Department of Energy Phase II STTR "Superalloy MMC Components For Advanced Turbine Components"

- Advanced Powder Solutions, Inc (APS)
- Wayne State University
- Houston, Tx/ Detroit Michigan
- October 31, 2018

Dean Baker / Asit Biswas
713-856-8555

Dr. Guru Dhida

DOE
UTSRT
Oct 2018

Overview

Acknowledgment:
First Year Results for an STTR Phase II Funded by DOE under Grant# DE-SC0015743
Program Manager : Patcharin (Rin) Burke of NETL

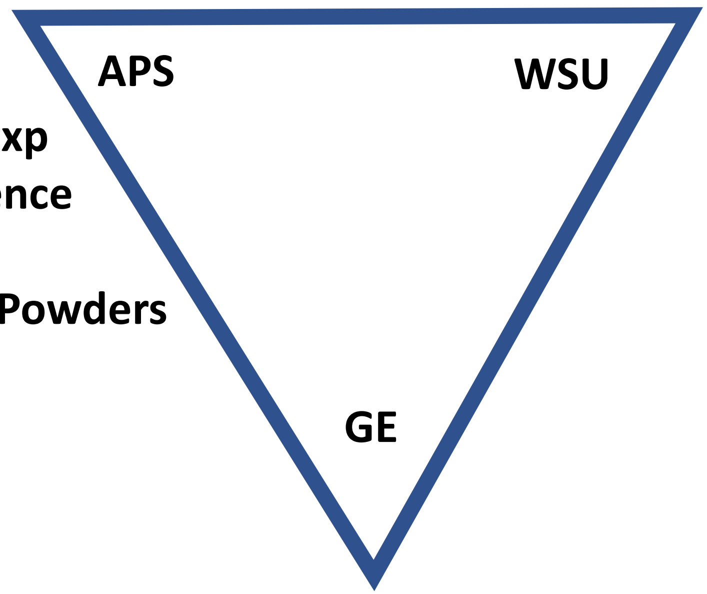
TEAM
GOALS/Benefit
Technology
REQUIREMENTS/COMMERCIALIZATION
Tasks
Results
Property/Structure
Examples

Background-APS/WSU
Contact info/other

Combination of Expertise

Advanced Powder Solutions Inc.
Houston, Tx
Dean Baker, GM
Asit Biswas, R&D Mgr

70 plus yrs materials Exp
30+ years CVD Experience
CVD FB Of Powders
Several Programs AM Powders
with WSU, PSU,others
(Al,Mg,Ni,W,Cu,etc…)



Wayne State University
Detroit, Michigan
Dr. Guru Dinda

14 Years AM Experience
DMLS with Environmental
Control, Tubes, Modeling,
Characterization
Materials- Ni, Ti, Al,Mg

END USER: General Electric Spartanburg S.C.
Srikanth Kottilingam Ph.D
Consulting Engineer,*MPE*
Design, Analysis, AM Processing
End User Modified Processing Rene 108

Others:
DOD Rockets
Hypersonics
Engines

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PROGAM GOAL/Commercial BENEFIT

Advanced cycles, with steam temperatures up to 760°C, will increase the efficiency of coal-fired boilers from an average of 35% efficiency (current domestic fleet) to as **high as 48%** (HHV). This efficiency increase will enable coal-fired power plants to generate electricity at competitive rates while reducing CO2 and other fuel-related emissions by as much **as 20 to 25%.** Based on a 20-year breakeven consideration, assumed capacity factor of 80%, and coal cost of $1.42/GJ ($1.50/MMBTU), an ultrasupercritical plant can **be cost-competitive** even if the total plant capital cost is 12 to 15% more than a comparable-scale facility built using conventional subcritical boiler and cycle designs.(GE)

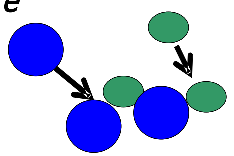
Materials **Goals**-Increase temp **100 C** - improved efficiency
Lower CTE- less thermal shock
Controlled, Higher Thermal Conductivity- lower heat damage
SIMILAR **GOALS FOR DOE END <u>USERS</u> ENGINES/ROCKET Materials**

APS Technology- Encapsulated Powders

BETTER POWDERS MAKE BETTER PRODUCTS
POWDERS ENGINEERED AT THE ATOMIC LEVEL IMPROVE PERFORMANCE

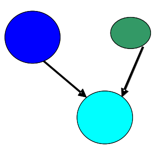
OLD WAY TO MIX AND BLEND

Core *ADDITIVES*



No even distribution
More Material Required
Greater Variability (+/ 1.0-2.0%)

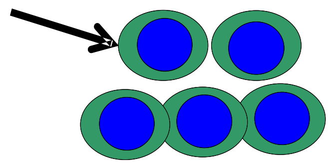
Alloy Melt



No Discrete layer control
No reaction Control

ADDITIVE(s) are coatings deposited Layer by layer particles

APS Coated Powders Technique
Nano to Micron coating layer



Process Enhancements

Finer Distribution & Better Control of Chemistry/Composition
This ALLOWS greater REACTION CONTROL as discrete layers
Ceramics Coated with Metal layers are ductile like Metals
Tailor Properties into the Powder that result in Product Properties
New Multifunctional Materials are easily and inexpensively created
Large Scale processing available -
Variability/Repeatability as low as +/- 0.06 wt%

Product Control: **Lower Cost, Mass control, Strength, Modulus, Shielding, Corrosion, Thermal, Mechanical, and electrical properties to name a few**

VALUE PROPOSITION SPECIFIC DOE PHASE II Enhanced Capability

1) 100 C Increase Max Temp
2) Higher Thermal Conductivity
3) Lower CTE
4) Multifunctional (combined) Properties
5) Improved Composition Control

RESULTS:
Improved Efficiency/Power
Higher Temps
Better Repeatability
Lower Costs for Power Generation/ Operation
Lower costs for maintenance

Powder- control, size, shape, flowability, reactions

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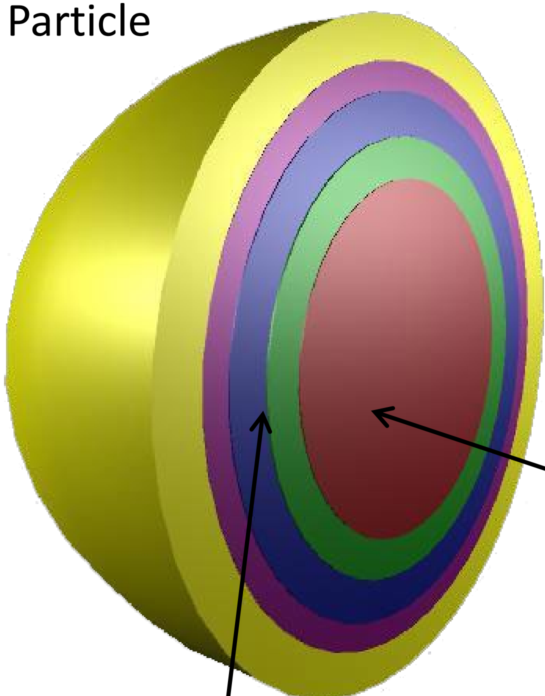
PERFORMANCE REQUIRED?

Case in Point- For high temp shroud conditions- goal increase strength, fatigue, reduce weight, modify CTE, thermal properties-for examples

Sectioned Powder Particle



Our powders are constructed by starting with a base (or core particle) and coating it with another element or composition- creating an "Onion" like layered structure. It is these designed layers, their composition, thickness and order deposited that create the reaction, the control and the performance. One can create the same exact composition using a different sequence of layers, and have performance variations.

Core or Base Particle = Metal, Ceramic Hollow Sphere, Diamond, Polymer, etc....

Core- Ex Alpha Add 5. AM DE process- High Temp Tensile, Thermal Conductivity, Lower CTE, Lower Mass

Results= when compared to wrought product.
800 C Ult Tensile=+25%, Density= - 8.0%
CTE = -10 %&, Conductivity= + 60 %

Outer Layers- 3-Metal transition to Haynes 282

PROGRAM OBJECTIVES

The specific Phase II Program objectives for the program are as follows:

1) **Evaluate and Optimize alloy (Haynes 282 and Rene 108 based alloys and their Modifications-12 systems) composition, coated ceramic additive and heat treat process with the powder (at least 10 modifications) using latest GE information and powder compositions**
2) **Determine which two AM processes (GE Fusion, WSU Direct Energy) to use for optimization.**
3) **Downselect the AM processes and fabricate more coupons for repeatability and characterization testing**
4) **For the down selected process fabricate full-scale parts for testing**
5) **Generate as much design allowable data as possible for end users with the funding available.**
6) **Perform component demonstration testing to increase TRL for the material.**
7) **Evaluate other powder compositions and consolidation techniques to achieve the best results for commercialization.**

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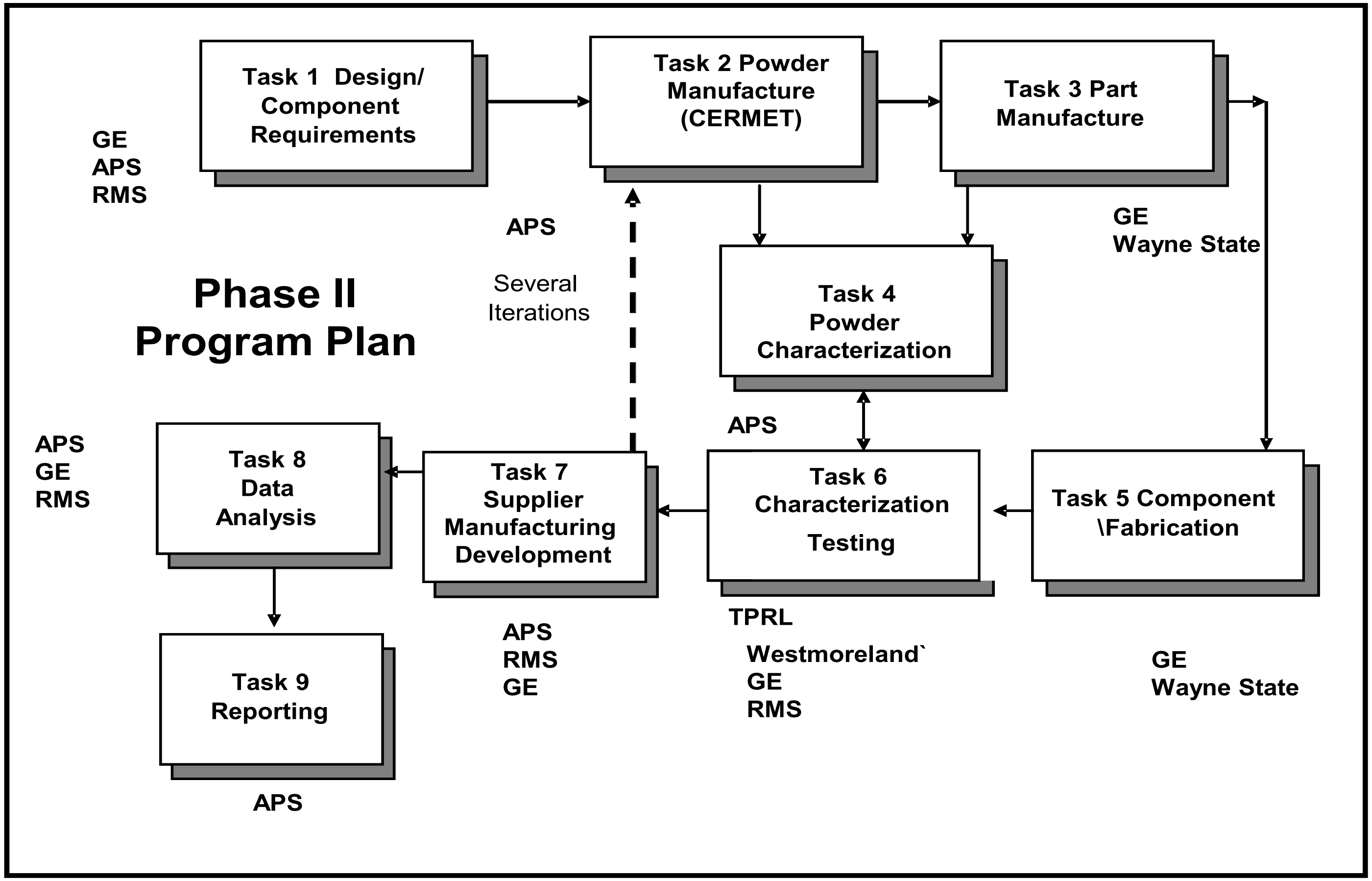
Program Task Overview



APS/WSU/GE .

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POWDER COMPOSITIONS EVALUATED

WSU Original Six different alloy systems- Haynes 282- WSU to consolidate-

- modify **Metal-** **COAT THE METAL MATRIX**
- **MODIFY POWDER 4 TYPES**
- **Change additive 5 TYPES**

  1,2,5,10,20 Vol%

  coating Type

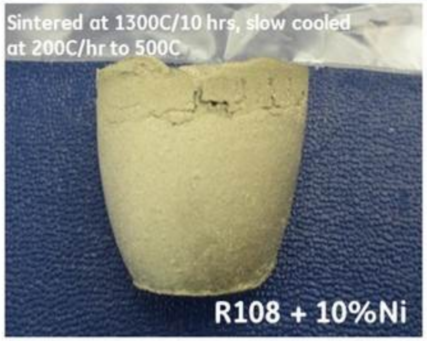
The GE systems to be investigated are:

GE Modified Rene 108 Control

- **Modify Metal- COAT THE METAL MATRIX**
  - **Oxide**
- **MODIFY POWDER 4 TYPES**
- **Change additive 5 TYPES**

  1,2,5,10,20 Vol%

GE AM SINTERING PROCESSING



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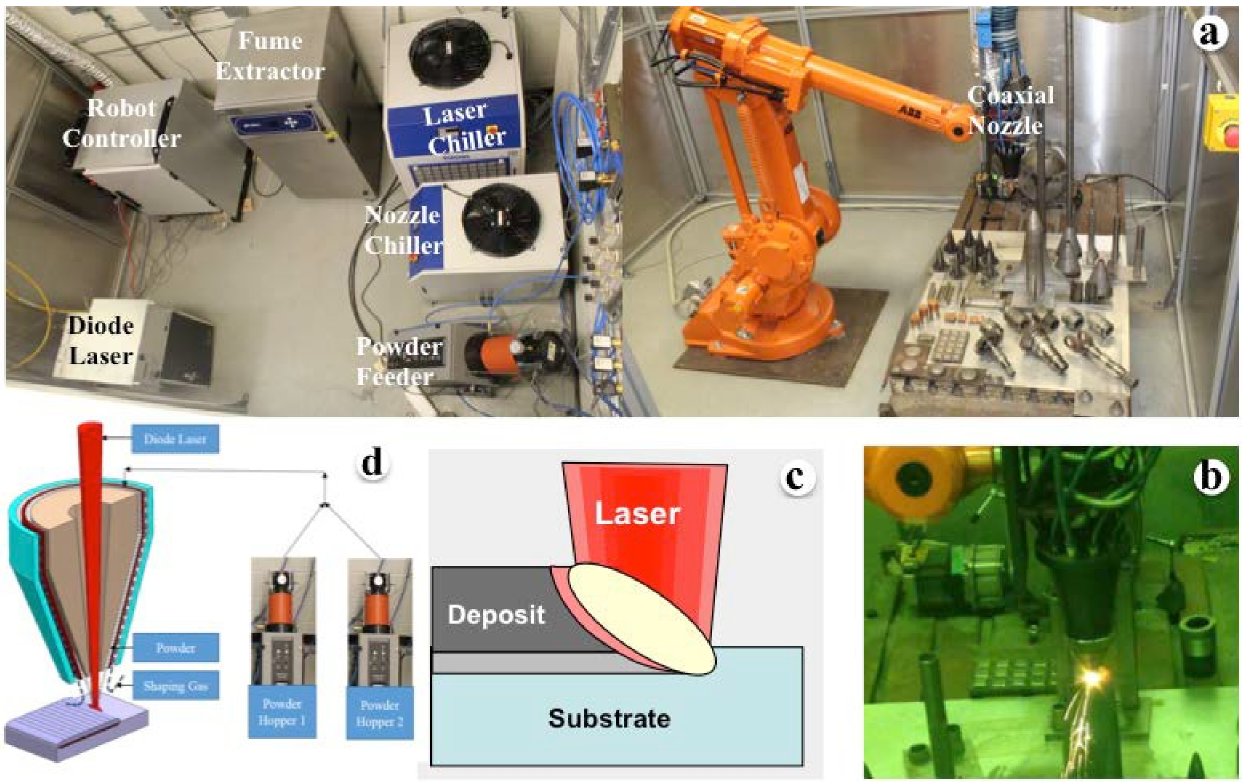
WSU AM Process Equipment



COMMERCIALIZATION OBJECTIVES

The secondary COMMERCIALIZATION objectives for the program are as follows:

1) **Manufacture Realistic Parts- first at WSU- in progress for the Stationary Shroud**
2) **Looking at Designs- specifically GE at this time- to analyze the effect of increasing the shroud on the entire system, identifying any roadblocks to commercialization that may occur though main goals are met. Begin discussions with additional customer end users.**
3) **This is an STTR, WSU has started looking at "options" for commercialization**
4) **For the down selected process fabricate full-scale parts for testing**
5) **Perform component demonstration testing to increase TRL for the material with external partners in DOD.**

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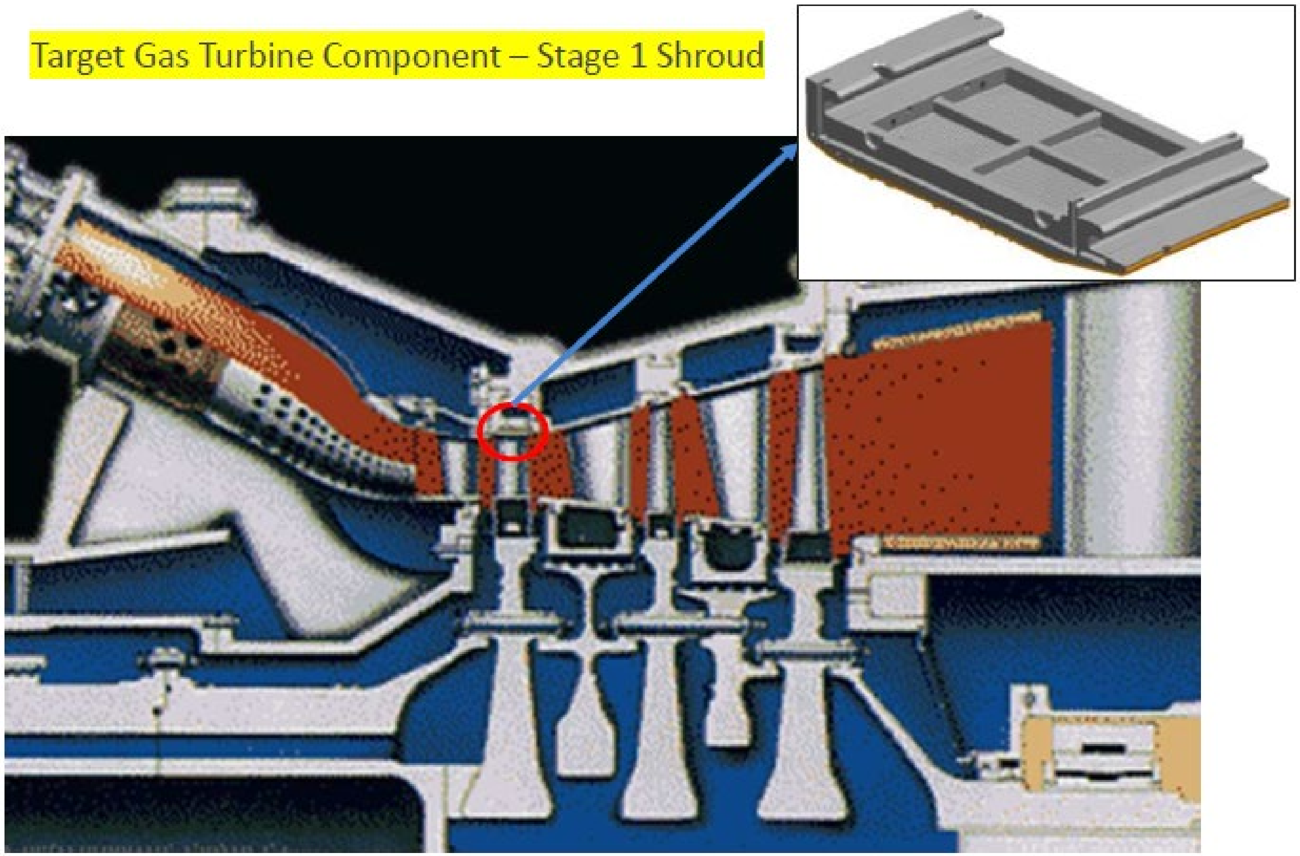
Specific Parts of Interest in Phase III

Target Gas Turbine Component – Stage 1 Shroud



PROGRAM REQUIREMENTS FOR COMMERCIALIZATION

Mechanical Property Requirements:

Property	Temp	Average
Yield Strength	RT	105Ksi
Yield Strength	1800F	51Ksi
Tensile Strength	RT	132Ksi
Tensile Strength	1800	76Ksi
Creep	1800F	370hrs @ 20Ksi for 2% Strain
Low Cycle Fatigue	1800F	350 cycles @0.6% strain, A Ratio=-1
Fatigue Crack Growth Rate	1600F	0.0004 inch/cycle @25Ksi$\sqrt{in}$, R=0.1

- ❑ Creep Target for this Effort: >120% of baseline

Patterned after GE Mod Rene 108

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Commercialization Stage

Requirements

Basic Testing Coupon Level

Tensile → Creep → LCF → Fatigue Crack Growth

Rt , 800 C, *
900 C, 200 C, 600 C)

1600-40 ksi,200 hrs*
1800-20 ksi,400 hrs

Part Manufacturing

Actual Part → Lab Scale Test → Full Scale Test

Field Trial

Mechanical/Thermal Property's

Microstructure (ex)

WSU AM Process Results

Haynes 282 (AM Direct Energy)

(988 C 4 Hours, Water Quench)

Property	282 Reported	Pure Control	10% Add 3	20% Add 3	10% Add 5	20% Add 5
Density (g./cm3)	8.3	8.27	7.5	7.00	7.7	7.3
Tensile Strength Failure RT (800 C)	160-164 [1103-1131MPa] (114-120) [786-827MPa]	168-172 [1158-1186 Mpa] (135-140) [931-965 Mpa]	155-158[1069-1090MPa] (140-142)[965-979MPa]	160-162 [1103-1117MPa] (145-150) [1000-1035MPa]	193-197 [1331-1358MPa] (148-152) [1020-1048MPa]	194-197 [1338-1359MPa] (150-155) [1034-1069MPa]
Specific strength MPa.cm3/g	132.89-136.27	140.02-143.41	142.53-145.33	157.57-159.58	172.86-176.36	183.29-186.14
ElongationDuctility (%)	4%	3	1-2	.6-1.0	2-3	3-5
Compression Failure yield (ksi)	155 [1069 Mpa]	158 [1089MPa]	152 [1048MPa]	158 [1089MPa]	146 [1007 Mpa]	160 [1103MPa]
CTE (ppm/C) (100-800 c)	12.1-15.5	13.2-16.8	11.5-14.0	9.5-13.2	11.3-15.9	10.4-12.0
Thermal Conductivity (W/mk) (800 C)	11 (26)	12.2 (28)	9.0 (24)	4.0 (16)	26-27 (42)	38-39 (49)

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COMPARISON OF SPS ALLOY PROPERTIES

Property	282 Reported	Pure Control	20% Add 5	10% Add 3	20% Add 3	ODS PM 1000	ODS PM 2000
Density (g./cm3)	8.3	8.27	7.00	7.7	7.3	8.3	7.18
Tensile Strength Failure RT (800 C)	160-164 [1103-1130MPa] (114-120) [786-828 Mpa]	168-172 [1158-1186MPa] 135-140 [931-966MPa]	160-162 [1103-1117MPa] (145-150) [1000MPa-1035MPa]	193-197 [1331-1358MPa) (148-152) [1021-1049MPa]	194-197 [1338-1359MPa] (150-155) [1034-1069MPa]	134 [924MPa] (34) [235 MPa	104 [717MPa] (18) [124MPa]
Specific strength MPa.cm3/g	132.89-136.14	140.02-143.41	157.57-159.57	172.86-176.36	183.29-186.16	111.33	99.86
Elongation Ductility (%)	4%	3	.6-1.0	2-3	3-5	10	12
Compression Failure yield (ksi)	155 [1069MPa]	158 [1090MPa]	158 [1090MPa]	146 [1007 MPa	160 [1103MPa]	NA	NA
CTE (ppm/C) (100-800 c)	12.1-15.5	13.2-16.8	9.5-13.2	11.3-15.9	10.4-12.0	11.5-14.5	10.7-15
Thermal Conductivity (W/mk) (800 C)	11 (26)	12.2 (28)	4.0 (16)	26-27 (42)	38-39 (49)	12 (37.0)	10.9 (22)

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COMPARISON OF ODS VS 20 % Ceramic Loading

Property	20% Add3	ODS PM 1000	Add3 Comparison (%)	20% ADD5	ODS PM 1000	ADD5 Comparison (%)
Density (g./cm3)	7.00	8.3	-15.6	7.3	8.3	-12.0
Tensile Strength Failure RT (800 C)	160-162 [1103-1117MPa] (145-150) [1000MPa-1035MPa]	134 [924MPa] (34) [235 MPa	20.1 323.3	194-197 [1338-1359MPa] (150-155) [1034-1069MPa]	134 [924 MPa] (34) [235 MPa	44.0 347
Specific strength MPa.cm3/g	157.57-159.57	111.33	42.3	183.29-186.16	111.33	66
Elongation Ductility (%)	.6-1.0	10	-90	3-5	10	-60
Compression Yield (ksi)	158 [1090MPa]	NA	NA	160 [1103MPa]	NA	NA
CTE (ppm/C) (100-800 c)	9.5-13.2	11.5-14.5	-16.6	10.4-12.0	11.5-14.5	- 8.0
Thermal Conductivity (W/mk) (800 C)	4.0 (16)	12 (37.0)	-66%	38-39 (49)	12 (37.0)	216

COMPARISON OF HAYNES 282 VS OTHER ALLOYS

Property	282 Reported	Pure Control	WSU 100	WSU 150	282 + 2% Add5	282+ 1% Add5	ODS PM 2000
Density (g./cm3)	8.3	8.27	8.3	8.3	8.1	8.1	7.18
Tensile Strength Failure RT (800 C)	160-164 [1103-1130MPa] (114-120) [786-828 Mpa]	168-172 [1158-1186MPa] 135-140 [931-966MPa]	191 [1321 MPa] 136-145	198 [1366 MPa)	185 [1276MPa]	185 [1270 MPa]	104 [717MPa] (18) [124MPa]
Specific strength MPa.cm3/g	132.89-136.14	140.02-143.41	159.1	164.6	153.7	153.0	99.86
Elongation Ductility (%)	4%	3	20.0	11.8	5.8	10.1	12

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COMPARISON OF STRESS/STRAIN CURVES

282+
2% Add5

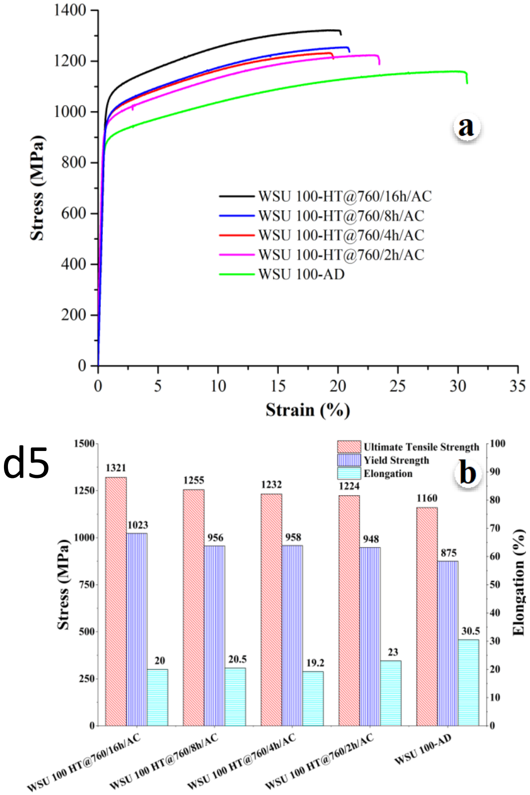

Figure : (a) Stress – strain curves of as-deposited and heat treated WSU 100 @760 °C/2h, 4h, 8h and 16h, and (b) bar graphs displaying the UTS, YS and elongation percentage of the stress strain curves.

WSU 100
And
150 alloys

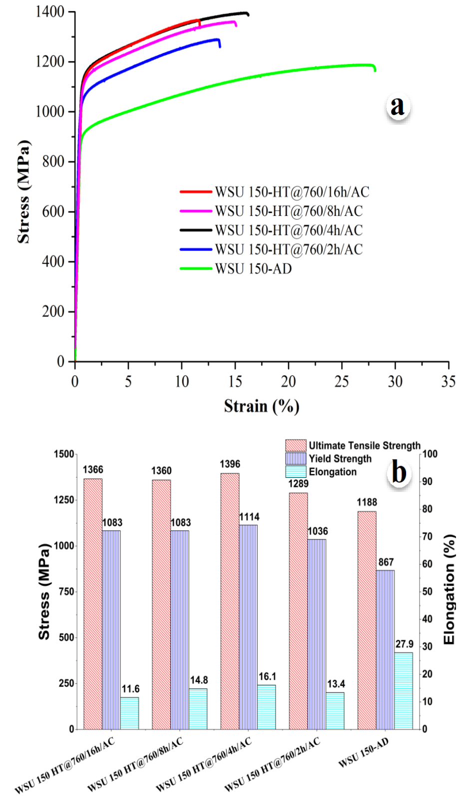

Figure: (a) Stress – strain curves of as-deposited and heat treated WSU 150 @760 °C/2h, 4h, 8h and 16h, and (b) bar graphs displaying the UTS, YS and elongation percentage of the stress strain curves

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Cross-section 282 + Add 5

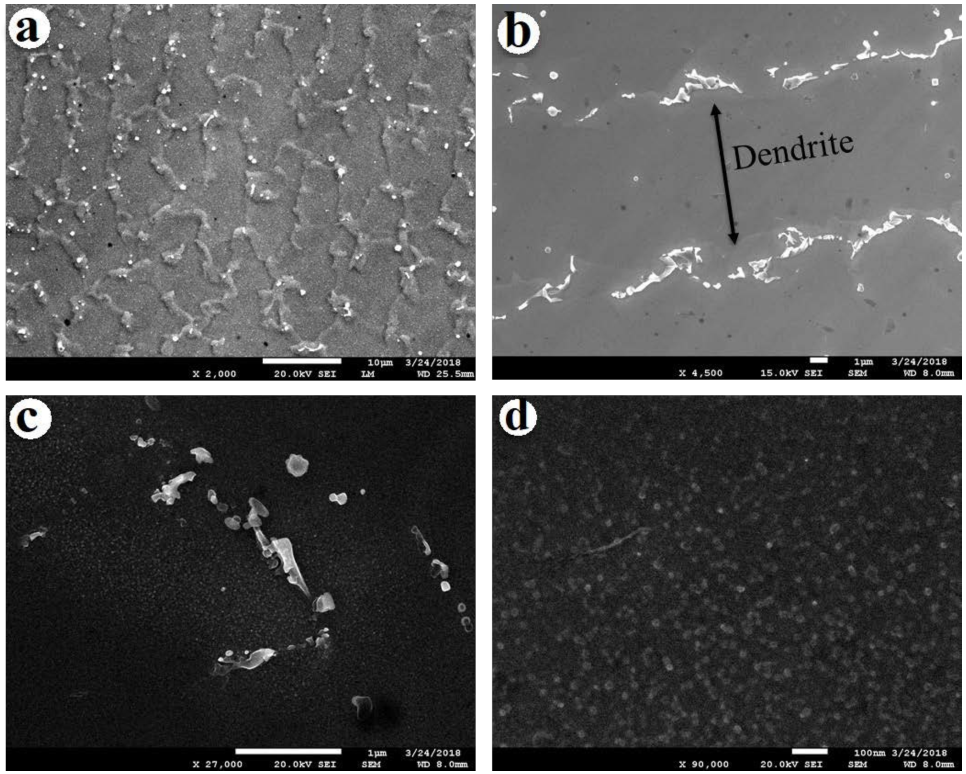

Figure (a) Low magnification SEM image of as-deposited Haynes 282 alloy along the vertical direction, (b) primary dendrite with bright carbide particles segregated in the interdendritic region, (c) high magnification image of the stable high temperature Mo and Ti rich MC carbides in the interdendritic region surrounded by the precipitation of γ′ only in the interdendritic region, and (d) the strengthening γ′ particles with an average size of 18 nm precipitated in the interdendritic region.

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QUESTIONS ??

BACKGROUND INFO

APS

WSU

PROGRAM CONTACTS

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APS Overview

•**Officers:**
–Dean Baker (General Manager)/ Asit Biswas(R&D Mgr)
34 Years Experience (LTV, GD, LMCO, Chromalloy, Tx A&M, etc)
32 Years Experience (APS, Powdermet, etc…)
•**C-Corp, •Founded: 2004, ISO 9002 (2014)**
–25 Employees (2 sales/Mgt, 16 Manufacturing, 3 engineering, 3 Office), 3 Distributors
- OVER $60 Million sales directly from SBIR developed technology

•**Facilities:**
•Texas- (Houston/Madisonville)-2 locations- (4 buildings) Powder Fabrication, Pressing, Thermal Spray, Machining (2017), Vertical Integration
- Oil and Gas, Aerospace, Medical, Electronics, Powders

•**Associations:**
•**Markets** – Oil and Gas, Aerospace, Electronics, Medical- Part/Powders

USAF
Phase I
Oct 2018

BACKGROUND MATERIALS

APS Additive Manufacturing Experience

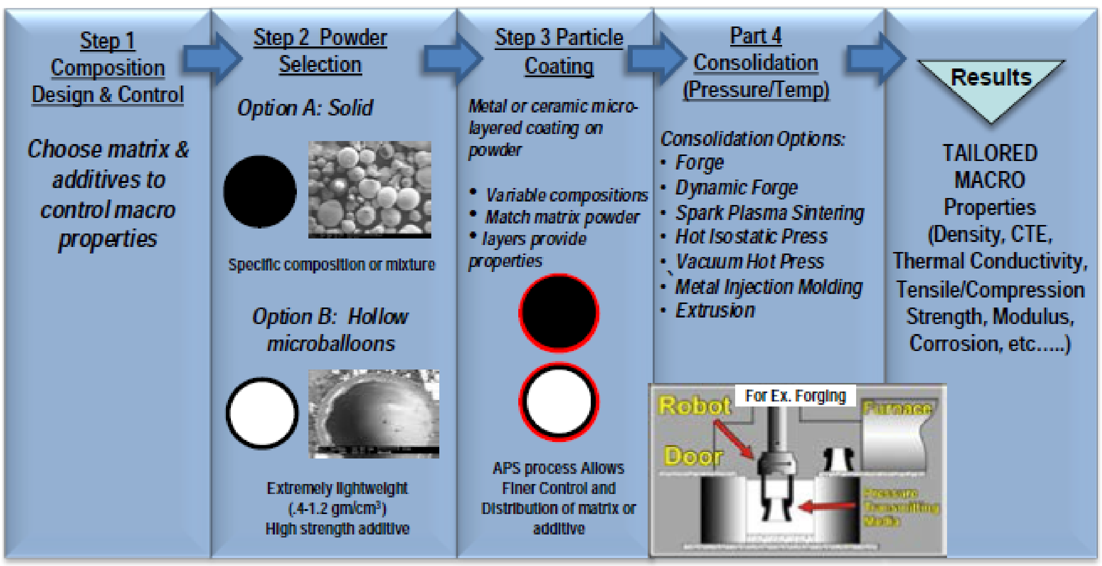
Matrix		
Nickel Based Tungsten Ti 6 Al 4 V Al 6061	SBIR- 2004-2007 UTSI, NASA UC Davis, LMCO RMS, NASA Huntsville	LENS ARCAM Direct Energy
Copper	US NAVY, Railgun Ga Tech, Univ of Texas	Graded Structures Carbides, Nitrides Wear , Melting
Al A 357	NRL, WSU, Replacement Higher Strength, PSU	EOS 280, from 38 to 52 ksi 12% Ductility
Al 7050	NRL, WSU, MOOG Wayne St, MITPSU	62 Ksi , 9 % Ductiilty
Mg. Mg/Al Lt Wt In var	DLA, WSU, MOOG Wayne St, MIT, Colo State U of Florida, RMS	High Mag (90 %) Content Be Replacement, 7000 Series Al Medical
Haynes 282/Rene 108	USAF, WSU, GE, ATK	Control Properties- Tensile at 800C 156 KSI, 7% Ductility (Haynes Cermet_
Lt Wt Nickel and Titanium	WSU, RMS, BOEING, LMCO Cal Nano, Kittyhawk, PMP	Compare 4 Process and Properties SPS, Forge, AM, HIP, Ni Alloy 4.9 gm/cm3 175 Ksi , 11% Ductility

Technical Approach

ADD CERAMIC POWDERS TO THE NICKEL BASED ALLOY TO PROVIDE HIGH TEMP STABILITY AND CONTROL OTHER PROPERTIES

Multilayer Nickel Based Coating Supplies Adhesion/Wettability

APS Four Step Micro Structure Layer Design/Build Approach Provides Lower Cost, Highly Tailorable Microstructures and Properties



Small modifications in processing of the initial powder manufacturing process enables entirely different materials and properties to be created using standard powder metallurgy consolidation equipment.

Wayne State University

Wayne State University is a public research university located in Detroit, Michigan. Founded in 1868, WSU consists of 13 schools and colleges offering nearly 350 programs to more than 27,000 graduate and undergraduate students. Wayne State University is Michigan's third-largest university, one of the 100 largest universities in the United States.

Significant Minority representation in Engineering graduate school.

Wayne State Overview

- Co-PI:
  - Dr. Guru Dinda, ME

13 Years Additive Manufacturing
U of Michigan 3 years, Focus Hope 5 years, 5 Years WSU
(Al, Steel, Mag, Ti64 , etc…)

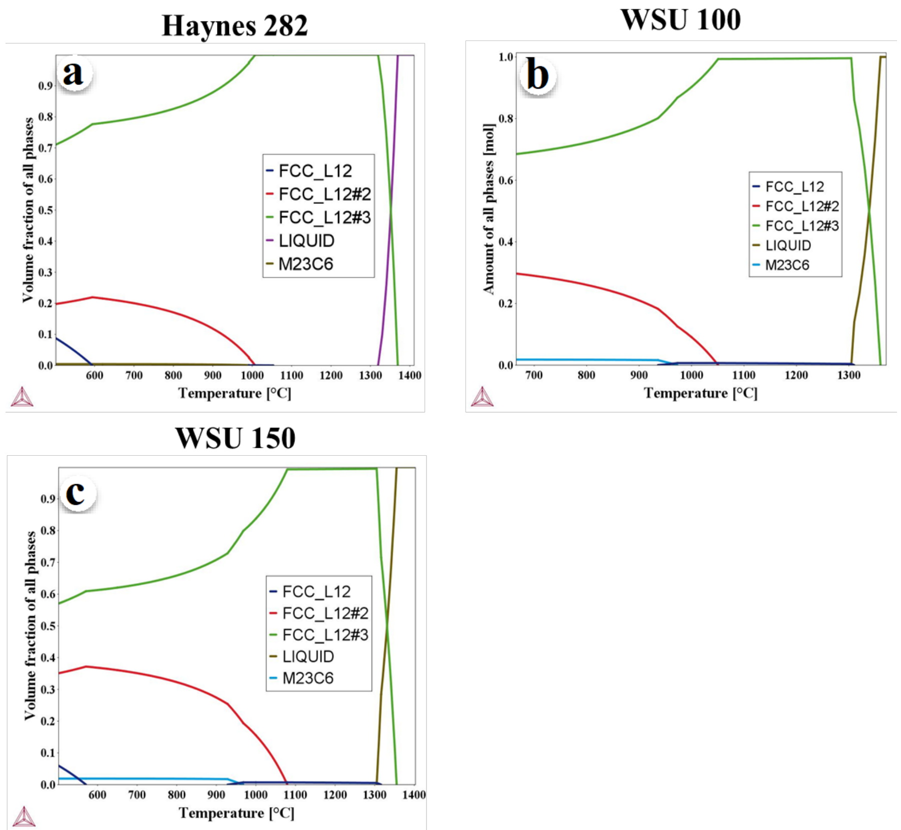
- WSU Founded:)
  - Engineering-Professors 130. (all perform funded research)
  - Research Revenue
- Facilities:

Engineering research Facilities

- Associations:
- APS , LMCO, GE, GM, Ford, etc….

AM HISTORY
In House AM equipment- Direct Energy Deposition base don Laser –-machine WSU designed/built – machine
Full Characterization in Dept Lab. – XRD, SEM, etc….
MTS 100 Kn Tensile Tester
FSW, Solid State Welding, CVR Plastic Deformation, Equiangular Extrusion, etc…

WSU Solidification Models



Calculated equilibrium volume fraction of phases in (a) Haynes 282, (b) WSU 100, and (c) WSU 150 alloys.