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Why Bigger is not Always Better – A discussion on the relationship between grain size and material strength.

- **Dislocations**
- **Grain Size**
- **Grain Boundaries**
- **Hall-Petch Strengthening**
- **Slip Plane**

The next issue of Technical Tidbits will focus on strain hardening as a material strengthening mechanism.

Grain Size and Material Strength

The previous edition of Technical Tidbits discussed dislocations and plastic strain. It was noted that most low-temperature, permanent deformation of metal comes from the movement of crystalline imperfections, known as **dislocations**, through the grains in the metal. This edition will examine the improvement of a metal's strength by limiting the movement of these dislocations by controlling **grain size**.

Given enough stress and thermal energy, dislocations will easily move throughout the crystalline grains, resulting in permanent distortion of the grain itself. However, once a dislocation reaches a grain boundary, it has nowhere to go. In other words, **grain boundaries** stop dislocations (see Figure 1). Thus, an easy way to improve the strength of a material is to make the grains as small as possible, increasing the amount of grain boundary. Smaller grains have greater ratios of surface area to volume, which means a greater ratio of grain boundary to dislocations. The more grain boundaries that exist, the higher the strength becomes.

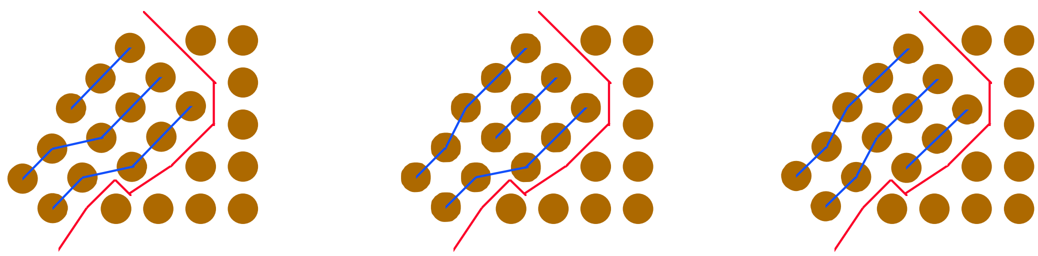

Figure 1. Representation of a Dislocation Stopped by a Grain Boundary (Red Line).

The following example illustrates this principle. Figure 2 shows a crude representation of two grains. For the sake of simplicity, the grains are illustrated as perfect rectangular prisms. Each prism is made up of several cubic units. For the sake of this analysis, each unit contains exactly six dislocations. For the larger grain, there are 2 x 3 x 4 = 24 cubic units, and the smaller grain is one cubic unit. The larger grain will have 24 x 6 = 144 dislocations, and the smaller grain has six. The larger grain has a total surface area of 2 x (2 x 4) + 2 x (2 x 3) + 2 x (3 x 4) = 52 square units. The smaller grain has a surface area of 6 square units. For every dislocation in the large grain, there is 0.36 square units of grain boundary. In the smaller grain, there is one square unit of grain boundary for each dislocation. There is a much greater chance for a dislocation to be stopped at a grain boundary in the smaller grain. Therefore, the smaller grain is stronger. In the larger grain, a dislocation can travel up to 4 units without being stopped by a grain boundary, indicating the potential for extensive plastic flow. In the small grain, no dislocation can travel more than 1 unit of distance. This type of strengthening is known as **Hall-Petch strengthening**.

Small grains also improve the overall strength of a metal another way. Within each grain, there are preferred planes where the atoms (in the form of dislocations) are free to move across each other. These are known as **slip planes**. If the applied stress coincides with a slip plane, the dislocations can move easily. If the applied stress is perpendicular to the slip plane, it would be extremely difficult for the dislocations to move. Therefore, each grain is weaker in certain directions than in others (see Figure 3). If all the grains in the base metal of an electrical connector are oriented the same way, the connector would certainly show signs of weakness in a particular direction. The same would be true if there were just one or two grains across a critical dimension. However, with many grains oriented in random directions, the microscopic directionality of strength would tend to be averaged out. This would provide equal strength in all directions.

Grain Size and Material Strength (continued)

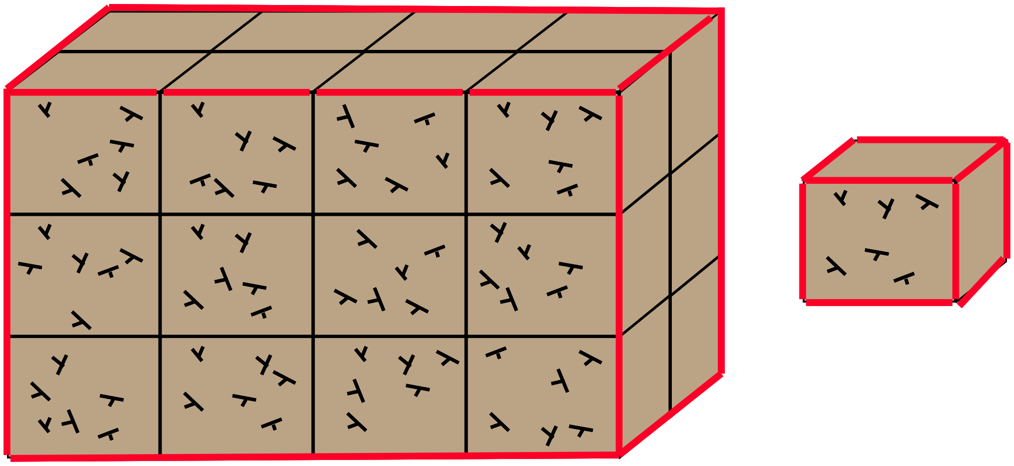

Figure 2. Crude Representation of Dislocation and Grain Boundary Density

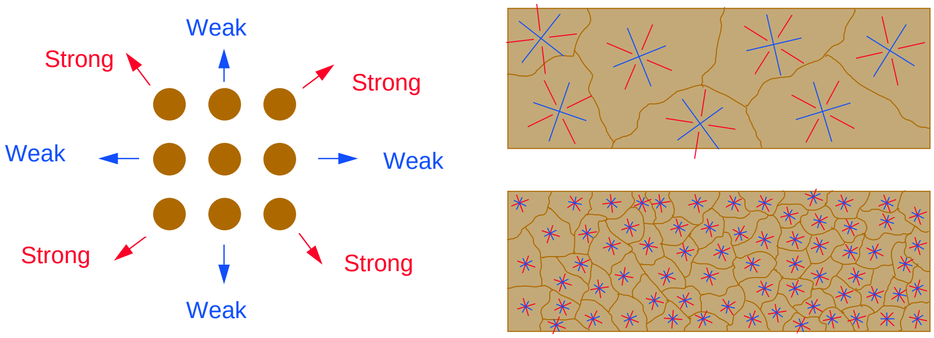

Figure 3. Strength Directionality

Most metal manufacturers will attempt to keep grain size to a minimum when manufacturing materials for use in electrical connectors. A fine grain size will certainly improve the yield strength and stress relaxation resistance of the finished product. Smaller grains will also generally improve the formability of a material, as was discussed in the March and April 2000 editions (issues 9 and 10) of Technical Tidbits. However, there are practical limits to how small the grains can be made. Fortunately, there are several other strengthening mechanisms that are even more effective than grain size refinement. These mechanisms will be discussed in future editions of Technical Tidbits.

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Materials Principles & Practice

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