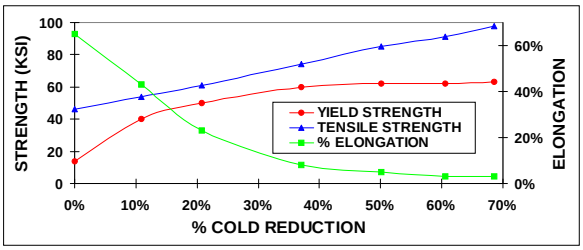


Figure 3. Effect of Cold Work on Strength and Ductility

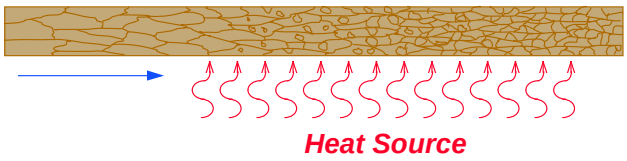


Figure 4. Growth of New Grains within old Grains during Annealing and Recrystallization

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