Ansys Granta EduPack™ Case Study

Aluminum Strengthening

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Ansys Software Used

This resource uses Ansys Granta EduPack™, a teaching software for materials education.

1. Metal Strengthening Mechanisms

Materials scientists and metallurgists are often interested in designing alloys for specific applications. One property that is of prime importance is strength; the ability of a material to withstand an applied stress without failure. For metals, strength can be improved by restricting dislocation motion during plastic deformation. There are several techniques that can accomplish this, such as:

1. Solid Solution Strengthening
2. Strain Hardening
3. Precipitation Strengthening
4. Grain Size Strengthening

The connection between these concepts, dealing with dislocations and microstructures, and real-world properties such as tensile strength, can be difficult to grasp. In this simplified case study, we will use the Granta EduPack Materials Science and Engineering (MS&E) database to explore the three main hardening mechanisms for aluminum alloys and how the composition and processing of Al dramatically impact material properties, ultimately dictating the performance of the material.

2. Exploring Strengthening of Al

The Granta EduPack MS&E database has an expanded section of Science Notes, labeled Structure (Figure 1), providing details on different strengthening mechanisms. These notes include helpful schematics for visualizing dislocations and microstructures, some of which are shown to the right in this page of the case study.
Three main strengthening mechanisms are common in Al alloys: *solid solution strengthening, strain hardening, and precipitation strengthening.*

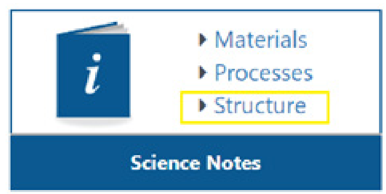

Figure 1: Science Notes Icon in the MS&E Homepage

Solid solution strengthening involves alloying metals with elements that form either substitutional or interstitial solid solutions with the native material. These solute atoms act as obstacles, slowing and preventing dislocation motion. A schematic of how these solutes can restrict dislocations is shown below in Figure 2.

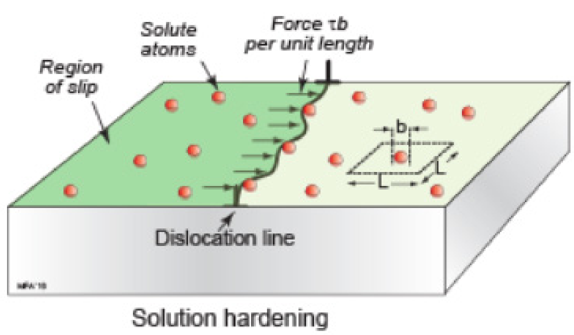

Figure 2: Schematic of solution hardening

Strain hardening (or work hardening) uses plastic deformation to generate dislocations, interfering with dislocation movement, as indicated in Figure 3a. Annealing can be used to control the degree of strain hardening and help tailor properties.

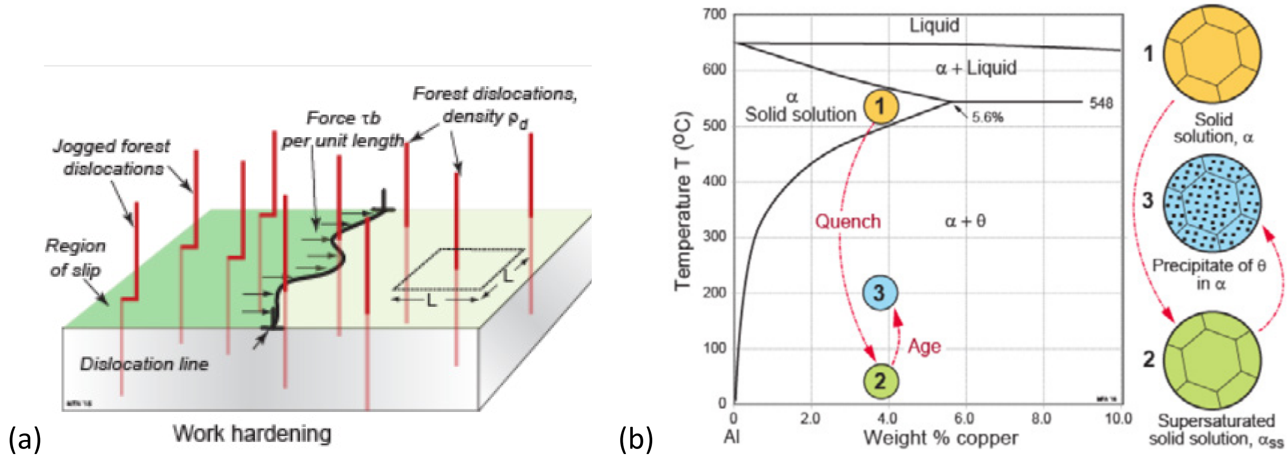

Figure 3: (a) schematic of dislocation "forest" in work hardening
(b) heat treatment profile shown on a phase diagram for precipitation strengthening

Precipitation strengthening (sometimes referred to as precipitation hardening or age hardening) hampers dislocation motion through small, strong particles dispersed within the microstructure. The mechanism of forming these in situ particles is shown in Figure 3b. In this precipitation strengthening example, an Al alloy with around 4 wt% copper is solution heat treated at 550 °C, allowing the Cu to complete dissolve into solid solution (Step 1). Upon cooling/quenching to precipitate particles (Step 2), an aging step can be performed at either a slightly elevated temperature (Step 3) or room temperature to grow the particles to a controlled size. Decreasing the temperature moves the alloy to a low-Cu solubility region of the phase diagram; this allows Cu-rich precipitates to form. The size and shape of these precipitates depend on the time and temperature of this aging step, so understanding these effects is key to proper processing. Many different alloys can undergo precipitation hardening: magnesium-based, titanium-based, copper-cobalt and copper-beryllium systems as well as stainless steels, and more.

3. Processing of Al Alloys

Aluminum and its alloys play a very important role in product manufacturing today. It is found in a variety of products, from buildings to computers to airplanes. It is second only to steel in world production. There are many different classes of Al alloys, each with their own composition ranges, processing techniques, and strengthening characteristics. The MS&E database organizes aluminum alloys into three categories: casting alloys, wrought (work hardened) alloys, and wrought age-hardened alloys. Wrought age-hardened alloys make use of both work hardening and precipitation hardening. Each broad category record shows general properties and highlights how, even within an alloy class, processing can impact properties. This can be explored further using the Property-Process Profiles databases to create plots like the one in Figure 4 comparing Fracture Toughness and Yield Strength.

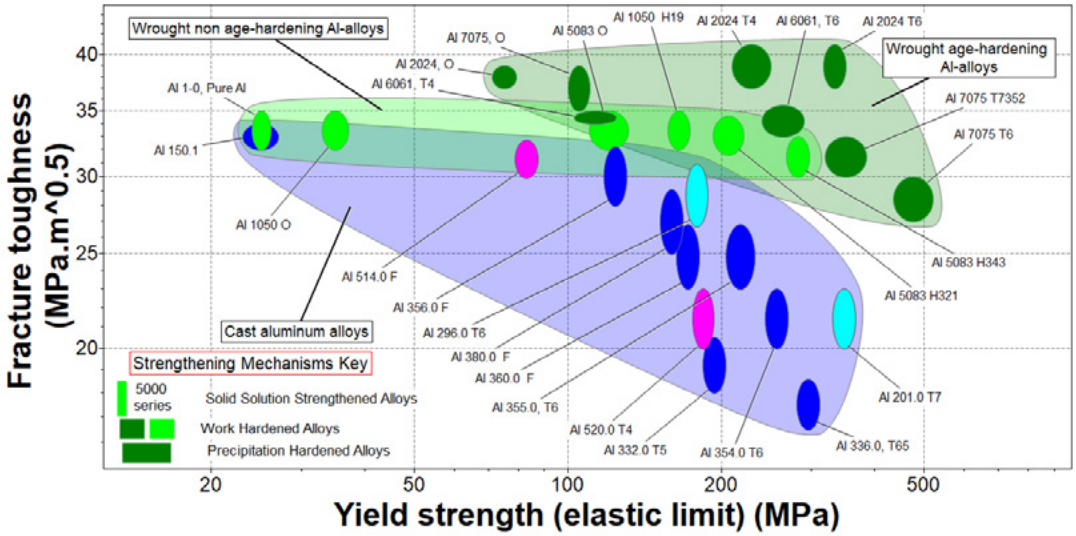

Figure 4: Chart of Fracture Toughness vs. Yield Strength for work hardened, solid solution strengthened, and precipitation strengthened aluminum alloys

The wrought age-hardened alloys, shown in dark green, have higher fracture toughness and yield strength than the other types of Al alloys. However, the wide range of properties within each category highlights the importance of composition and processing conditions. By examining alloys and their processing conditions side by side, more advanced understanding of materials selection and decisions can be made.

4. Conclusions

In this simplified case study, we have explored strengthening mechanisms in Al alloys and the impact they have on properties, utilizing the Granta EduPack MS&E database. The purpose of strengthening mechanisms is to slow the movement of dislocations caused by plastic deformation. The three most common strengthening mechanisms in aluminum were discussed:

- Solid-solution strengthening
- Strain hardening (work hardening)
- Precipitation strengthening (age hardening)

Each of these mechanisms uses a different method of slowing down dislocations: solid solution strengthening utilizes solute atoms; work hardening uses other dislocations; and precipitation hardening uses small precipitates within the material. The amount of strengthening gained from each technique is dependent on the composition and processing. Large variations can exist for similarly strengthened alloys, as shown in the Fracture Toughness vs. Yield Strength plot. This was shown in a comparison of Fracture Toughness and Yield Strength plot. Materials scientists can utilize these variations to carefully design alloys for specific applications' strength requirements.

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Document Information

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