Advanced Melt Manufacturing of Covetic Materials

CPS Agreement 28419

National Energy Technology Laboratory-Office of Research and Development

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Overview

Timeline

- First award in FY15
- First covetic melt July 2015
- Project on task
- Partnered with ANL in response to a lab call for FY19

Budget

	FY 18	FY 19
DOE Funded	0.4M	0.4M

Barriers

- The Key barriers of this project include the difficulty of working with molten metal.
- The structure of the optimized material is on a fine scale.
- Uniformity of product.

Partners

- NETL and ANL have closely collaborated for several years on this project.
- NETL has an NDA agreement with GDC Industries for exchange of IP to advance commercialization.
- NETL is an active participant in the bi-annual Covetic materials meetings for the past several years.

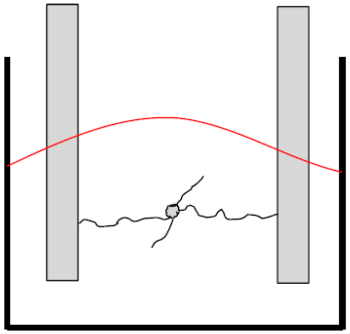
Project Objective

- The purpose of this research is to improve the melt processing of metal alloys with significant additions of integrally-bound nano-scale carbon phase (i.e., "covetic" nano-materials) in order to produce materials with consistent properties including improved conductivity characteristics (both electrical and thermal).
- What is the problem?
  - Previous research by the US Navy and Univ. of Maryland, verified the unique structure and properties of covetic Al and Cu (alloys with integrally-bound nano-scale carbon resulted in higher thermal and electrical conductivity). These unique alloys are attractive for numerous advanced energy applications (power transmission lines, motor windings, electrical contacts, heat-exchangers, etc)[1].
  - However, the process as-invented provides material of highly variable quality and compositional accuracy [2] resulting in variable performance characteristics. Thus, there is a needed for developing improved melt practices and thus consistent products for wide spread commercialization.
- NETL is utilizing its extensive knowledge of melting and process control to develop a methodology to produce consistent, reliable, enhanced materials.
- Why is it difficult?
  - The process, as developed by others, is a non-traditional melt processing method (an electrical current is applied to the melt during induction melting).
  - There is lack of fundamental knowledge of the methodology, which needs to be developed in order to improve the process.
  - In order to ensure the transfer to industry, laboratory experiments need to be conducted at scales that easily translate to industrial practices.

[1] https://powerpedia.energy.gov/wiki/Covetic_Nanomaterials
[2] D. Forrest, "ONR Research Summary: Accelerating Insertion of Cu and Al Covetic Materials for Naval Applications," 2012.

Technical Innovation

- Melt processing of covetic materials is far from an every day occurrence.
- Our approach is to independently replicate the “conventional” covetic conversion and evaluate materials conductivity performance.
  - Detailed records of the process
  - Evaluate critical parameters
  - Explore controlled atmosphere processing routes



Technical Approach—Overarching Approach

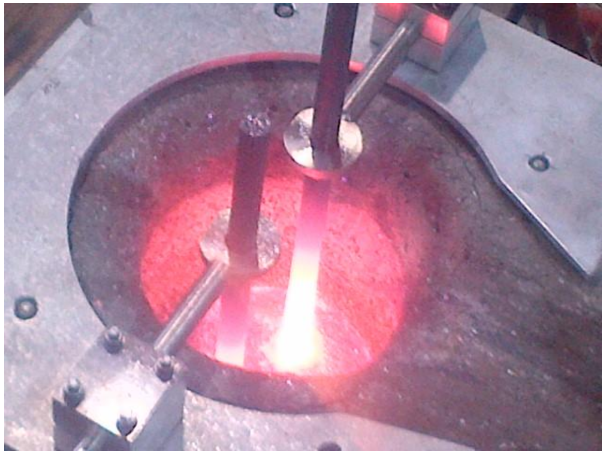
- NETL's overall approach is to:
  - Replicate/improve the induction melt methodology to produce these alloys and better understand and control critical variables
  - Utilize knowledge gained from the induction melt techniques in exploring alternate processing routes including:
  - Controlled atmosphere processing.
- NETL melted/fabricated covetic materials has been made available to ANL for advanced, independent characterization.
- NETL has further melted/fabricated covetic materials initially processed by ANL and then returned these to ANL for advanced characterization, thus efficiently utilizing the strengths of both labs.

NATIONAL ENERGY TECHNOLOGY LABORATORY ⟷ Processing ⟷ Argonne NATIONAL LABORATORY

⟷ Characterization ⟷

Technical Approach—Process Refinement

- Not many details of the melt practice are widely available.
- Conceptually, a melt is formed in an induction furnace, carbon is added and current is applied between graphite electrodes within the melt.
- Our approach has been to replicate what is known of the established melt practice and extensively document our experiences including:
  - Temperature measurements
  - Form of carbon used
  - Current, voltage and hold times



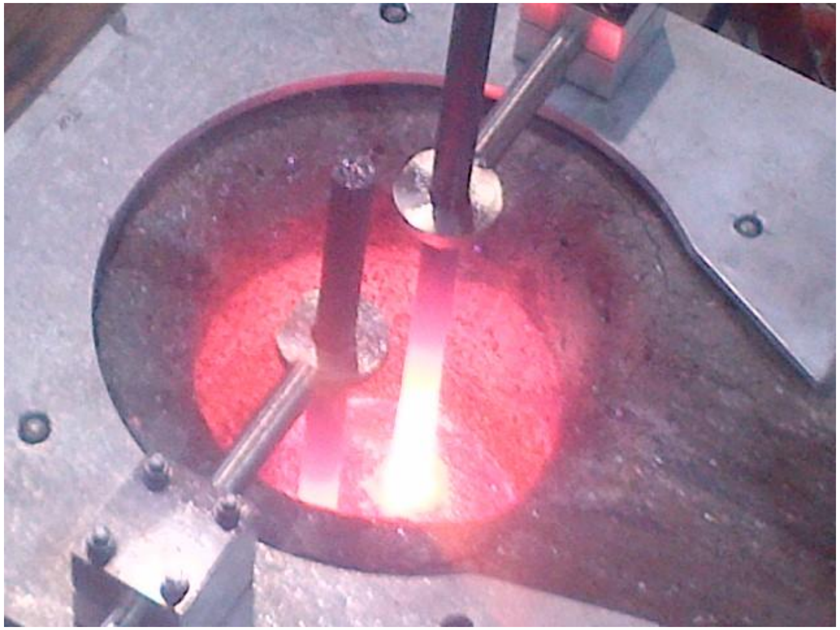
Technical Approach—Covetic Alloys

- Covetic alloys have the promise of interesting properties such as:
  - High thermal and electrical conductivity
  - Enhanced oxidation/corrosion resistance
- Our approach to creating new covetic alloys is twofold:
  - Using the established covetic conversion route of induction melting to create covetic “master alloys” that are added to conventional remelt stocks
  - Using melt processing to covert conventional alloys to covetic alloys in—situ.

Results and Accomplishments

Refinement of Existing Melt Practice

- Modified NETL's 300 pound air induction furnace to replicate conventional covetic melt practice.
  - Dedicated 100KW induction power supply.
  - Secondary power supply (1000A) for covetic reaction.
  - Current lead fixtures have been built.
  - Multiple melt trials have been made.
  - Portions of ingots have been fabricated and samples supplied to ANL



Results and Accomplishments

Refinement of Existing Melt Practice

- Improvements over initial trials include
  - Digital readout of externally applied DC current.
  - Active stirring
- Future plans include recording of DC current.

Results and Accomplishments

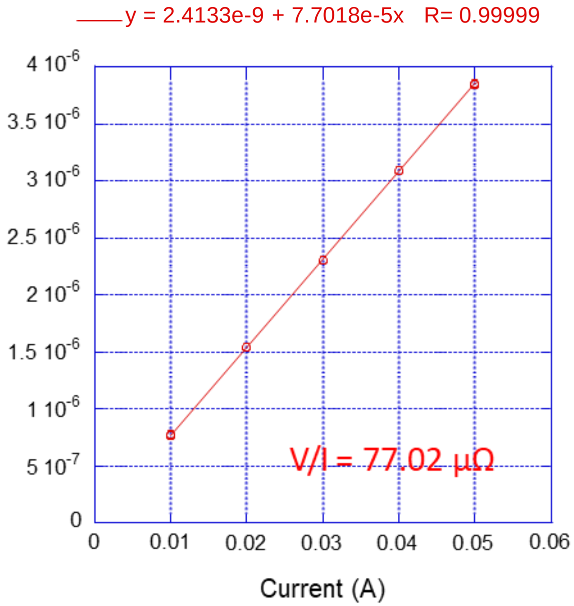
Wrought Material Processing—First Steps to Evaluation

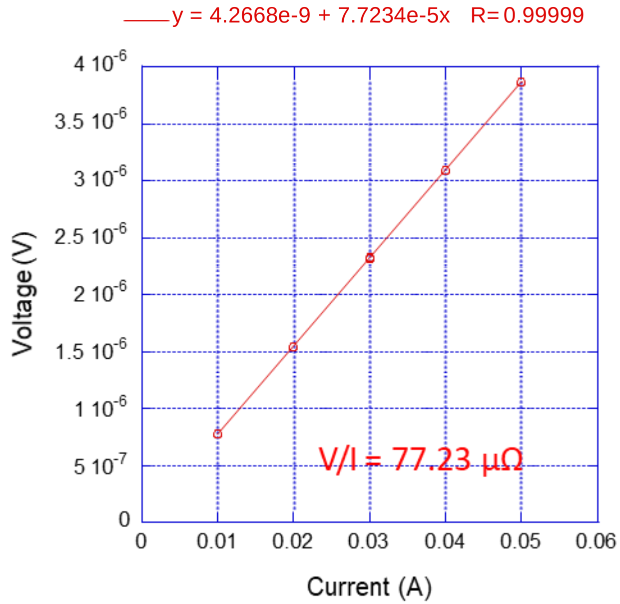
- Several sections were hot worked into plate by forging and rolling.
- This material had good hot work characteristics.

Results and Accomplishments

Refinement of Existing Melt Practice—Test Results

Sample 791531RD (NETL 16-A106 Cu-2%C) electrical conductivity along rolling direction: 1.153 x 1.998 x 22 mm³, d_{vv} = 10.0 mm After annealing at 500°C/1h





Room temperature = 76.7°F, and sample temperature = 77.9°F (25.5°C) during the measurement.

Resistivity @20°C: 1.736, 1.7415μΩ·cm. Average resistivity @20°C is 1.739 μΩ·cm. Conductivity = 99.2% IACS.

We observed 3.8% increase in electrical conductivity after annealing at 500°C for 1 hour.

Resistivity = $\frac{A}{d_{vv}} \cdot \frac{V}{I} = 1.774\ \mu\Omega \cdot \mathrm{cm}$

Resistivity = $\frac{A}{d_{vv}} \cdot \frac{V}{I} = 1.779\ \mu\Omega \cdot \mathrm{cm}$

Tests performed at ANL—many thanks

Results and Accomplishments

Refinement of Existing Melt Practice — Test Results

Electrical Properties Summary

Orientation	Condition	% IACS 15-A127	% IACS 16-A106
RD	CW	89.2	95.6
RD	500C/1h	92.0	99.2
TD	CW	87.6	94.3
TD	500C/1h	91.5	98.3
		Conventional	Covetic

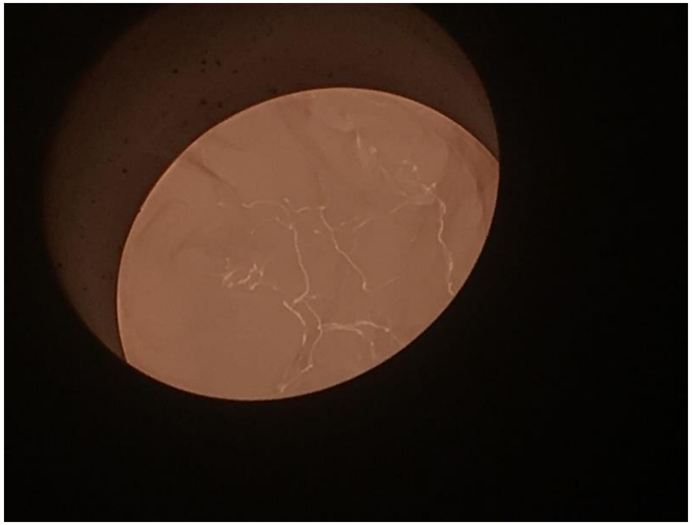
- NETL produced covetic copper shows enhanced conductivity compared to conventional copper under all condition

Tests performed at ANL—many thanks

Results and Accomplishments

Alternative Melt Processing

- De-risking melt processing of covetic alloy technology by demonstrating a consistent process for melt processing of covetic copper.
- NETL is setting up an enclosed furnace to achieve covetic carbon without atmospheric contamination. To our knowledge, NETL was the first to apply this technique to making covetic material.
- Considering its uniqueness and potential value as an invention, NETL has chosen not to disclose the technique here.



Transition (beyond DOE assistance)

- This is important for meeting DOE clean energy goals including:
  - Improved/more efficient electrical distribution
  - Improved/more efficient transformer performance
  - Improved/more efficient heat exchangers
- Once demonstrated, the commercialization route will be to approach conventional alloy producers to generate interest.
  - Presentations and publications will be made at relevant professional meetings such as ASM, AFS, TMS, and Specialty Metals Producers Consortium meetings.
- This technology is expected to have a market pull due to the unique properties solving a number of existing problems.