
Heat Treating Aluminum Alloys
“Any sufficiently advanced technology is indistinguishable from magic” –*Arthur C Clarke*

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Why do we heat treat?

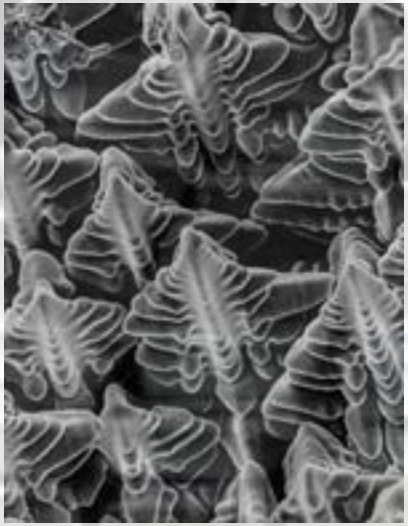
- Improve properties
  - Mitigate Segregation in ingots / castings
  - Create better distribution and shape for hardening particles
  - Adjust hardness (down) after extreme mechanical processing

Why do we heat treat?

- Improve properties
  - Optimize Strength and ductility for the intended appplication.
    - High strength usually accompanied by low ductility
    - Refinement of microstructure through thermal and mechanical processing can improve strength and ductility at the same time.

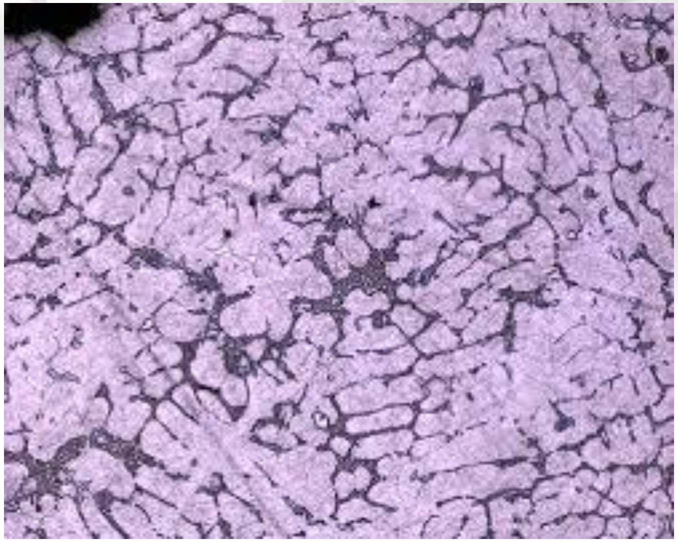
Why do we heat treat?

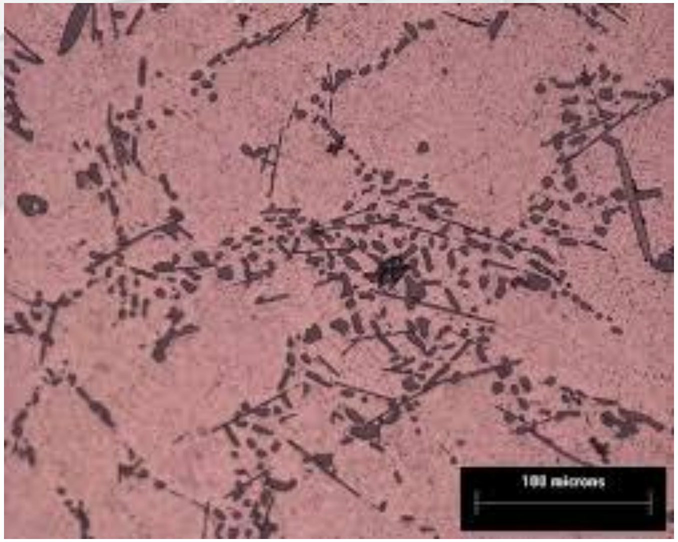
– Mitigate Segregation in ingots / castings
  - Solids tend to freeze out pure
  - Most of the alloying elements will be found in the last material to solidify
  - Welding is a casting operation



Why do we heat treat?

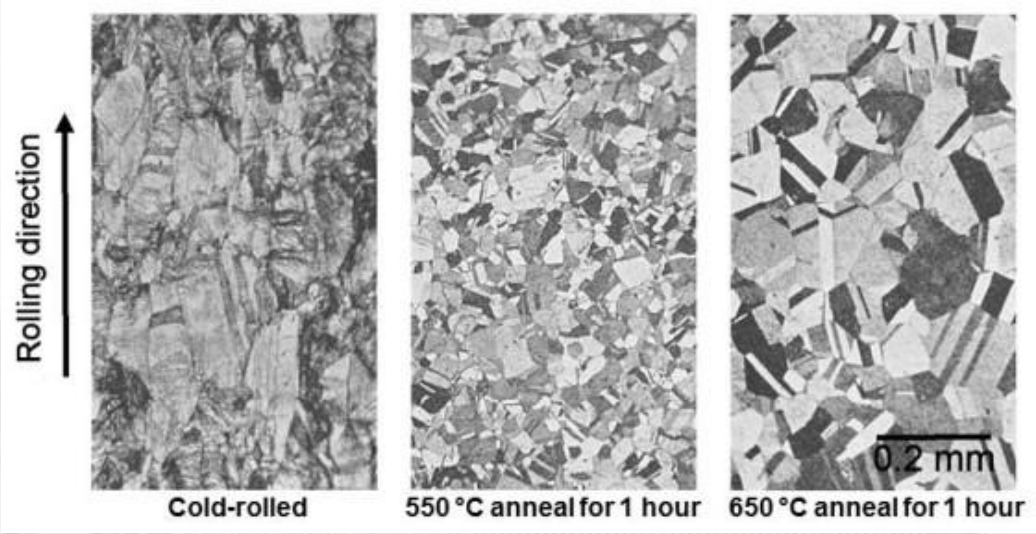
– Create better distribution and shape for hardening particles
  - Cracks propagate through continuous grain boundary precipitates
  - A fine, even dispersion of hardening particles is generally most desirable.



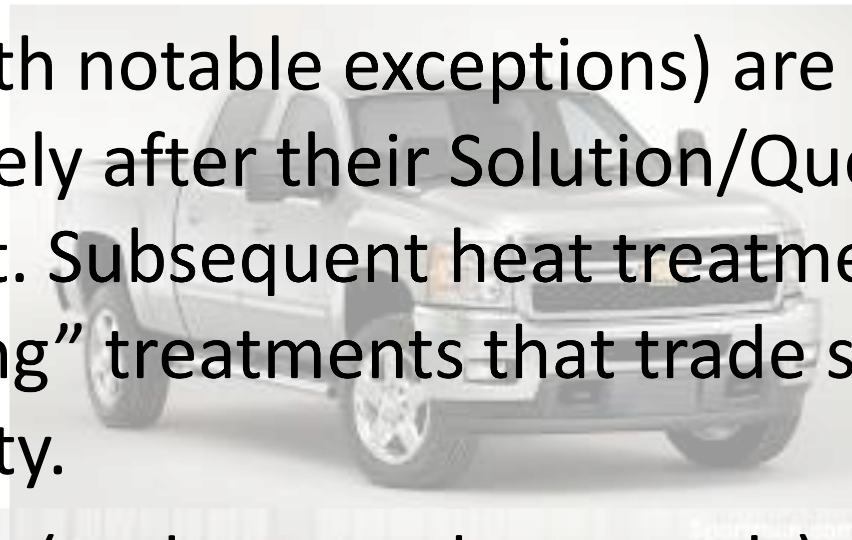
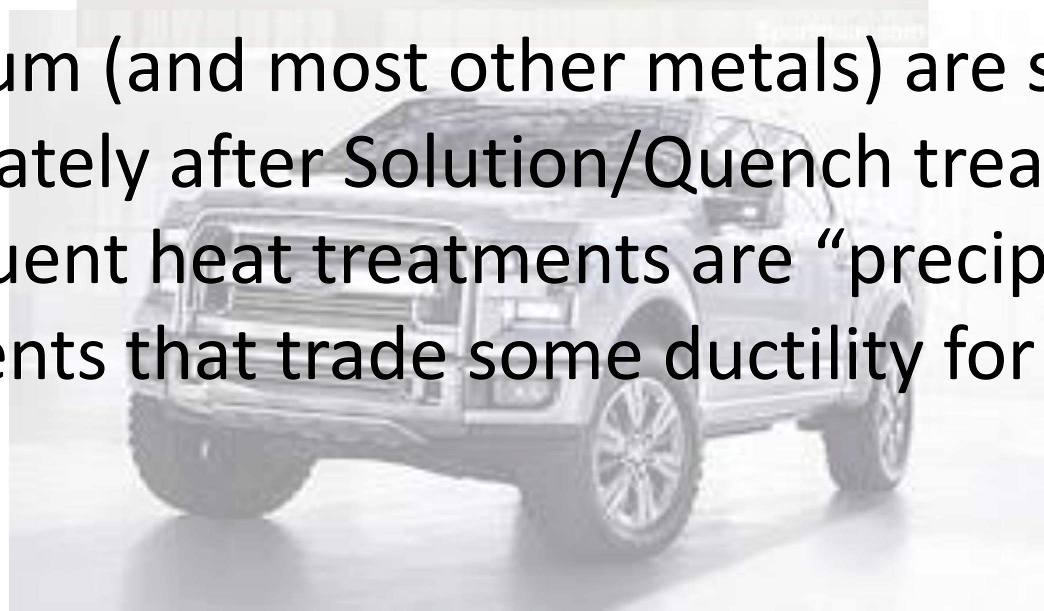


Why do we heat treat?

– Adjust hardness (down) after extreme mechanical processing
  - Highly elongated and aligned grain structure and high residual stress level due to deformation leads to anisotropic properties.
  - Annealing relieves the high residual stress, recrystallization helps homogenize the chemistry and refine the grain size.



What is different VS Steel?

- Steels (with notable exceptions) are hardest immediately after their Solution/Quench treatment. Subsequent heat treatments are “tempering” treatments that trade some strength for ductility.
- Aluminum (and most other metals) are soft immediately after Solution/Quench treatment. Subsequent heat treatments are “precipitation” treatments that trade some ductility for strength.

What do we heat treat?

- Non-Heat treatable alloys
- Precipitation Hardened Alloys
- Room Temperature aging Alloys

What do we heat treat?

- Non-Heat treatable alloys
  - Generally restricted to annealing / recrystallization
  - Examples include:
    - Alloy 5083 Truck bodies (Annealed at 775F, recrystallize above 600F)
    - Alloy 1450 Foils, extruded shapes

What do we heat treat?

- Precipitation Hardened Alloys
  - Alloy 6061 Rolled/Drawn or Extruded/forged (T6: Solution 985F, Age 320F for 18 hours or 350F for 8 hours)
  - Alloy 7075 (T6: Solution 870F-900F, age 250F 24 hours)
    - Can begin to melt as low as 890.

What do we heat treat?

- Room Temperature aging Alloys
  - Alloy 2024 (T3: Solution and quench 493F)
    - Used for rivets on the DC3, kept in a freezer to prevent room temperature aging before the rivets were installed / driven.

How do we heat treat?

- Process the metal through one or more cycles of elevated temperature for measured time.
- Time and temperature are not interchangeable. Raising the temperature is not the same as increasing the time. (But due to increased diffusion rates treatments at higher temperature tend to be shorter).
- Think of how rock candy is made.

Solution / Anneal

- Here we take the metal near it’s melting point and let it come to equilibrium.
  - Annealing, make the metal as soft as possible without melting.
  - Solution treating, soften as above with the added task of dissolving the alloying elements in the base metal at a higher concentration that room temperature allows.

Boil the water and saturate with sugar at high temperature.

Age / Precipitation Harden

- Only useful in alloys that have enough alloying elements dissolved to make them precipitate back out.
- The resulting particle size and distribution will determine the properties achieved.
- Two processes have to happen, nucleation and growth
  - Nucleation sites are places where the alloy comes out of solution initially
  - Growth occurs once the nucleation site reaches a critical size

  We place the strings into the cooling water and let the sugar crystals grow

Age / Precipitation Harden

- Only useful in alloys that have enough alloying elements dissolved to make them precipitate back out.
  - Many commercially useful alloys intentionally do not have enough alloying additions to allow precipitation (Beverage cans, Foil some extruded shapes used in homebuilding etc).

Age / Precipitation Harden

- The resulting particle size and distribution will determine the properties achieved.
  - Generally we want the finest particle size and finest dispersion for best mechanical properties
    - Think of a pound of clay with a pound of gravel mixed in VS the same clay with a pound of sand.
  - Sometimes this is compromised for non-mechanical reasons such as corrosion.

Age / Precipitation Harden

- Two processes have to happen, nucleation and growth
  - Nucleation sites are places where the alloy comes out of solution initially
    - The tiny bubbles that are just starting to form as water begins to boil. Low heat and barely boiling yields many small bubbles.
  - Growth occurs once the nucleation site reaches a critical size
    - As alloying elements diffuse through the base metal, they aggregate to the larger particles and cause the bubbles to grow further and coalesce . High heat creates a rolling boil where the bubbles are larger before they reach the surface.

Age / Precipitation Harden

- The previous slide tells us that low and slow will generally produce the best properties.
- Contrary to many assertions I found on the web, one hour at high temperature and eight hours at low temperature do NOT produce the same particle size and distribution, and thus they do not produce equivalent results. (But they may both meet the specification)
- Practical considerations in manufacturing processes frequently dictate higher temperatures and shorter times if they can achieve acceptable results.

Practical Heat Treating

- Equipment
  - What can you use for small scale heat treating?
- Accuracy
  - How close do you need to be to the prescribed temperatures and times?
- Results
  - How can you determine the effectiveness of your heat treatment?

Practical Heat Treating

- Equipment
  - What can you use for small scale heat treating?
    - Torch (Readily available, uneven heating and cooling rates)
    - Home oven / toaster oven (Readily available if single, must verify temperatures and know the “working zone”
    - Farrier’s Forge (Safely gets hotter than a toaster oven, probably don’t have one)
    - Laser temperate reader (Good at surface temperatures, can’t embed in a block for testing)
    - Thermocouples (Can be found with some meters, can be embedded to help ensure core part temperatures are correct)

Practical Heat Treating

- Accuracy
  - How close do you need to be to the prescribed temperatures and times?
    - Solution Treatment – Temperature is most critical, time is really a practical minimum. 10-15 extra minutes is unlikely to do much harm, 10F-15F too high can create incipient melting.
    - Aging +/- 10F is great, +/-25 is acceptable. Lower temperature aging can tolerate larger errors in time without over-aging.

Practical Heat Treating

- Results
  - How can you determine the effectiveness of your heat treatment?
    - Honestly, testing.
    - Destructive testing is likely impractical, but could be done on a spare part.
    - Hardness testing does not reveal all you need to know, but may be your only good choice
    - Try it and see if it breaks. Not recommended, particularly for aircraft parts.

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- http://www.weldmyworld.com/blog/2015/07/gmaw-electrodes.html
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Aluminum Alloy Designation Tree