Melt Processing of Covetic Materials

CPS Agreement 28419

National Energy Technology Laboratory-Office of Research and Development

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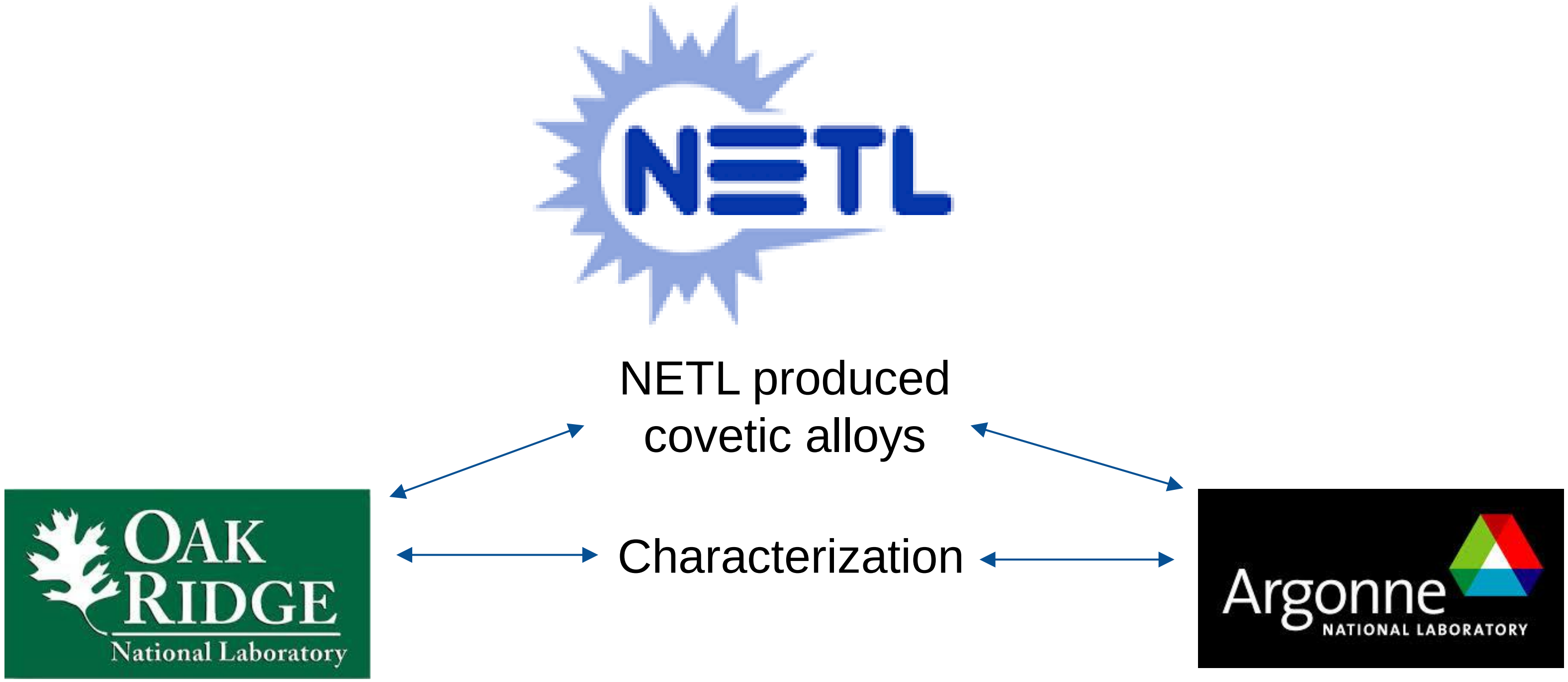
Project Objective

- 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 products and improved performance characteristics.
- What is the problem?
  - Previous research by the US Navy and Univ. of Maryland, verified that the principal claims of the unique structure and properties of covetic Al and Cu (alloys with integrally-bound nano-scale carbon precipitates with higher thermal and electrical conductivity and increased oxidation resistance). 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 by others provides material of highly variable quality and compositional accuracy [2]. This resulted in variable performance characteristics. Thus, there is a needed for developing improved melt practices that produce consistent products for wide spread commercialization of these unique materials.
- Why is it difficult?
  - The process, as developed by others, is a non-traditional melt processing method (an electrical current is applied to during IM).
  - 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 transferred 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 Approach— Overarching Approach

- NETL's overall approach is to:
  - Evaluate and re-melt existing materials. This will provide information on: (a) the stability of nano-carbon and (b) the ability to recycle these unique materials—which is important for life cycles.
  - Replicate the IM methodology to produce these alloys in order to determine reasons for variability in the product
  - Improve current IM methodology and develop alternative melt process methods to produce more uniform alloys.
- NETL melted/fabricated covetic materials will be made available to ORNL and ANL for advanced characterization.



Technical Approach—Existing Materials

- Covetic materials have interesting properties such as:
  - High strength
  - High thermal and electrical conductivity
  - Enhanced oxidation/corrosion resistance
- Our approach to evaluating existing materials is to subject them to a barrage of metallurgical analysis including:
  - Hot working
  - Microstructural analysis (LM, SEM, TEM)
  - Tensile testing
  - Conductivity measurements
  - DTA analysis

Technical Approach—Existing Materials

- Critical to the formation of covetic materials is the melt processing aspect. Once established, it is purported that materials remain covetic after repeated melting.
- To evaluating existing materials tendency to retain the covetic carbon, our approach will be to remelt these using induction melting with the following atmosphere conditions:
  - Vacuum
  - Inert gas
  - Air melting.

Technical Approach—Refine melting

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

Technical Approach—Alternate methods

- Alternate methods are being explored to achieve covetic carbon. These methods apply current to the melt through different means than the IM method. (Patent application pending).
- Some materials have been made and hot worked into plates.
- Further evaluation includes:
  - Chemistry
  - XRD
  - Microstructural analysis (LM, SEM, TEM)
  - Tensile testing
  - Conductivity measurements
  - DTA analysis

Transition and Deployment

- 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 illicit 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.

Measure of Success

- If we are successful in producing covetic materials it could conceivably start a whole new industry or at least a new product line at existing advanced alloy manufacturing facilities.
- As such, the economic impact could be significant.
- The potential energy savings could also be significant with increased efficiency in heat exchangers or reduced electrical losses due to lower resistance materials.

Project Management & Budget

- Project duration: October 1, 2014 – September 30, 2016
  - Project started 7 months ago.
- Project milestones:
  - Task 1: Evaluate existing/available material—delayed, no material available.
  - Task 2: Remelt existing/available material—delayed, no material available.
  - Task 3: Replicate current covetic melt process. Due 31Dec2015—on schedule.
  - Task 4: Improve covetic melts. Due 30Jun2016—on schedule.
  - Task 5: Alternate melt methods. Due 30Sep2015—on schedule.
- Informal monthly and formal quarterly reports submitted to document progress.

Total Project Budget	
DOE Investment	$250,000
Cost Share	
Project Total	$250,000

Results and Accomplishments

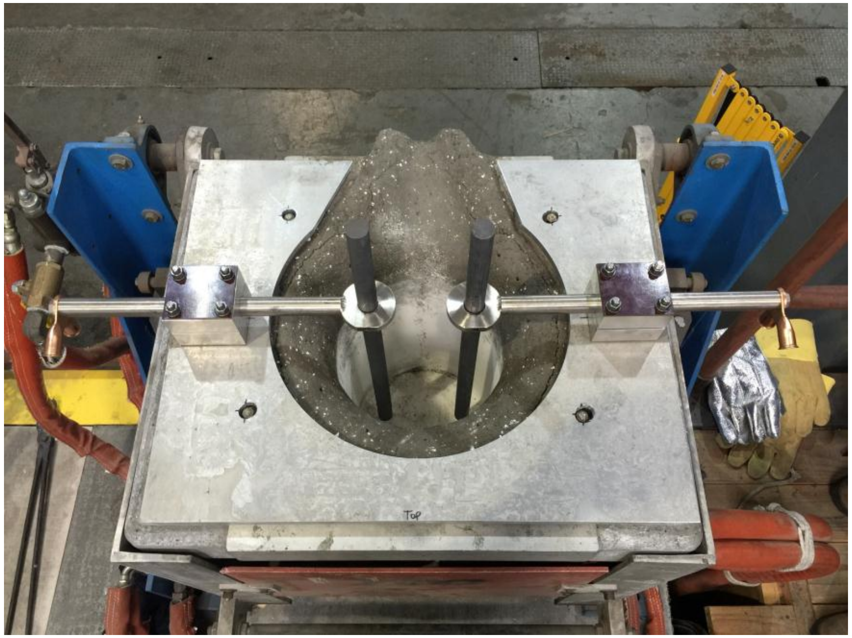
Evaluation of Existing Materials

- To-date, it has been difficult to obtain samples of the existing covetic materials which reinforces their critical lack of availability.
    - Others within the DOE program are trying to locate existing covetic alloys
- Uncertain if we will meet our milestone since it is dependent on the availability of outside material.
- Critical evaluation will be made on material produced at NETL via replication and refinement of the existing IM process.

Results and Accomplishments

Refinement of Existing Melt Practice

- Modified NETL's 300 pound air induction furnace to replicate conventional covetic melt practice.
  - Power supply (1000A) purchased and installed.
  - Dedicated induction power supply has been run through shakedown and power has been applied to the coils.
  - Current lead fixtures have been built.



Results and Accomplishments

Refinement of Existing Melt Practice

- Safety permit also modified for operations. Initial inspection 12May2015
- Expecting to make our first melts by June 2015.

Results and Accomplishments

Alternative Melt Processing

- While working on the SARS process and procurement and installation of equipment for making covetic materials via the established method, NETL has explored alternative methods.
- 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 but rather present some of our early findings.

Results and Accomplishments

Alternative Melt Processing

- Alternative melt trials produced material.

This melt had problems with porosity which is often observed in covetic alloys

This melt produced a solid ingot (116lb) and was subsequently hot worked in 20-30lb sections.

Results and Accomplishments

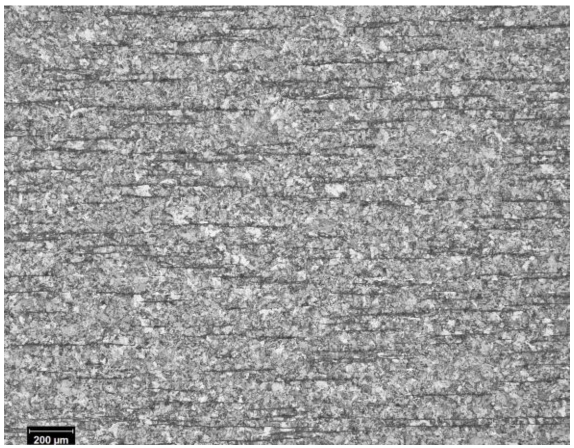
Alternative Melt Processing

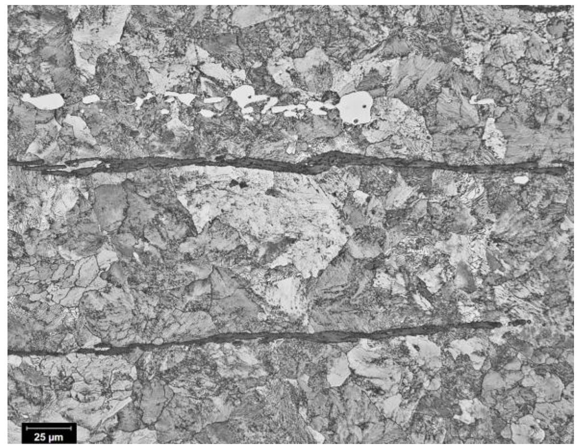
- Several sections were hot worked into plate by forging and rolling.
- This material had good hot work characteristics.

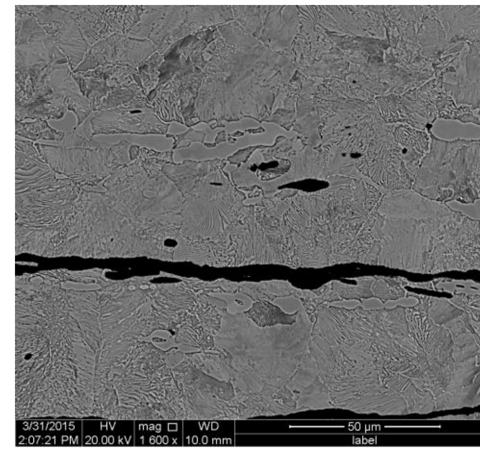
Results and Accomplishments

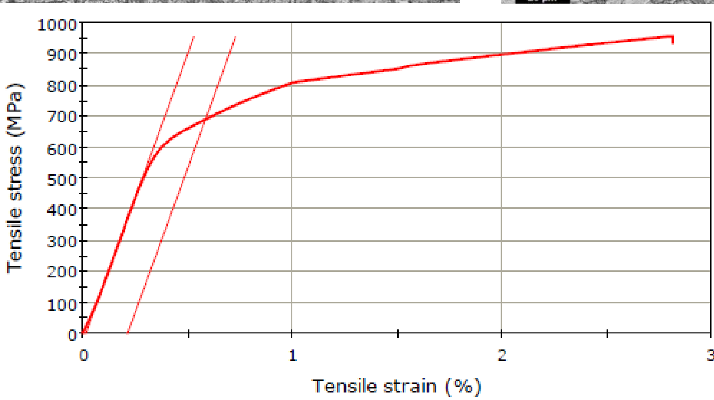
Alternative Melt Processing

- Microstructure: α-Fe with some Fe_3C
- TEM analysis is ongoing to determine the level of covetic carbon
- Tensile ductility is improved by post rolling heat treatment.

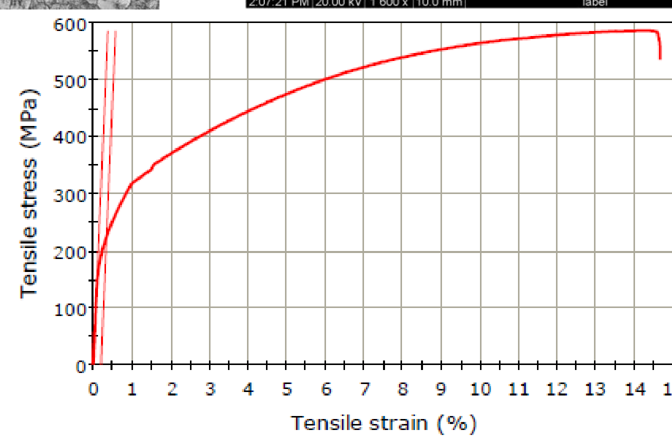








As-rolled



Heat treated

Next Steps

- We anticipate our covetic IM station to be fully permitted/operational by summer.
- The first shake down melts should produce material for hot working.
- Hot worked material will be evaluated at NETL and made available to ORNL and ANL.