

From Waste Steel to Matériel: Additive Manufacturing Enabled Agile Manufacturing

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WPI

Project Team



Worcester Polytechnic Institute (WPI)

- 1) Sorting and characterization of waste
- 2) 3D printing test structures
- 3) Investment casting using 3D printed structures
- 4) Post process protocols

**Drs. Diran
Apelian, Brajendra
Mishra, Richard
Sisson, and
Jianyu Liang**



Army Research Labs (ARL)

- 1) Supply metal scrap representative of FOB
- 2) Technical data on mobile foundry
- 3) 3D printing of polymer patterns

**Drs. Brandon
McWilliams
and Jian Yu**

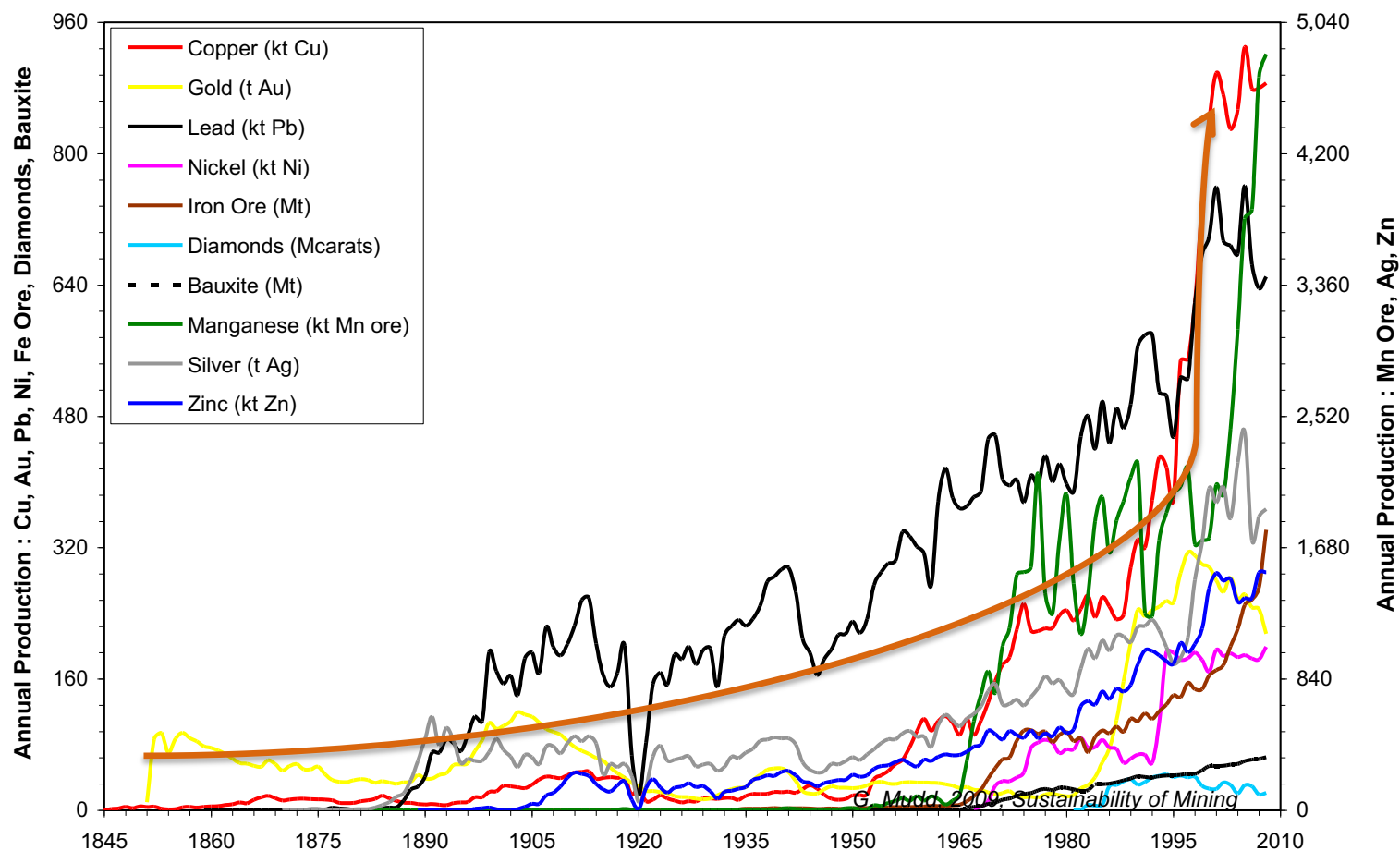


Energy Research Company (ERCo)

- 1) Develop LIBS probe for in situ real time composition analysis
- 2) Design testing procedure, calibration methods, and melt exposure requirements

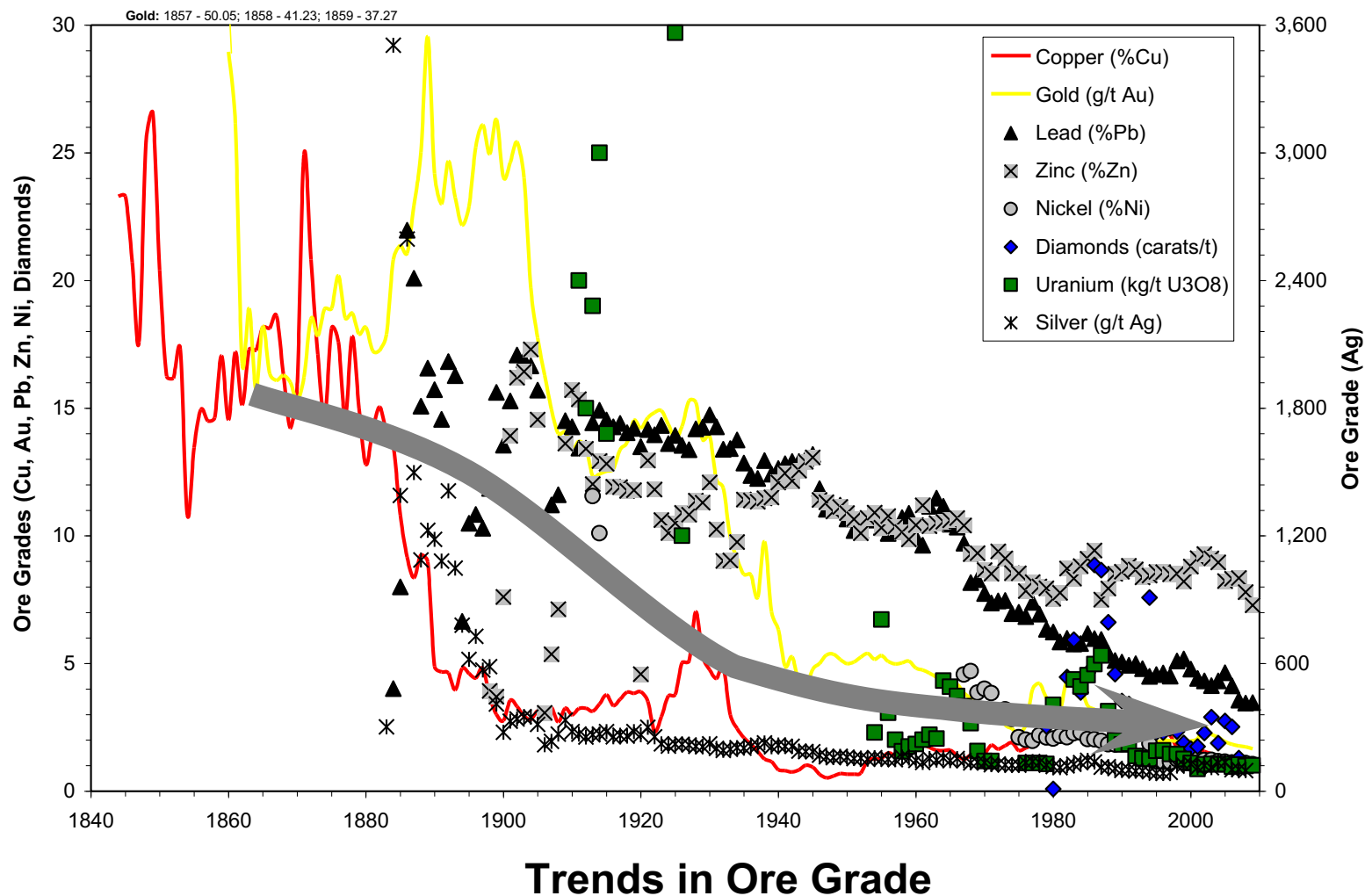
**Mr. Robert De
Saro and Mr.
Joe Craparo**

Background



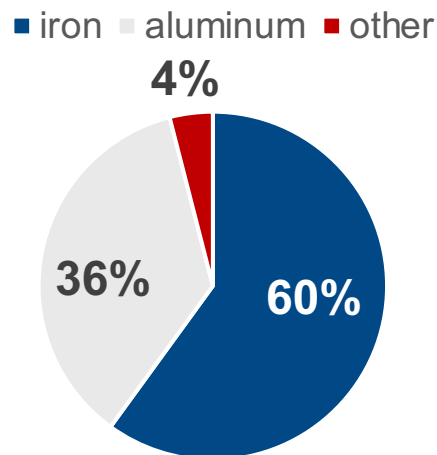
Metal Production Trends

Background



Problem Statement

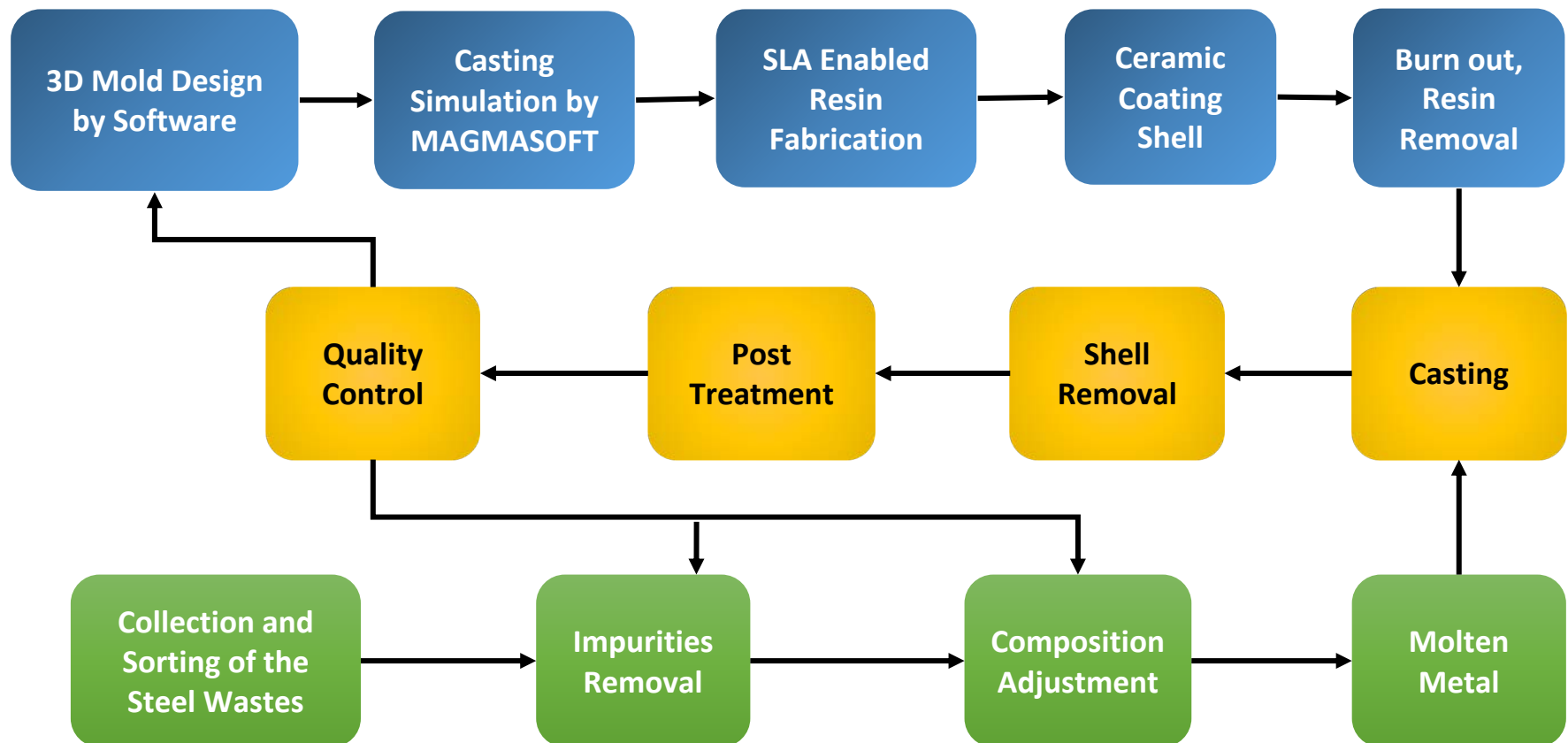
- Energy and time consuming.
- Need to develop a metal recycling process with **chemical composition control and monitoring**.
- Need a manufacturing process make high quality steel parts **directly from waste metal**.



Recommended breakdown of metal waste recipe at FOBs

Technical Approach

Proposed manufacturing process for ferrous wastes.



Path From Waste Metal to New Alloy



Waste material from ARL



Sorting & Blending



Melting & Pouring



As-cast ingots



Tensile bars machining



Characterization

Waste Metal Database & Composition

Identify

Waste metal Characterization

- Use OSE technology (Optical Emission Spectrometry) to identify waste alloy composition.
- Portable OES (Hitachi High-Tech PMI Master UV Touch) was selected to characterize waste metal chemical composition.
- Established a waste metal database. Visual and dimensional information, as well as chemical composition were recorded.



Waste metal Database

Metal Waste	Part Description	Weight (lb.)	Dimensions (inch)	Alloy Recognition
	Plate with partial rust and painted coating	4.02	9.00" x 8.50" x 2.25"	4340
	Block entirely covered in rust	15.69	6.00" x 6.00" x 5.75"	Non-Specified
	Brake Rotor entirely covered in rust	11.98	10.00" x 2.00"	Carbon Steel
	Small Round Stock partially covered in rust	0.28 (per piece)	1.125" x 2.00"	12L14

Waste Metal Blending Model

- Created a blending model for heat calculation and composition adjustment

Steel 1 Carbon Steel 45 ksi YS																		
				CE	DI	% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Ni	%Al	%Co	%Cu	%V	%Sn
	Recovery					0.9	0.95	0.95	1.0	1.0	0.97	0.99	0.99	1.0	1.0	1.0	1.0	1.0
	Target Composition	Aim	0.40	0.80														
		Min		0.60	0.15	0.40	0.50			0	0	0						
		Max	0.50	0.90	0.30	0.60	1.20	0.035	0.035	0.50	0.20	0.50						
	Heat Composition			0.43	0.89	0.147	0.506	0.768	0.021	0.013	0.190	0.054	0.343	0.015	0.005	0.180	0.009	0.011
	Heat Size (lb.)	70																
Waste Parts	Name	Remain	Added (lb.)	Fraction	Dimensions	% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Ni	%Al	%Co	%Cu	%V	%Sn
#3-35	Plate with Square Hole	45.400	54.600	0.780	27.75" x 15.125" x 1.0"	0.136	0.050	0.809	0.017	0.008	0.077	0.014	0.084	0.019	0.003	0.188		0.009
#4-15	Big Thread Barrel 5	32.780	10.000	0.143	4.5" x 24"	0.355	0.320	0.739	0.055	0.022	0.879	0.284	1.870		0.017	0.090	0.052	0.020
#3-32	Big L Beam	27.810	5.000	0.071	3.0" x 3.0" x 64.0"	0.087	0.270	0.972	0.002	0.048	0.123	0.037	0.189		0.009	0.284	0.022	0.015

The Use of ML Tool

Original Data Source

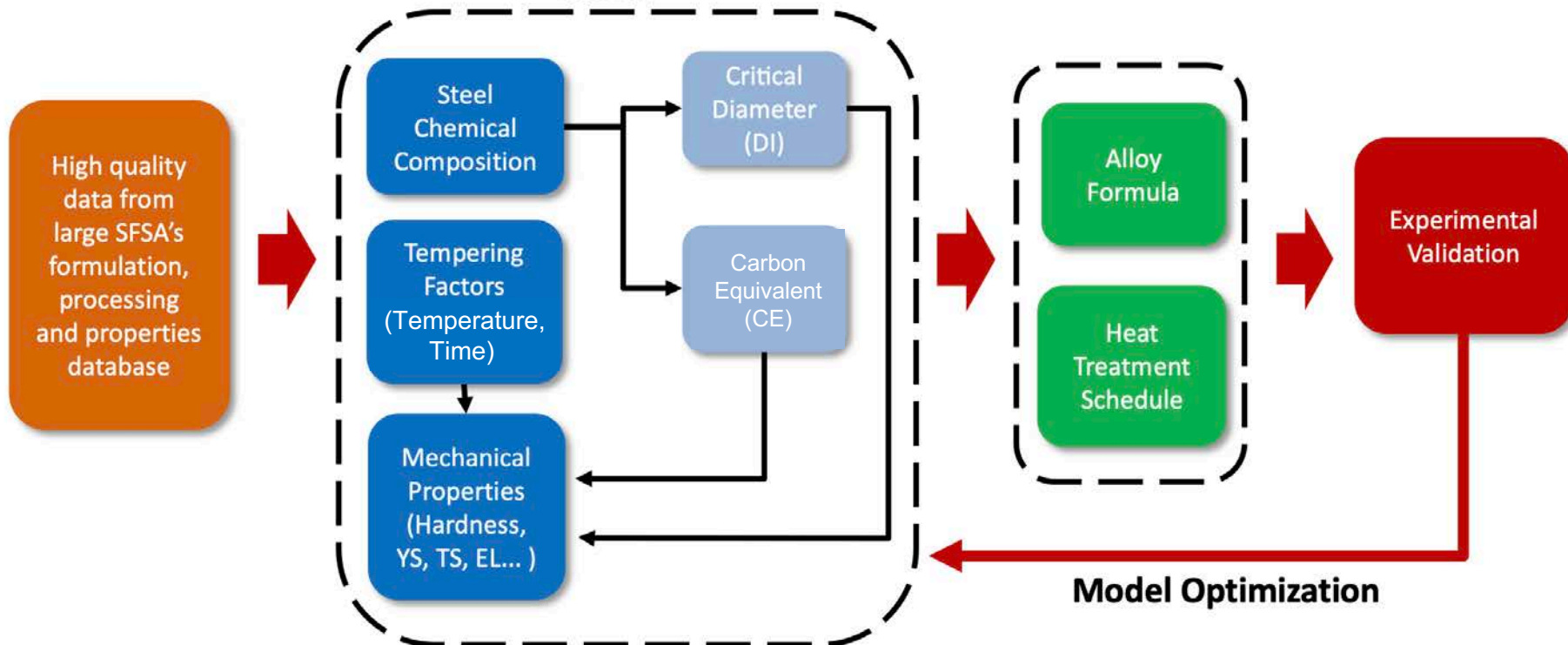
Data Driven Analysis

Prediction

Validation

Learn relations between factors.
Data regression analysis by fuzzy neural network

Predict usable parameters for
desirable performances



Artificial Neural Network Model for Metal Recycling

Input layer

Hidden layers

Output layer

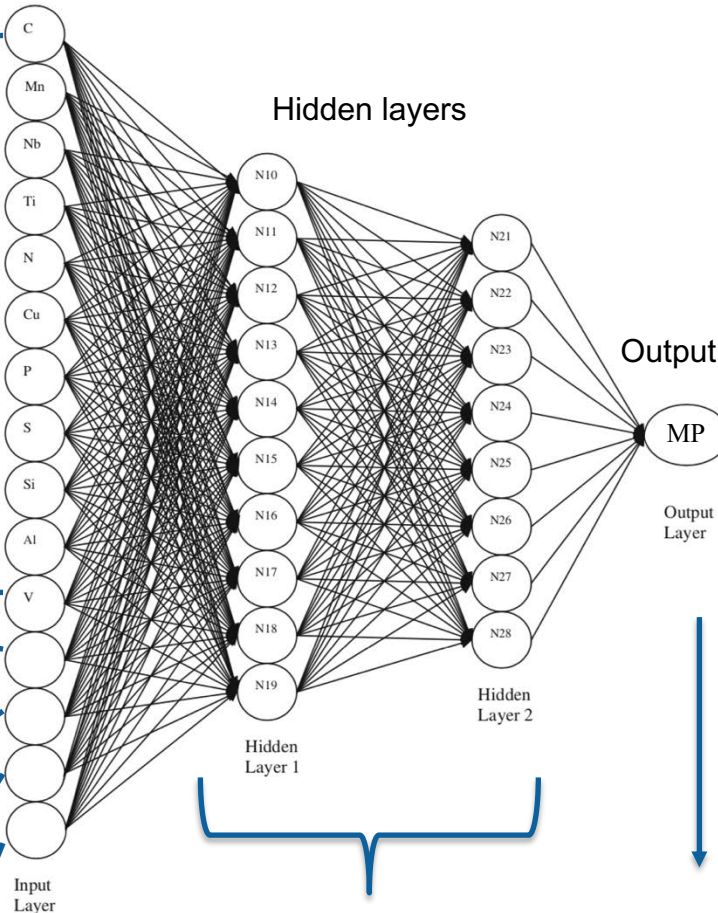
Chemical composition

Normalizing condition

Austenitizing condition

Tempering conditions

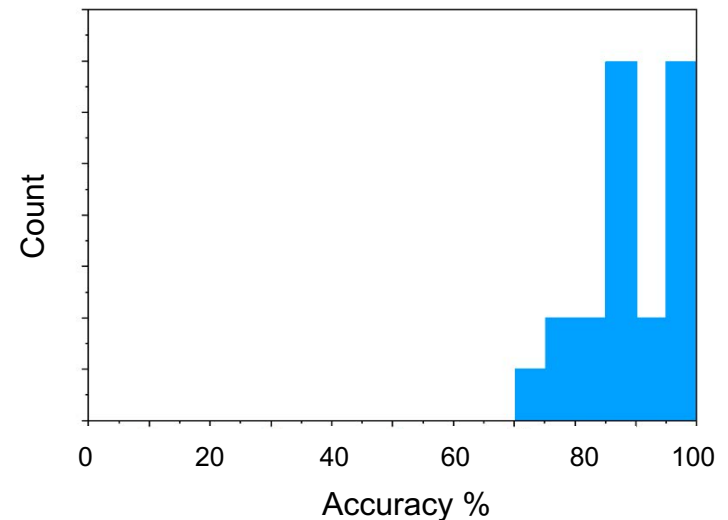
Coolant type



Hidden layers.
Artificial neural network
algorithm

Mechanical
properties,

- 20,000+ cast steel data from SFSA.
- Chose 86XX (2100 data points) to study relation between chemical, HT conditions, and mechanical properties.

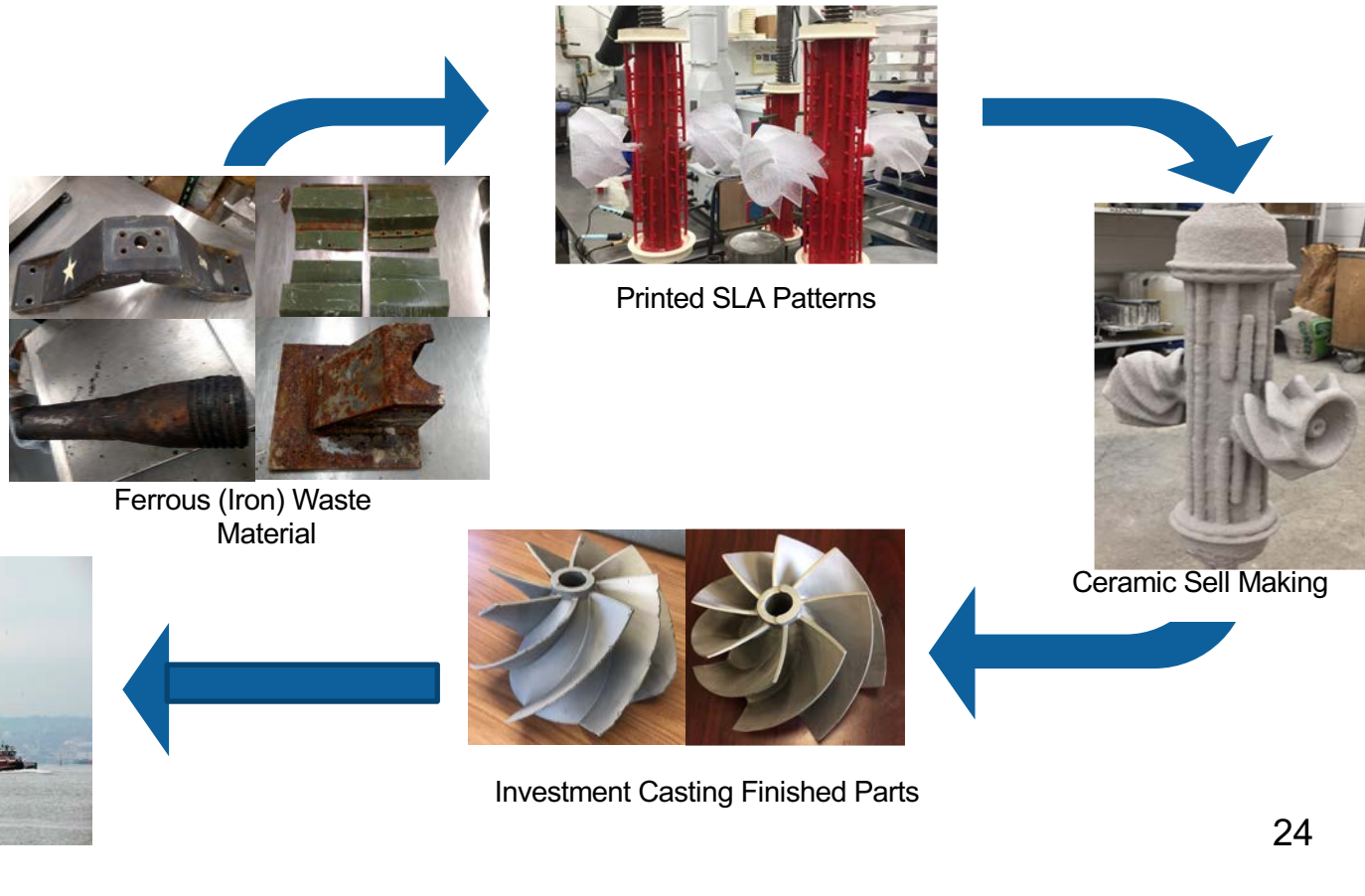


- Predict accuracy on mechanical properties. (21 results test out of 2100 data)



Guidance post-
process condition

SLA Enabled IC Process



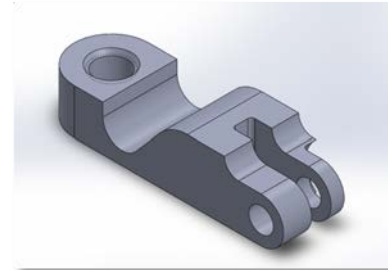
Results – SLA Pattern Design and Fabrication

Design Intent

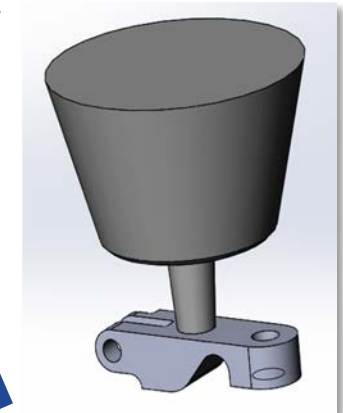
- Start with single part production
- Combine casting tree with the part
- Fabrication entirely through SLA printer

Optimization of SLA pattern design

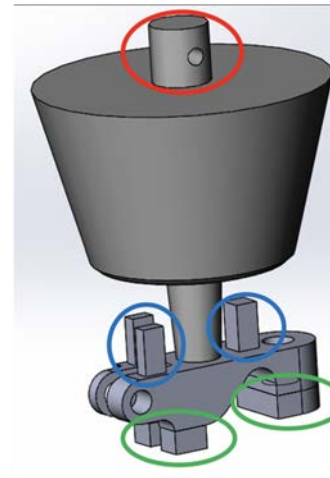
- **Mold holding fixture point (Red circle)**
- **Vent/Riser to allow air escape (Blue circle)**
- **Chills to ensure the cast piece is completely cast (Green circle)**



Solenoid Control Stop



SLA pattern design



Optimized SLA pattern design



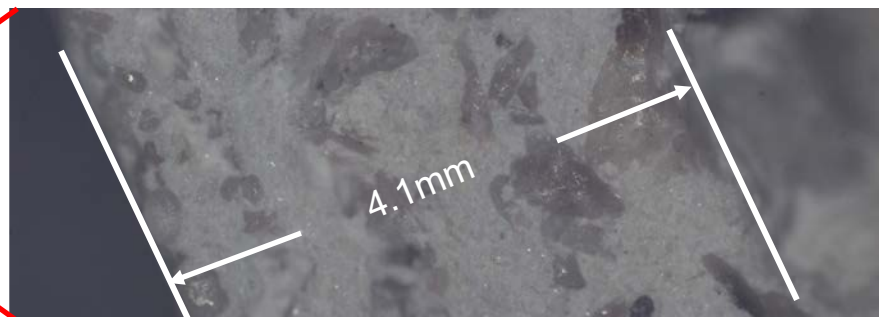
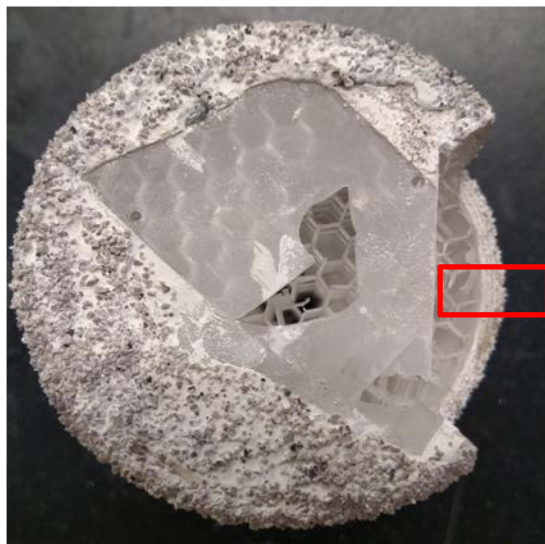
Results – Ceramic Shell Production

- Primary slurry recipe:

- LUDOX HS30
- Distilled Water
- Zircon CG, Std
- REMET Wet-In Wetting Agent
- Fumexol/Burst 100 Antifoam

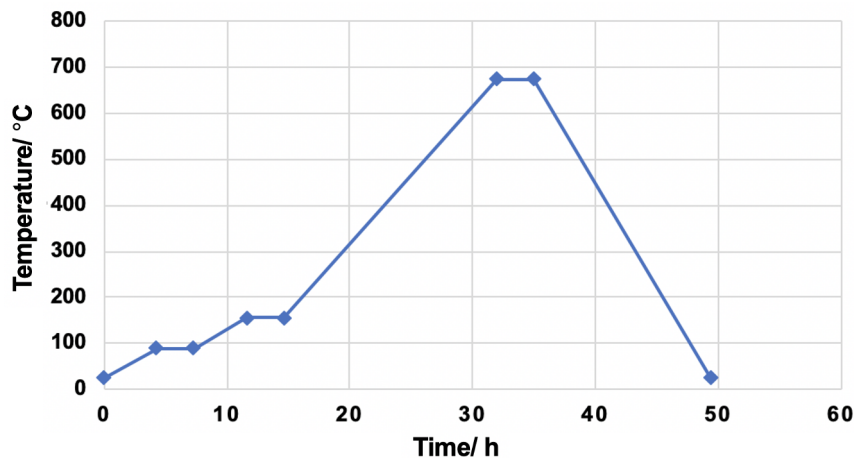
- 6-Layer Ceramic Shell Attempted

Layer	Slurry	Stucco
1	Primary	Zircon Sand
2	Primary	Zircon Sand
3	Primary	Mulgrain 47 60S
4	Primary	Mulgrain 47 60S
5	Primary	Mulgrain 47 22S
6	Primary	Mulgrain 47 22S



Ceramic shell thickness: 4.1mm

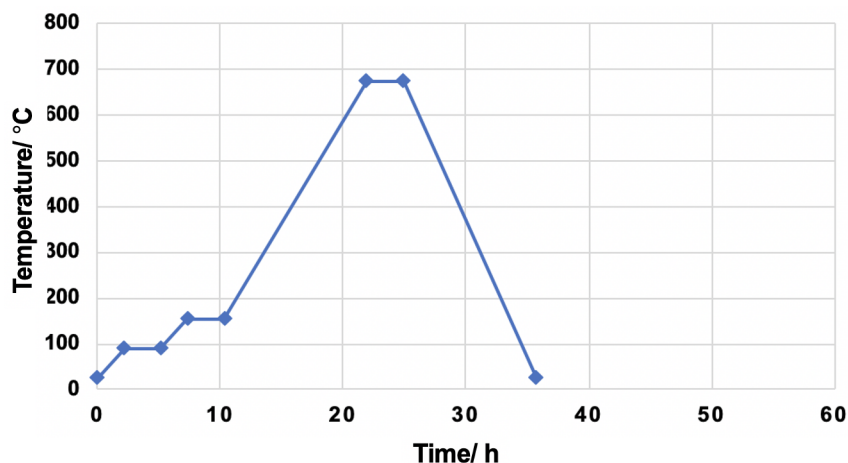
Results – Burnout Optimization



- Burnout schedule for ceramic shell

1. Ramp up to 90°C @ 0.25°C/min, hold for 3 hrs
2. Ramp up to 155°C @ 0.25°C/min, hold for 3 hrs
3. Ramp up to 675°C @ 0.50°C/min, hold for 3 hrs
4. Ramp down to Room Temperature (approximately 25°C) @ 0.75°C/min

Total burnout time ≈ 50h



- Improved burnout schedule

1. Ramp up to 90°C @ 0.50°C/min, hold for 3 hrs
2. Ramp up to 155°C @ 0.50°C/min, hold for 3 hrs
3. Ramp up to 675°C @ 0.75°C/min, hold for 3 hrs
4. Ramp down to Room Temperature (approximately 25°C) @ 1.00°C/min

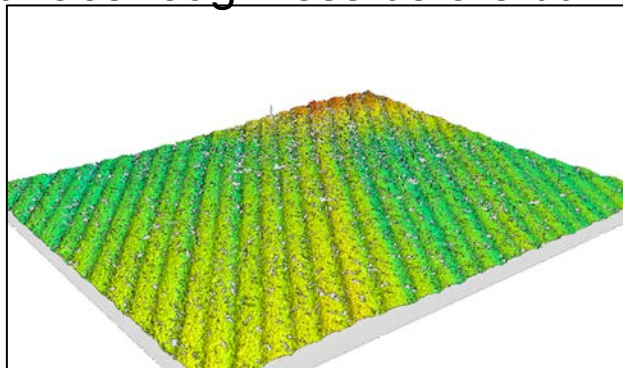
Total burnout time ≈ 37h

Results – Burn Out



Ceramic shell after burnout

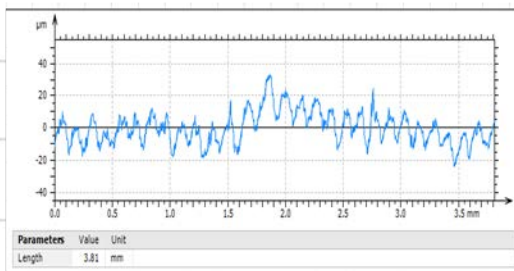
- Surface roughness before burn out



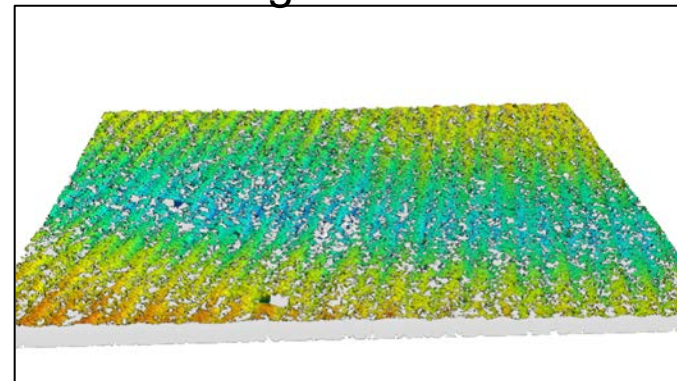
ISO 25178

Height Parameters

Sq	17.2	μm
Ssk	1.12	
Sku	5.11	
Sp	152	μm
Sv	134	μm
Sz	286	μm
Sa	13.1	μm



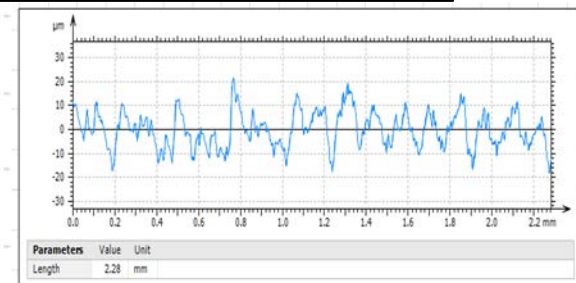
- Surface roughness after burn out



ISO 25178

Height Parameters

Sq	20.2	μm
Ssk	0.235	
Sku	2.48	
Sp	119	μm
Sv	91.8	μm
Sz	211	μm
Sa	16.7	μm



Thank You!