ONR Manufacturing Science

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Office of Naval Research – 33MT

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Man Science Program Objective

Basic (6.1) scientific research to develop fundamental understanding of the processes and materials that will enable advances in manufacturing technology of Naval components.

Focus on Navy-unique or Navy-centric topics

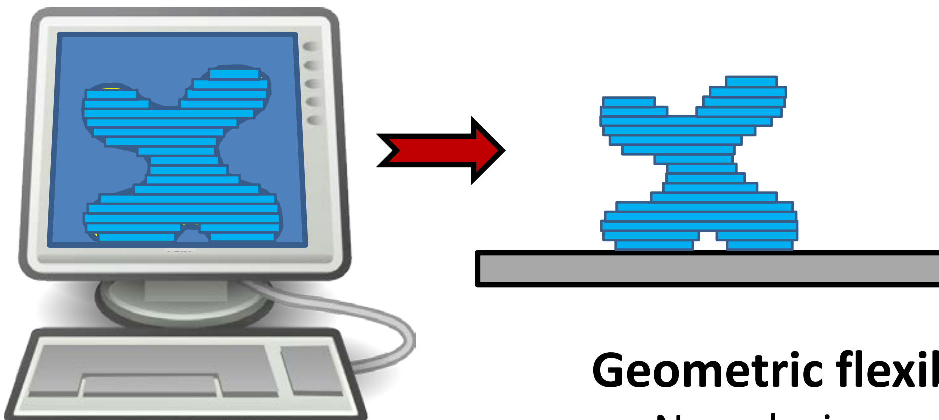
- Current focus is on alloys for additive manufacturing
- New program call being developed—ideas?

Typical program: 2 year base program
3rd year option
$100-150k/year

UNCLASSIFIED

Additive Manufacturing

Fabrication of a 3D component from a 3D computer model by sequential deposition of 2D layers



1) Generate 3D CAD drawing on computer

2) Section into 2D slices

3) Deposit slices layer by layer to make part

Geometric flexibility
- New design
- 5x more durable

Part complexity and Topology Optimization
- 25% lighter

Part consolidation
- Single part vs 21 parts

Streamlined supply chain

Good Example of AM Benefits:
<u>New GE fuel nozzle</u>

Naval Advantages of AM

Additive Manufacturing Enables:

- Net or near-net shape products
- Rapid prototyping
  - Low volume production
- Easy complexity
  - Internal features, topologically optimized structures, part consolidation
- New supply chain paradigm
  - Production of obsolescent parts
  - Manufacturing parts on demand

Previous ONR Man Science Program Components

Cyber-enabled Manufacturing Systems

- Modeling of powder packing and weld pool
- Development of Scanning Laser Epitaxy
- Optimization for fine structures and joints
- Real-time sensing via optical emission spectroscopy
- Real-time sensing via ultrasonic characterization
- Process modeling
- Integration for real-time process control

AMANE Program Motivations

- Many critical components have manufacturing lead times of 6 months to several years
- Many current Naval alloys do not have a corresponding AM alloy that will satisfy Naval needs (e.g., 5083)
- Current AM alloys were developed for conventional manufacturing environment, not multi-use facility without post processing facilities (as in expeditionary manufacturing)

Current Research Program

Additive Manufacturing Alloys for Naval Environments (AMANE)

Objective: Design, develop and optimize new metallic alloy compositions for additive manufacturing (AM) that are resistant to the effects of the Naval/maritime environment.

AMANE Program Approach

Use an Integrated Computational Materials Engineering (ICME) methodology coupled with experiments to develop new AM alloys for Naval applications by determining the effects of alloy chemistry, AM processing parameters, and post-processing conditions on mechanical and electrochemical/corrosion properties.

Two AMANE Thrusts

1) Conventional Manufacturing

- Optimize alloy for Naval AM applications
  - Achieve properties equivalent or better than wrought
- Stay within current compositional specs if possible

2) Expeditionary Manufacturing

- Multi-purpose alloy with good combination of properties
- Achieves properties in as-built condition—no post-processing (e.g., HIP) required
- Enable an "80% solution"

AMANE Programs

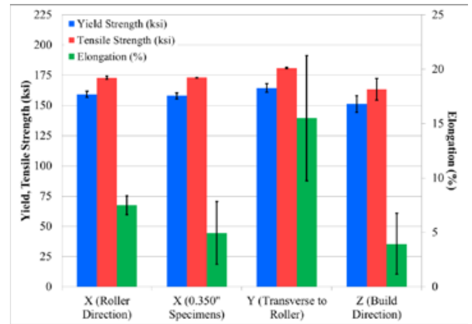
Six AMANE programs

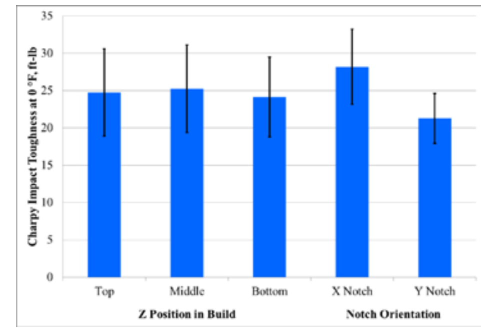
- Development of High Strength Naval AM Steels (NSWCCD)
- ICME Optimization of High Strength Naval AM Steels (QuesTek)
- ICME Optimization of HSLA Naval Steels for AM (Pitt)
- Design of Nickel-based Alloys for Naval AM Applications (PSU)
- Design of Aluminum Alloys for Naval AM Applications (UCF)
- Development of Amorphous Metals for Extrusion AM (Yale)

Development of High Strength Naval AM Steels

Objective: Evaluate a high-strength, high-toughness and blast-resistant 10%-nickel steel composition for additive manufacturing

Payoff: A new high-strength, high-toughness AM steel that does not require post-processing, holding promise as a generic high strength alloy for expeditionary manufacturing





10Ni Steel alloy has high strength and good toughness, but needs better elongation

Approach: Determine the optimum AM processing parameters, microstructures, and properties for a developmental steel welding consumable composition with demonstrated cooling rate insensitivity and unexpected favorable properties.

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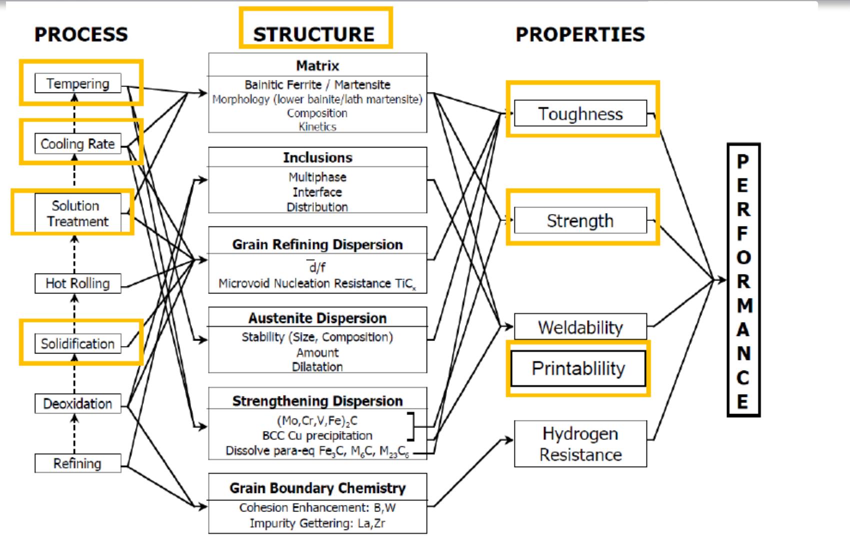
ICME Optimization of High Strength Naval AM Steels

Objective: Use a computational alloy design optimization methodology to improve the 10%-nickel steel composition being studied by Carderock for additive manufacturing

Payoff: An improved high-strength, high-toughness AM steel that does not require post-processing, for use as a generic high strength alloy for expeditionary applications



ICME methodology for the AM 10Ni steel development

Approach: Use various physics-based and empirical models to predict the Ms temperature, DBTT, compositional sensitivity, cracking susceptibility, and hot cracking susceptibility as a function of composition and processing parameters, and compare model results to selected bead-on-plate AM builds

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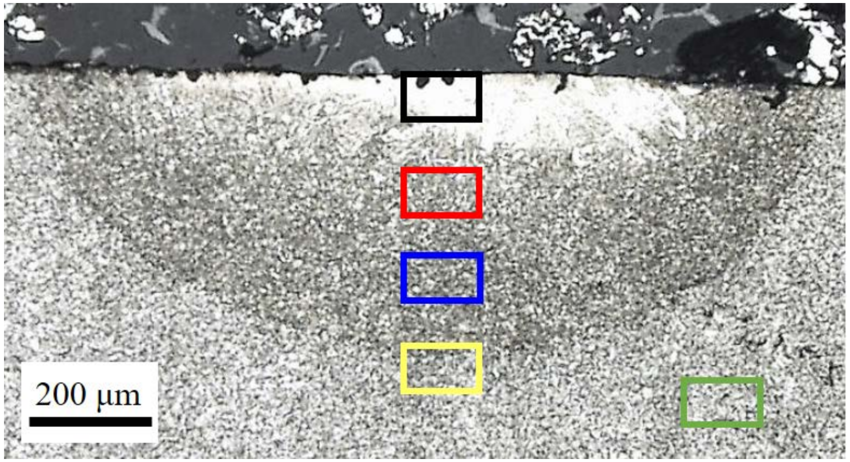
ICME Optimization of HSLA Naval Steels for AM

Objectives: Using an ICME approach:

— Determine the optimal composition range for AM within the current high strength, low alloy HSLA-100 composition window

— Identify the optimal composition range for AM steel based on the HSLA-100 alloy design

Payoff: Identification of the optimum AM composition and processing windows for HSLA-100 components



Different regions in laser track of candidate alloy

Approach: Use CALPHAD modeling and various in-house models to predict the microstructures and properties of potential alloy compositions, prepare samples of prototype alloys by laser melting on arc-melted or suction-cast alloys, and characterize the microstructure and properties

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Design of Nickel-based Alloys for Naval AM Applications

Objectives

Use computational alloy design to optimize the composition of Inconel (IN625) for additive manufacturing of Naval components

Versions of this alloy are currently available, but do not meet the stress corrosion cracking requirements for Naval applications.

Calculated thermodynamic properties using DFT for over 1000 phases, including γ, γ', γ'', δ-A_3B, C14-Laves, and A_2B phases in Ni, Co, Fe, and Cr

										Al 0.73	Si 0.63
Sc 5.50	Ti 1.16	V -0.34	Cr -1.14	Mn 0.84	Fe -0.85	Co -1.50	Ni 0.00	Cu 0.40	Zn 0.88		
Y 10.2	Zr 6.44	Nb 1.88	Mo -0.97	Tc -2.48	Ru -1.98	Rh -1.26	Pd 0.52				
	Hf 3.42	Ta 1.10	W -2.18	Re -4.33	Os -4.13	Ir -3.01	Pt -0.79				

Relative diffusivity of elements in $Ni_{31}X$

Approach

- Use computational methods (DFT & CALPHAD calculations) to design an improved IN625-type alloy with a combination of high strength and superior seawater resistance.

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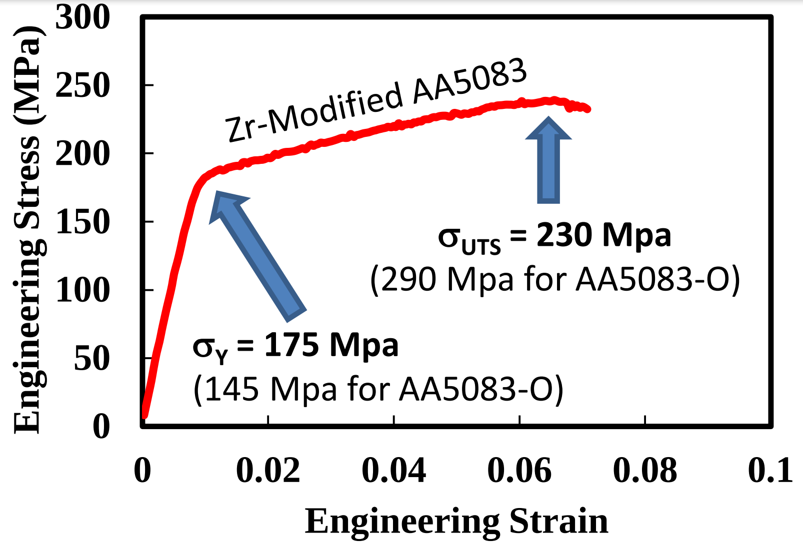
Design of Aluminum Alloys for Naval AM Applications

Objective: Design, develop, and deliver new and/or modified aluminum alloys for AM fabrication of corrosion-resistant components

There is currently only a single commercially-available aluminum alloy for AM, and it does not have the required corrosion resistance for Naval applications. This program targets aluminum AM alloys with the mechanical properties and corrosion resistance of current marine aluminum alloys (2XXX and 5XXX alloys, respectively).

Approach

- Use physics-based and empirical models to design a new Al AM alloy with a combination of high strength and superior corrosion resistance.



Superior performance in new AA5083+Zr alloy

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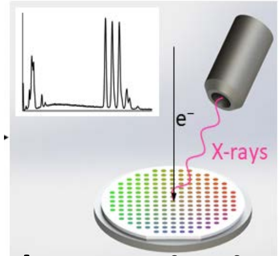
Development of Amorphous Metals for Extrusion AM

Objective:

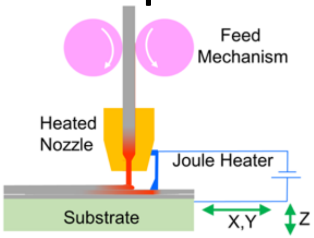
Design and develop new bulk metallic glass compositions for application with extrusion-based AM

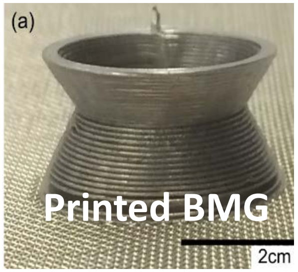
Payoff: Development of new structural metallic glass alloys with high formability, high deposition rates (tens of cm^3/h), and corrosion resistance for extrusion-based AM



Characterization

AM Deposition





Approach: Employ theoretical models, combinatorial sample fabrication, and high-throughput characterization techniques to design, fabricate, and characterize potential bulk metallic glass compositions for extrusion-based AM, and determine the best processing parameters and resulting properties of these BMG parts

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