Aluminum Alloys for Additive Manufacturing
A Metallurgical Perspective of the Modern Economy
The Fourth Industrial Revolution

18th - 19th Centuries
- Mechanization
- Water/Steam Power
- Textiles, Iron, Steam Engine

1870 – 1914
- Mass Production
- Electric Power
- Steel, Oil, Internal Combustion

1980s – Now?
- Digitization
- Automation
- The PC, Internet, Telecommunication

The Present
- Smart Factories
- Super Computing, Big Data, The Internet of Things

“Industry 4.0”
- Computerization of manufacturing
- Enabled by breakthroughs in artificial intelligence, robotics, internet, autonomy, 3D printing, nanotechnology
- Allows for extreme customization and personalization
- The Sharing Economy
- The Maker Movement
What is Additive Manufacturing

**Subtractive Manufacturing**
- Material is cut from a larger piece until the final shape is achieved
- Lathe, mill, drill, etc.
- Components are assembled into a final part (weld, braze, bolt, glue, etc.)

**Additive Manufacturing**
- Successive layers of material are built up until the final shape is achieved
Powder Bed Fusion

- Metal powder
- Laser
- Platform
Advantages to Additive Manufacturing

Left: LEAP Fuel nozzle, 18 parts reduced to 1, improved fluid dynamics

Right: Turboprop engine, 800+ parts reduced to 30, reduced weight, eliminated parasitic loss, improved efficiency. Both manufactured by GE Additive
NanoAl’s history of innovation includes:

- High strength, high conductivity, and creep resistant wire and cable
- High strength, weldable sheet products
- High strength casting alloys
- Custom alloy design and novel solutions
Aluminum Applications

F1 Cylinder Head

- 60% weight reduction
- 10X more surface area for cooling
- Improved vibration management
- Manufactured by FIT West
Aluminum Applications

Aerospace Heat Exchanger

- Complex geometry is impossible by any other method
- Improved cooling efficiency
- Weight reduction
Designing a Strong Alloy

Solid-Solution Strengthening
- Single atoms

Dispersion Strengthening
- Precipitates: 5 – 100 nm
- Dispersoids: 100 – 300 nm
- Secondary Phases: 100’s nm – 10’s μm

Grain Boundary Strengthening
- 10’s nm – 100’s μm

Hierarchy of Scale
- Picometers
- Nanometers
- Micrometers
- Millimeters


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Characterization of Nanoscale Features

Atom Probe Tomography (APT)
Resolution: single atoms

Transmission Electron Microscopy (TEM)
Resolution: 50 pm

Atomic Force Microscopy (AFM)
Resolution: < 1 nm

X-Ray Diffraction (XRD)
Resolution: atomic spacing

Scanning Electron Microscopy (SEM)
Resolution: < 10 nm

Hierarchy of Scale

Picometers  Nanometers  Micrometers  Millimeters
Atom Probe Tomography (APT)

- Surface of material is vaporized one layer at a time
- Instrument detects the element and its position in the material
- Software reconstructs a 3D model
- First instrument which allowed us to “see” an atom

Transmission Electron Microscopy (TEM)

- Specimen is thinned so that it becomes “electron transparent” – About 100 nm
- Electron beam is generated in the column, passes through the specimen, and is recorded by a CCD camera below the specimen
- Reveals crystal structure and chemistry with sub-nanometer resolution

Atomic Force Microscopy (AFM)

- AFM probe “taps” along the material surface – measures topography and surface chemistry
- Recently developed scanning Kelvin probe force microscopy (SKPFM) is used to identify micro-galvanic couples between metal and strengthening phases
- Micro-galvanic couples influence overall corrosion
- SKPFM measures corrosion potential between phases – analogous to electric potential of a battery

X-Ray Diffraction (XRD)

- Identifies the crystal structure of all phases present in the sample
- Determines relative quantity of all phases present
- Can measure grain size, lattice strain, and atomic spacing
Electrons are generated in the column above the specimen, and are reflected off the specimen towards the detector.

Advantages of SEM include large field of view, large depth of field, and large depth of focus.

Gives topographic, chemical, and crystallographic information.
Economic Opportunities in Additive

- Additive manufacturing was a $5.1B industry in 2015
- NIST projects it to be a $50B industry by 2030, and a $100B industry by 2040

- GE Additive
  - Believes there to be a $76B opportunity in additive
  - Started on September 27, 2016
  - As of this week they have 1,000 employees
  - They will have 20,000 employees involved in additive by the end of 2017
  - Plan to sell 10,000 3D printers in next 10 years
  - Investing $10M in schools in next 5 years
Ensure that AM curricula provide students with an understanding of:

- AM and traditional manufacturing processes to enable them to effectively select the appropriate process for product realization;
- the relationships between AM processes and material properties;
- “Design for AM”, including computational tools for AM design as well as frameworks for process selection, costing, and solution generation that take advantage of AM capabilities.

Establishment of a national network for AM education that, by leveraging existing “distributed” educational models and NSF Programs, provides open source resources as well as packaged activities, courses, and curricula for all educational levels (K-Gray).

Promote K-12 educational programs in STEAM and across all formal and informal learning environments in order to leverage the unique capabilities of AM in engaging students in hands-on, tactile, and visual learning activities.

Provide support for collaborative and community-oriented maker spaces that promote awareness of AM among the public and provide AM training programs for incumbent workers and students seeking alternative pathways to gain AM knowledge and experience.

- https://community.asme.org/additive_manufacturing/m/default.aspx
Thank You!