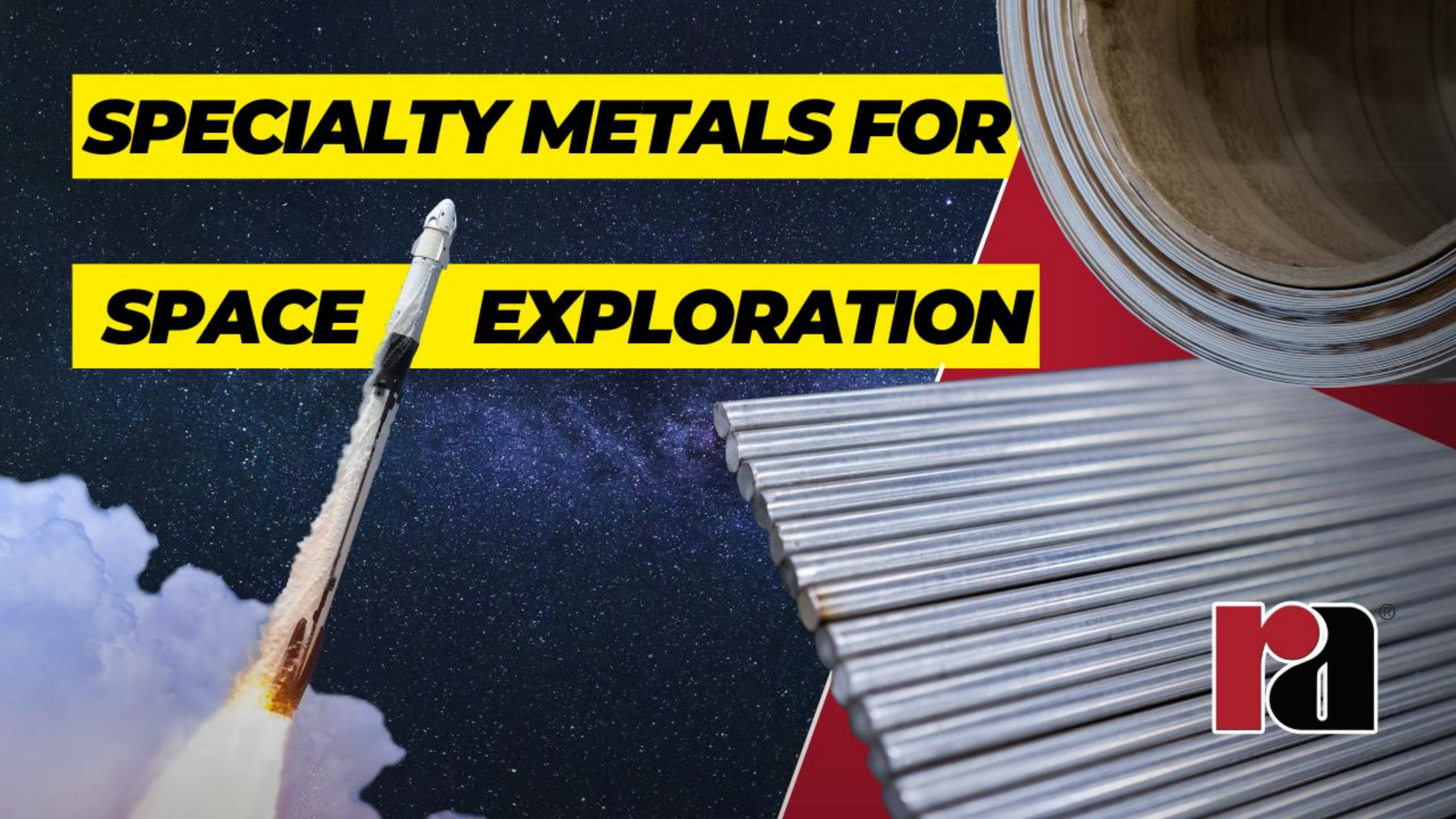

SPECIALTY METALS FOR
SPACE EXPLORATION

# Agenda

- Rolled Alloys Company Overview
- Commonly Utilized Materials
  - Austenitic Stainless Steels
  - PH Stainless Steels
  - Heat Resistant Alloys
  - Superalloys
- Melt Practices Overview

# Rolled Alloys Overview

- Rolled Alloys is a global supplier of specialty alloys that offers value added services such as state-of-the-art material processing, a best-in-class e-commerce site, and metallurgical expertise.

- Alloys -
  - Nickel Alloys
  - Stainless Steels
  - Duplex Stainless Steels
  - Titanium Alloys
  - Cobalt Alloys

- Forms -
  - Plate
  - Sheet
  - Bar
  - Pipe and Fittings
  - Weld Consumables

# Rolled Alloys Overview

- Rolled Alloys offers an array of different processing options to provide customers with custom cut parts.
- Processing Capabilities -
  - Laser Cutting
  - Plasma Cutting
  - Waterjet Cutting
  - Abrasive Saw Cutting
  - Plate Beveling
  - Shear Cutting
  - Bar Saw Cutting
  - Laser/Punch Combo
  - Pipe Threading
  - Pipe Beveling

ROLLED ALLOYS

# Speaker – Nick Hicks

Nick is an Applications Engineer within the Metallurgical Services department of Rolled Alloys. Nick holds a B.S. in Mechanical Engineering from the University of Toledo and is pursuing his M.S. in Materials Science from Worcester Polytechnic Institute. Nick's day-to-day duties include answering technical inquiries, providing performance analysis services, and understanding the needs of developing market segments. Nick has been with Rolled Alloys since 2018 and currently serves as an Emerging Professional board member on ASM's Heat Treat Society, is Rolled Alloy's designated ASTM A01 voting member, and is Rolled Alloy's designated representative for the Materials Technology Institute.

# Metallurgical Services

- Rolled Alloys has a Metallurgical Services team dedicated to serving our customers, by providing both knowledge and laboratory services. The services that our Metallurgical Services group offers are value added and free of charge to customers.
- Services -
  - Technical Assistance
  - Laboratory Services
  - Lunch and Learns
  - Sample Program

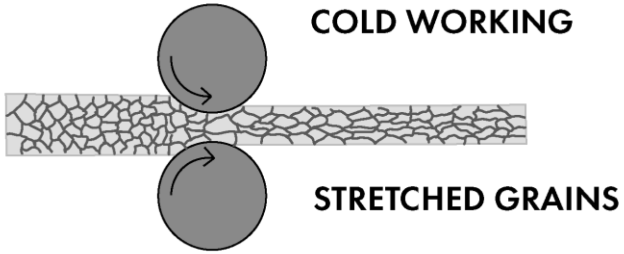
ROLLED ALLOYS

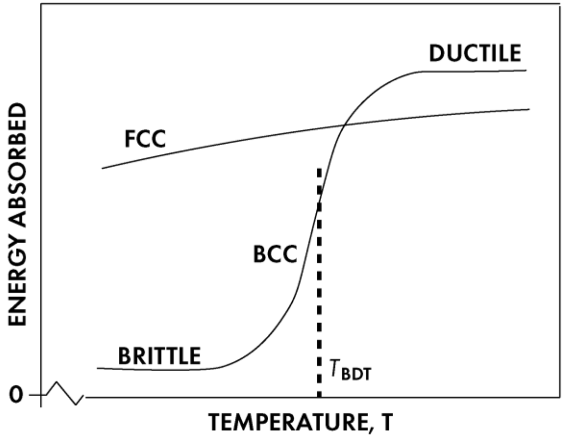
# Commonly Utilized Materials

ROLLED ALLOYS

# Austenitic Stainless-Steel Overview

- Austenitic stainless steels are the most common class of stainless steel.
- The most common group of austenitic stainless steels is the 300-series stainless’s.
- 300 series stainless steels are modifications of 304 (18% chromium and 8% nickel) .
- They can only be hardened through cold work.
- Austenitic stainless steels are used for a variety of reasons such as:
    - Impact toughness to cryogenic temperatures
    - High temperature properties
    - Corrosion resistance




ROLLED ALLOYS

# Commonly Utilized Austenitic Stainless Steel’s

| Grades | Description |
|---|---|
| **304** | The original “18-8” stainless steel. Offers useful resistance to corrosion in many environments. Usable up to 1600°F. |
| **316** | A grade that improves upon the corrosion resistance of 304 through the addition of molybdenum. Usable up to 1600°F. |
| **321** | A titanium stabilized grade that is commonly utilized in the 1000 – 1600°F temperature range. Titanium is added to combat intergranular corrosion at temperature. |
| **347** | A niobium stabilized grade that is commonly utilized in the 1000 – 1600°F temperature range. Niobium is added to combat intergranular corrosion at temperature. |

ROLLED ALLOYS

# Cold Work and Low Temperature Properties

| | 304/304L Cond A* | 304/304L Cond S* | 304/304L Cond B* |
|---|---|---|---|
| **UTS, ksi** | 70 | 95 | 125 |
| **0.2% YS, ksi** | 25 | 75 | 100 |
| **Elongation, %** | 40 | 25 | 12 |

* Properties are all minimums per ASTM A276

| | 304/304L @ RT** | 304/304L @ -320°F** | 304/304L @ -425°F** |
|---|---|---|---|
| **UTS, ksi** | 90 | 230 | 250 |
| **0.2% YS, ksi** | 35 | 70 | 100 |
| **Elongation, %** | 60 | 35 | 25 |
| **Impact Energy, ft-lbs** | 150 | 85 | 85 |

** Typical Condition A Properties

ROLLED ALLOYS

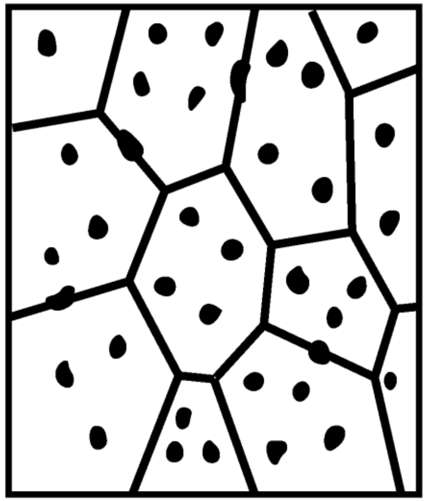
# Austenitic Stainless-Steel Uses

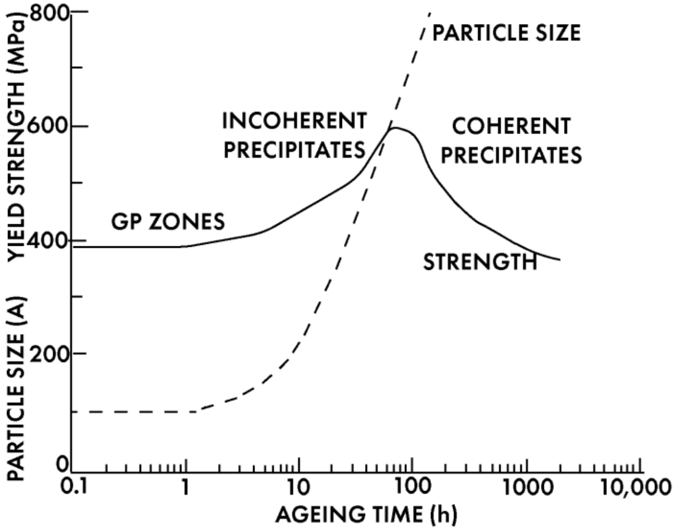
- Propellant Tanks:
  - Typically utilize cold worked material for enhanced mechanical properties
- Cryogenic Fluid Conveyance Systems
- Cryogenic Fluid Storage Tanks
- Flexible Hosing
- External Support Brackets
- Piping
- Fittings and Flanges

ROLLED ALLOYS

# PH Stainless Steel Overview

- A class of stainless steel that can be hardened upon heat treatment.
- When heat treating to enhance a PH grades mechanical's, it is often referred to as "precipitation hardening" or "aging".
- During this process, the material will form and grow precipitates, which will play a role in a material's mechanical properties.
- Material is commonly supplied in the solution annealed condition and sent out for subsequent heat treatment to be conditioned.





# Commonly Utilized PH Stainless Steels

| Grades | Description |
| --- | --- |
| **17-4 PH** | A chromium-nickel-copper precipitation hardening stainless steel. Aging material will precipitate out a copper containing phase. High strength, moderate corrosion resistance. |
| **15-5 PH** | A chromium-nickel-copper precipitation hardening stainless steel. Aging heat treatments will precipitate out a copper containing phase. High strength, moderate corrosion resistance, better toughness than 17-4, and supplied remelted. |
| **13-8 PH** | A chromium-nickel-aluminum precipitation hardening stainless steel. Aging heat treatments will precipitate out an aluminum containing phase. High strength, moderate corrosion resistance, and supplied vacuum melted + remelted. |

*First number is chromium content, and second number is nickel content.

# Strength Comparison Among PH Grades

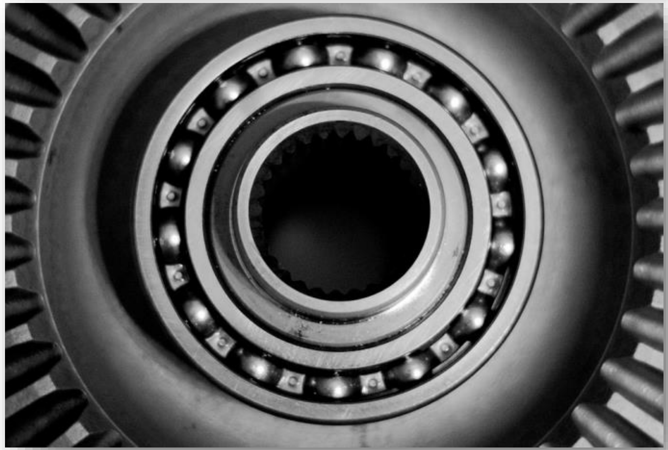
| | 304/304L* | 17-4 H900** | 17-4 H1150** | 15-5 H900** | 15-5 H1150** | 13-8 H950** |
|---|---|---|---|---|---|---|
| **UTS, ksi** | 70 | 190 | 135 | 190 | 135 | 220 |
| **0.2% YS, ksi** | 25 | 170 | 105 | 170 | 105 | 205 |
| **Elongation, %** | 40 | 10 | 16 | 10 | 16 | 10 |
| **Hardness, HRC** | - | 40 | 28 | 40 | 28 | 45 |

* Minimum properties per ASTM A276
** Minimum properties per ASTM A564

ROLLED ALLOYS

# PH Stainless Steel Uses

- Fasteners
- Bearings
- Bushings
- Valve Bodies
- Wear Surfaces
- Components requiring high strength at moderately low temperatures.



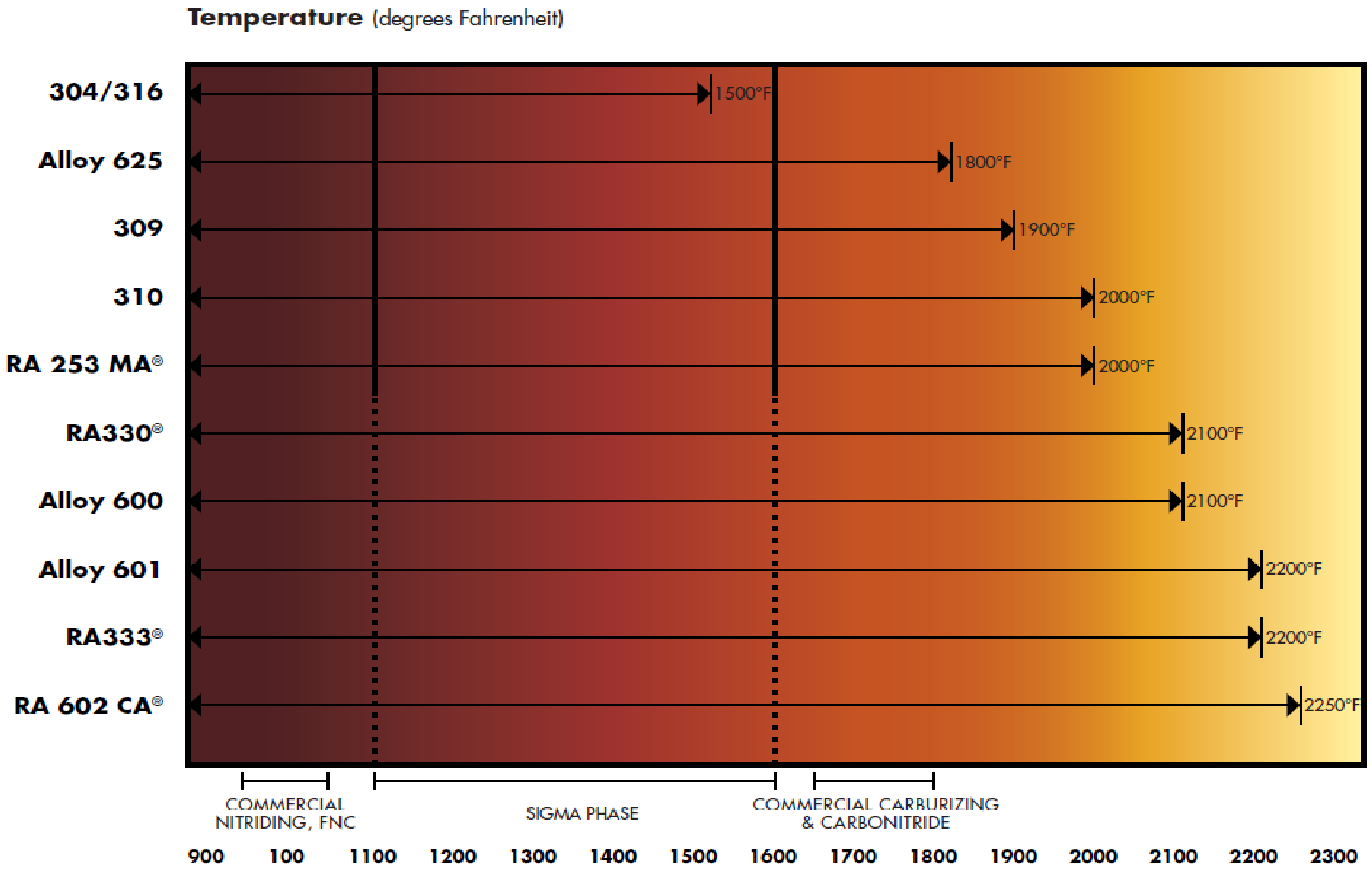
ROLLED ALLOYS

# Heat Resistant Alloys Overview

- A group of stainless steels and nickel alloys that are produced specifically for high temperature service environments.
- Ways to enhance an alloys heat resistance:
  - Carbon, nitrogen, and nickel added for higher strength at high temperature.
  - Silicon and aluminum added for suboxide.
  - Rare earth metals added for better oxide adherence.


ROLLED ALLOYS

# Heat Resistant Alloys Overview




ROLLED ALLOYS

# Oxidation

Acceptable

Unacceptable

ROLLED ALLOYS

# Superalloys Overview

- Superalloys are complex alloys that are utilized for critical components requiring resistance to high temperatures, strength at temperature, and corrosion resistance.
- Primary types of superalloys:
  - Nickel-Based
  - Cobalt-Based
  - Iron-Based
- Depending on chemistry, a superalloy could be solid solution strengthened or precipitation hardenable.
- Solid solution strengthened is a form of strengthening accomplished through alloying.

ROLLED ALLOYS

# Superalloys Overview

| Grades | Description |
|---|---|
| **625** | Ni-based solid solution strengthened alloy that has great corrosion resistance and high temperature usability up to 1800°F. Molybdenum and niobium content provides solid solution strengthening. |
| **718** | Ni-based precipitation hardened alloy that exhibits high strength up to 1400°F. The primary hardening precipitate is niobium and nickel containing. |
| **Alloy X** | Ni-based solid solution strengthened alloy that exhibits great corrosion resistance and high temperature usability up to 2000°F. |
| **188** | Co-based solid solution strengthened alloy that exhibits usability up to 2000°F and good wear resistance. High tungsten content provides solid solution strengthening. |

ROLLED ALLOYS

# Strength Comparison

| | 304/304L @ 70°F* | 304/304L @ 400°F* | 304/304L @ 800°F* | 304/304L @ 1200°F* |
|---|---|---|---|---|
| **UTS, ksi** | 90 | 70 | 66 | 48 |
| **0.2% YS, ksi** | 35 | 23 | 19 | 15.5 |
| **Elongation, %** | 60 | 50 | 43 | 34 |

*Typical Condition A Tensile Properties

| | 718 @ 70°F** | 718 @ 400°F** | 718 @ 800°F** | 718 @ 1200°F** |
|---|---|---|---|---|
| **UTS, ksi** | 208 | 198 | 192 | 168 |
| **0.2% YS, ksi** | 174 | 163 | 157 | 148 |
| **Elongation, %** | 21 | 20 | 19.5 | 19 |

**Typical AMS 5596 in PH Condition Tensile Properties

ROLLED ALLOYS

# Superalloy and Heat Resistant Alloy Uses

- Engine Internals:
    - Hot Gas Manifolds
    - Pre-Burner Manifolds
    - Turbopump Impellers
    - Main Injector
    - Main Combustion Chamber
    - Nozzles
- Metallic Heat Shields
- High-Strength Cryogenic Equipment

ROLLED ALLOYS

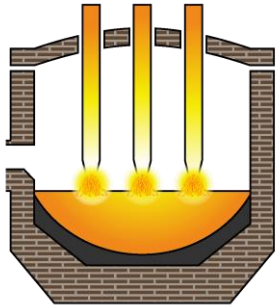
# Melt Practices

ROLLED ALLOYS

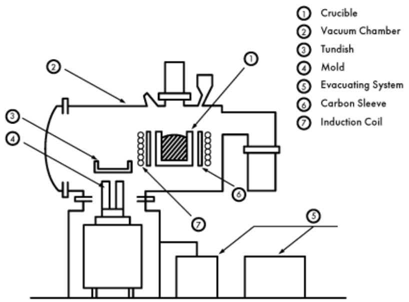
# Melting Processes

**Primary Melting**

Electric Arc Furnace (EAF)

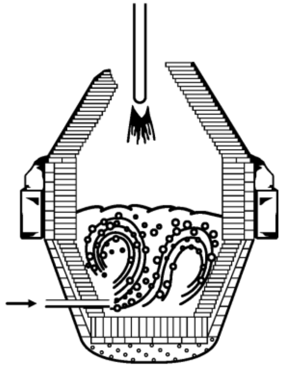


Vacuum Induction Melting (VIM)



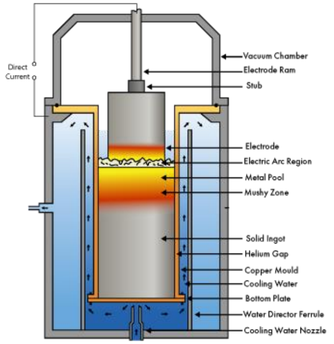

**Refining**

Argon Oxygen Decarburization (AOD)

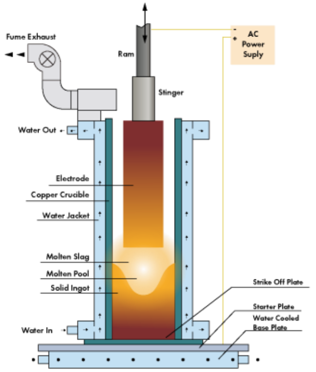


**Secondary Melting**

Vacuum Arc Remelt (VAR)

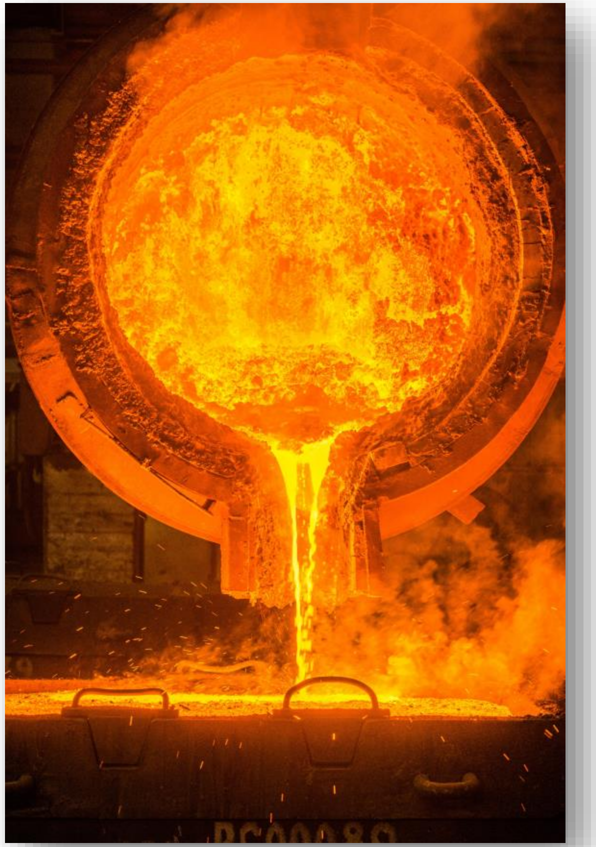



Electroslag Remelt (ESR)



# Single Melt vs. Remelted Material

- Single Melt –
  - Single melt materials are much lower in cost compared to that of remelt materials as there are fewer processing steps.
  - Single melts are generally employed for lower-cost materials and/or when the end use is less critical.
- Remelt –
  - Improved cleanliness and improved solidified structure.
    - Greater chemical homogeneity and uniform mechanical properties.
    - Minimizing number of non-metallic inclusions.
    - Remaining inclusions are more evenly distributed.
  - Remelting is an additional process that is typically employed when end use is critical.



ROLLED ALLOYS

# QUESTIONS OR COMMENTS?

**NICK HICKS**
**APPLICATIONS ENGINEER**
**NHICKS@ROLLEDALLOYS.COM**
**734-850-0172**

**METALLURGICAL HELP DESK:**
**HELP-TECH@ROLLEDALLOYS.COM**