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Annealing to Increase Metal Ductility

Many metal fabrication processes involve cold-working, such as cold rolling sheet and plate, wire drawing, and deep drawing. Due to metallurgical changes that occur to a metal during cold working, the ductility of a metal decreases as the amount of cold-working increases. There comes a point when additional cold working is not possible without causing the metal to crack. At this point, it is necessary to anneal the metal if continued cold-working is required.

During an anneal, metallurgical changes occur that returns the metal to its pre-cold-worked state. These changes result in a reduction of the metalôs yield and tensile strength and an increase in its ductility, enabling further cold working. In order for these changes to occur, the metal must be heated above its recrystallization temperature. The recrystallization temperature for a particular metal depends on the metalôs composition. This specific annealing process is sometimes called a recrystallization anneal, though other names like process anneal are also used.

Metallurgical effects of cold working

During cold-working there is an increase in the number of dislocations in a metal compared to its pre-cold-worked condition. Dislocations are defects in the arrangement of atoms in a metal (discussed in Principles of Metallurgy). The increase in the number of dislocations causes a metalôs yield and tensile strength to increase and its ductility to decrease. After a certain amount of cold work, a metal cannot be cold worked further without cracking. The amount of cold working that a particular metal can withstand before cracking depends on its composition and microstructure.

Metallurgical effects of recrystallization anneal

During a recrystallization anneal, new grains form in a cold-worked metal. These new grains have a greatly reduced number of dislocations compared to the cold-worked metal. This change returns the metal to its pre-cold-worked lower strength and increased ductility. With continued time at the annealing temperature, some of the newly formed grains grow at the expense of neighboring grains. There is some further decrease in strength and increase in ductility as the average grain size increases during the grain growth phase.

The final grain size depends on the annealing temperature and annealing time. For a particular annealing temperature, as the time at the temperature increases the grain size increases. For a particular annealing time, as the temperature increases the grain size increases. A particular alloy with larger grains has lower strength and more ductility than the same alloy with smaller grains.

The figure shows micrographs of a brass alloy that was cold-rolled to 50% of its original thickness and annealed at two different temperatures. Figure (a) shows the microstructure of the cold rolled sample. Figure (b) shows the microstructure of a sample that was cold rolled and then annealed at 1022 °F (550 °C) for 1 hour. Figure (c) shows the microstructure of a sample that was cold rolled and then annealed at 1202 °F (650 °C) for 1 hour.

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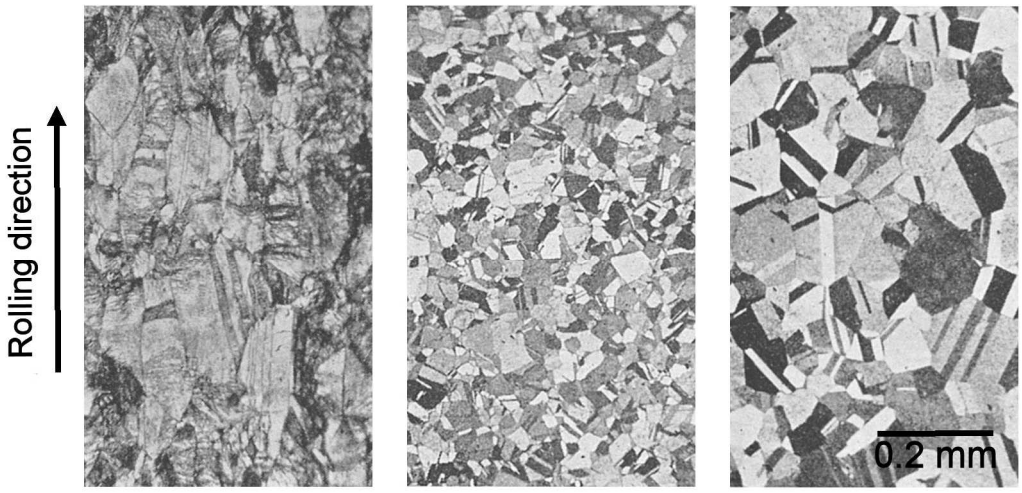

(a) (b) (c)

The cold-rolled sample had a yield strength of 80 ksi (550 MPa). The sample that was annealed at 1022 °F (550 °C) for 1 hour had yield strength of 11 ksi (75 MPa). Many small grains are present in this sample. The sample that was annealed at 1202 °F (650 °C) for 1 hour had yield strength of 9 ksi (60 MPa). Fewer, large grains were present in this sample compared to the sample in Figure (b).

Other reason for recrystallization anneal

In addition to enabling additional cold-working, recrystallization annealing is also used as a final processing step to produce metal sheet, plate, wire, or bar with specific mechanical properties. Control of the annealing temperature and time, heating rate up to the annealing temperature, and amount of cold-working prior to anneal is important for obtaining the desired grain size, and therefore the desired mechanical properties.

I hope this article was helpful. However, if you still have a specific metallurgy question that was not addressed, I offer a 15-minute phone consultation for $60. Iôve found that many questions can be answered in 15 minutes, helping to get people back on track. Hereôs the link to purchase the consultation http://www.imetllc.com/metallurgy-consultation/.

If the article was helpful and you'd like to learn more about metallurgy, please check out some of my on-demand metallurgy courses at http://www.imetllc.com/metallurgy-courses/. More information about dislocations, the metallurgy of recrystallization annealing of metals, and the effects of grain size on metal strength is in the Principles of Metallurgy course.