U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Wear-Resistant NanoComposite Stainless Steel Coatings and Bits for Geothermal Drilling

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Oak Ridge National Laboratory

High Temperature Tools and Sensors,
Down-hole Pumps and Drilling

Overview Slide

Project Goal: To develop ultra-hard and wear resistant nanocomposite stainless steel coatings and bulk components for geothermal drilling applications

- Partners
  - Oak Ridge National Laboratory: Bill Peter (PI); Peter Blau (Tribology); Ryan Dehoff (Laser Processing); Yuki Yamamoto (Metallography); Kevin Harper; Wei Chen; and Andrew Klarner
  - Carpenter Powder Products (In-Kind Support, Purchase Order for Materials)
  - Identifying Future Collaborates/End Users for Next Phase
- Timeline: 2 Years
  - Project Start Date: 10/09
  - Project End Date: 9/11
  - Percent Tasks Completed: 25%
- Budget: Total project funding: $1085K (FY09 690K, FY10 535K)
  - Percent Spent to Date: 15%
- Barrier: Barrier C as per the Multi Year RD&D Plan: EGS Well Construction Capability – The inability to drill and complete wells meeting EGS requirements (high temperature, high flow rate, low cost) results in a greater risk of impairing production or even losing wells when drilling.
  - Suitable Drill Bits and Alternative Drilling Methods- Drill Bits

Research Impact

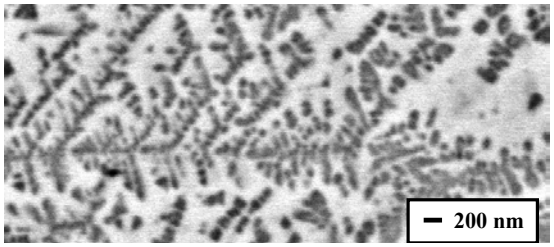
- Current state of the art geothermal drilling technologies are “borrowed” from the oil and gas industry
  - Different environments encountered during drilling of geothermal wells
  - Rock is typically much harder, higher temperatures are encountered during drilling, exposure to harsh chemical environments (bromides, chlorides, etc.)
- Development of new materials specifically designed to increase life of roller cone bits, poly-crystalline diamond bits, and other drilling heads will lead to:
  - Increased drilling rates and decrease down time
  - Decrease costs and expand possible site locations
  - Previous studies have shown doubling lifetime of bits and penetration rate would decrease overall well costs by 15%
- Corrosion/wear resistant steels developed in this project will optimize hardness versus fracture toughness for geothermal drilling
- Potential savings in tool costs (up to 1/2 cost of WC-Co)

Roller Cone Bit

Source: http://en.wikipedia.org/wiki/Roller_cone_bit

Technical Approach

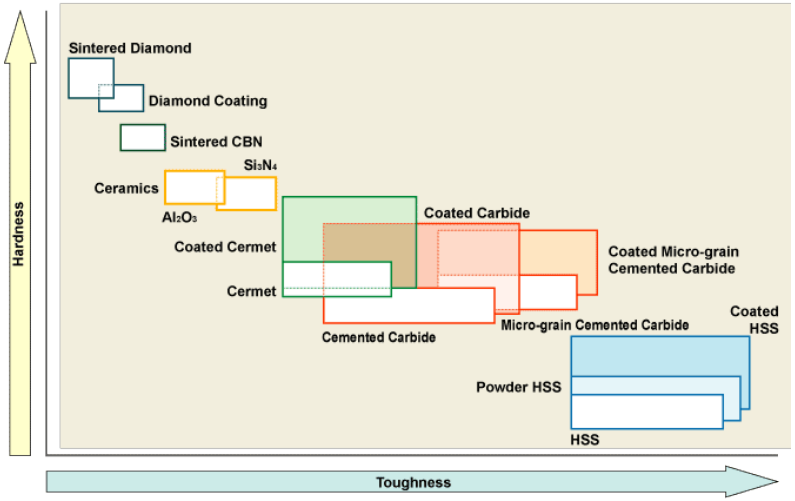
ORNL and collaborators have developed a method for producing amorphous or nanocrystalline metal powder with extremely high quantities of carbon and boron not possible through conventional processing



Electron image of "in-situ" nanocrystalline dendritic growth in devitrified Fe-based coating from amorphous powder

Project Focus:

- Develop new super-saturated stainless steel alloy powders
- Develop laser and bulk consolidation processing methods to "dial-in" desired microstructures for optimal geothermal properties (hardness versus toughness)
- Evaluate the microstructure, corrosion resistance and mechanical behavior of coatings and bulk components fabricated with this composition to compare with current steels, WC-Co, and poly-crystalline diamond
- Development of new laboratory test methods to simulate harsh environments associated with geothermal drilling operations



Toughness Versus Hardness for Cutting Materials
Source: http://www.mitsubishicarbide.net/mmus/en/product/technical_information/information/sessaku.html

Project Milestones, Outcomes, and Deliverables

- Milestones:
  - Milestone 1: ORNL will have performed wear tests using abrasive wear loop apparatus, salt fog tests for corrosion, and fracture toughness/impact tests to compare coatings and bulk samples with H13 steel, 316 stainless steel, and WC/20% Co. Completion Date: 12/30/10
  - Milestone 2: ORNL will develop, validate and create baseline data using a unique testing apparatus for simulating geothermal conditions. Samples of the optimized coating and bulk samples will be tested. Completion Date: 6/30/11
- Performance Outcomes and Measures:
  - The coatings/bulk samples must have equal or better salt fog test results than the 316 stainless steel, equal or better abrasive wear test results than H13 steel, and equal or better fracture toughness results than WC/20%Co. Completion Date: 6/30/11
- Deliverables:
  - A final project report containing metallurgical, mechanical, laboratory tribology data, and corrosion results will be provided. Completion Date: 9/15/11
  - Coated Component. Completion Date: 9/15/11

Project Management

- Management Plan
  - Bimonthly meeting/teleconference updates
  - Monthly Reports, Quarterly Reports, Annual Report
- Schedule (FY10-FY11)

Task:	FY 10 Qtr 1	FY10 Qtr 2	FY10 Qtr 3	FY10 Qtr 4	FY 11 Qtr 1	FY11 Qtr 2	FY11 Qtr 3	FY11 Qtr 4
I.1. Fabrication of Amorphous Metal Powders and Laser Coating	←	—	—	—	—	→		
I.2. Characterization and Testing of Corrosion Resistance & Hardness			←	—	—	→		
2.1 Development of New Testing Apparatus to Simulate Geothermal Drilling Conditions		←	—	—	→			
2.2 Fabrication and Lab Testing of Coatings and Bits Against Different Rock Types					←	—	—	→

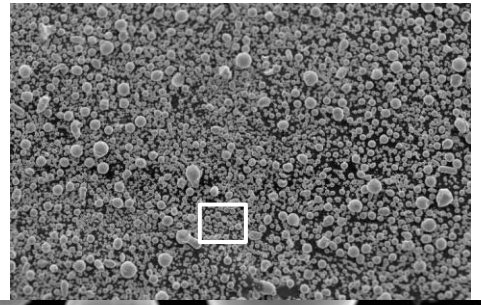
- Leveraging: R&D sponsored by EERE-ITP, OCWRM-Yucca Mountain, and DARPA SAM Projects

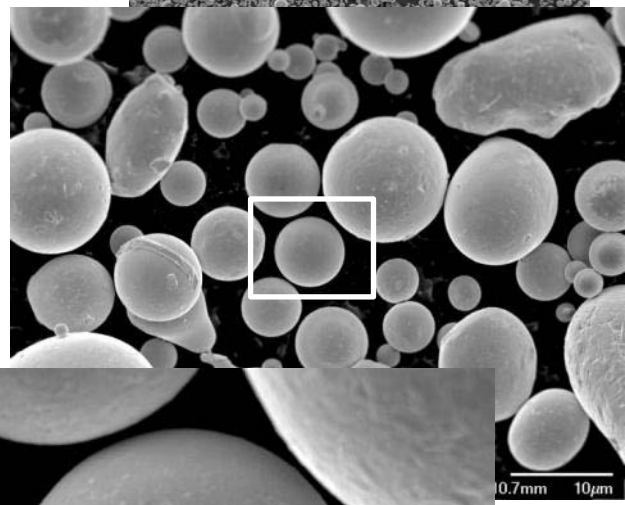
Year 1 Tasks: Current R&D

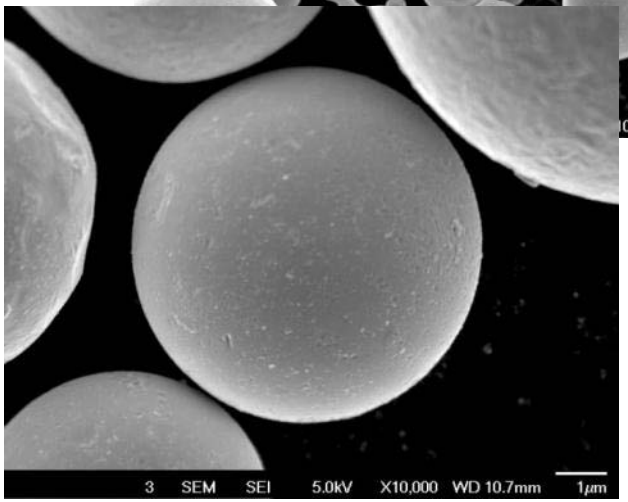
- Task I.1: Fabrication of Amorphous metal powders and laser coatings
    - Powder production and characterization:
        - Morphology, size distribution, chemistry, and microstructure
    - Laser Cladding and Sample Fabrication:
        - Parametric Study of processing parameters
        - Bulk samples produced by hot pressing and other practices
- Task I.2: Characterization and Testing of Corrosion Resistance and Hardness
    - Microstructure analysis and Hardness
        - Both coating material and bulk samples
    - Wear Properties
        - Abrasive loop wear testing
    - Corrosion Tests
        - Standard salt fog and immersion tests

Year 1 Progress: Powder Synthesis

- Powder Production:
  - Carpenter Powder Products:
    - Gas atomization of nearly 500 lbs. of new alloy powder
    - Powder chemistry met specification
    - Sieved into 2 sizes, +325 and -325 Mesh
- SEM Microstructural Analysis:
    - Small powder size distributions amorphous due to higher cooling rates
    - Larger powder size distribution is nanocrystalline
    - EDX shows powder chemistry is homogeneous throughout







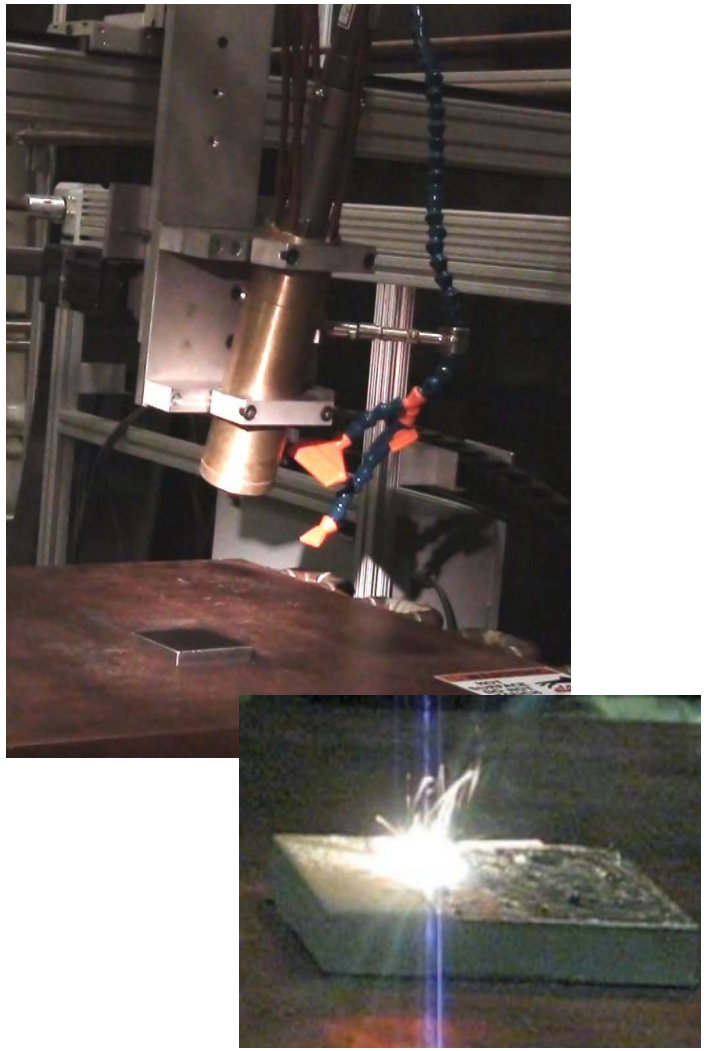
Year 1 Progress: Laser Fusing and Consolidation

Laser fusing of Coatings

- ORNL capabilities include a 4 kw Nd:YAG laser capable of fusing powder coatings to steel substrates
  - Extensive parametric study to evaluate optimal processing parameters (> 30 Samples)
  - Coatings were successfully fused to H13 steel substrates and demonstrate full metallurgical bonding
- New Capability: One of kind POM Direct Metal Deposition System (online June, 2010)

Bulk Consolidation of Powders:

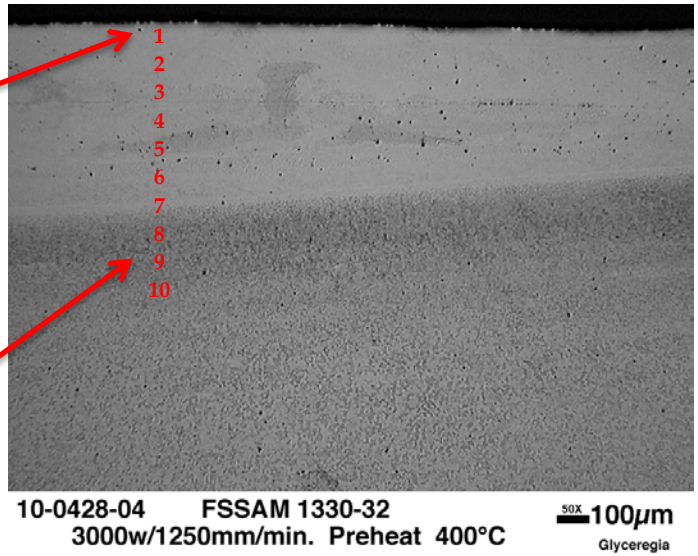
- Samples were produced using vacuum hot pressing and by Carpenter's Dynaforging Technology using various parameters

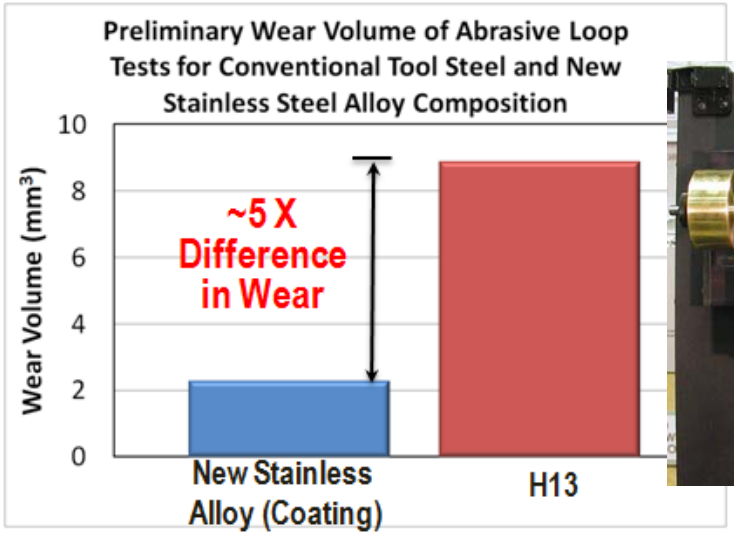


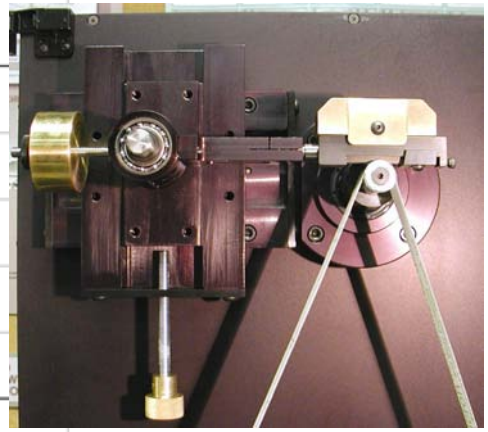
Year 1 Progress: Preliminary Mechanical Results

- Vickers Hardness:
  - Nearly 5X increase in hardness over substrate material
  - Gradual reduction in hardness due to convective mixing with substrate material
- Wear testing:
  - Preliminary coatings show increased wear resistance over H13
  - **Year 1 Milestone Achieved for Wear**

1	1088
2	808
3	821
4	735
5	739
6	402
7	244
8	203
9	205
10	211







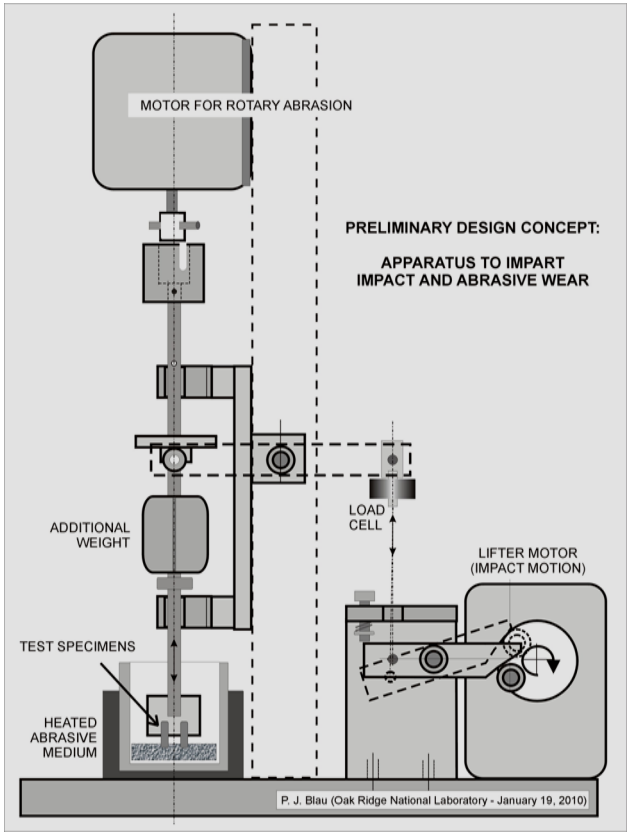
Abrasive Loop Test Apparatus/Setup

Future Directions

Year 1 Tasks: Corrosion Behavior and Fracture Toughness Properties

Year 2 Tasks: Laboratory Wear Performance

- Development of testing apparatus to simulate geothermal conditions
  - Independently-adjustable impact rate and abrasive sliding velocity
  - Ability to add thermal effects or aggressive electrolytes to the abrasive medium – sand or stones
  - Load cell provides real-time monitoring of impact cycles and normal load
- Laser coated samples and bulk consolidated samples will be tested using test apparatus to simulate down hole drilling environments



Year 2 Milestone: Coating and bulk components must have better performance than H13 and WC/20%Co respectively

Summary

Year 1:

- Successfully produced amorphous/nanocrystalline powders
- Fused powders as coatings and bulk consolidated into components
- Coatings show Vickers hardness of nearly 1100 and better wear resistance than H13. Year 1 Milestone Achieved for Wear
- Corrosion testing is currently being performed
  - Preliminary results indicate corrosion milestone will be met
- Progress on testing apparatus is ahead of schedule

Project Summary:

- Pathway to the development of a new low cost material suitable for geothermal applications
- If successful, material could demonstrate improved mechanical properties for increased drilling rates, increased lifetime, decreased down time, and decreased overall well costs.