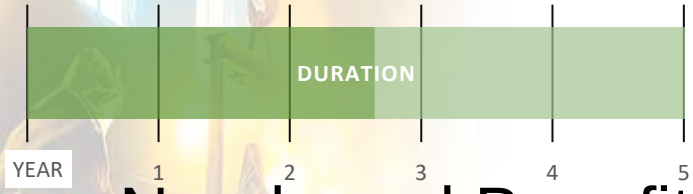
Quantifying Process Relationships for Surface Defects on Chemically Bonded Sand Systems

Robert Tuttle, Western Michigan University

Emergent Metal Casting Technologies (EMCS)

AMC Technology Review

June 24-25, 2026



Overview

AMC
AMERICAN METALCASTING CONSORTIUM

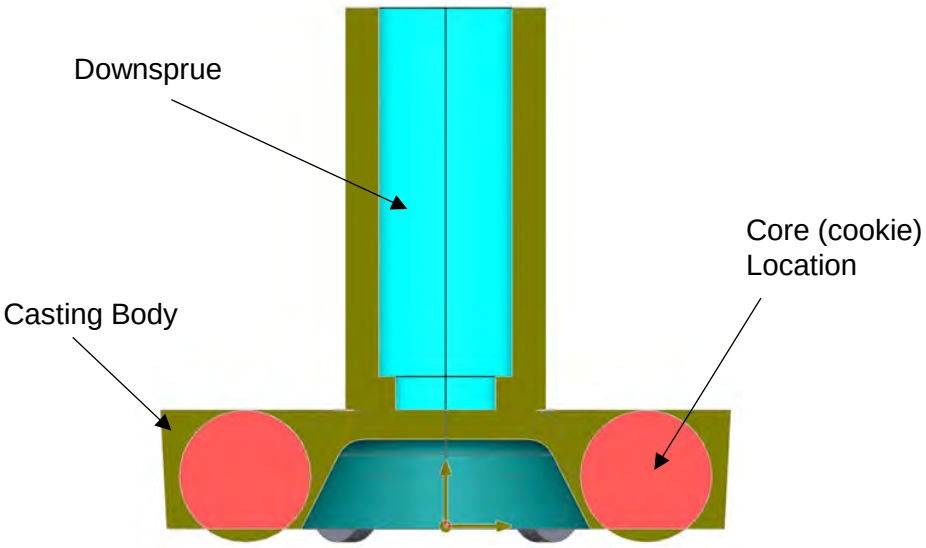
- Needs and Benefits
  - Improved modeling relationships between the surface defects on sand cast metal components and casting process variables / parameters to improve casting surface quality and eliminate casting defects
  - DoW will benefit from reduced procurement costs and lead times
- Progress
  - Finished aluminum and cast iron experiments
  - Working on steel casting experiments
- Transition
  - Results will be presented at Metalcasting congress
  - Modeling results and guidelines will be transitioned to the casting industry through AFS Virtual Knowledge Platforms
- Cost Share
  - $133,411 provided of $278,009 cost share proposed, 34% of total government funds received

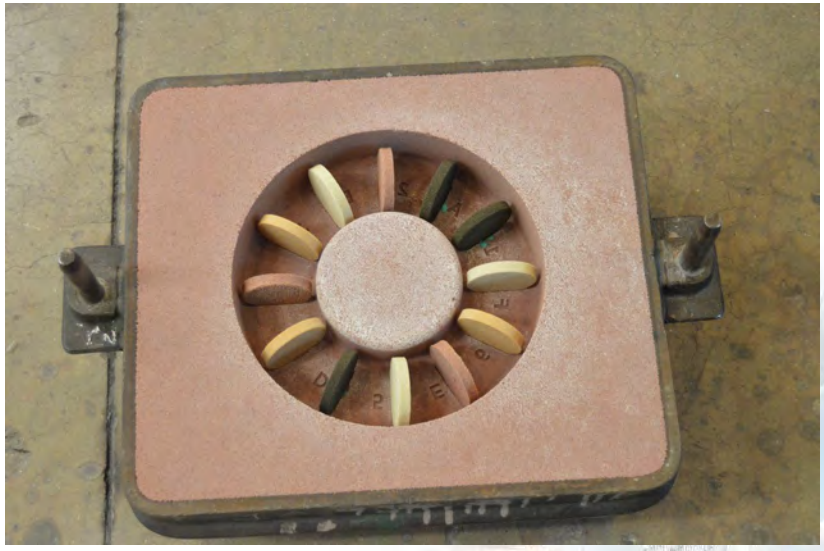
Needs: The Problem

- Sand castings experience a variety of surface defects the increase processing time, scrap, and cost
  - Penetration/burn-on and veins are examples
- Despite significant research over the decades these issues persist
- Currently no wholistic or analytical tool to predict defects prior to creating a product

Needs: Objective

The goal of this project is to model the relationships between surface defects on cast metal components and casting process variables/parameters so proactive actions can be taken using model predictions to improve casting surface quality and eliminate casting defects.





Needs: Technology

- Develop guidelines and models for adjusting casting process parameters to reduce defects
  - One model for defect classification
  - One model for defect prediction
  - Use these to reduce defects (50%) and rework (20%)
  - Need better understanding of the relationships between process parameters
    - Use test casting to examine a variety of parameters (i.e., binder, sand, metal, pressure, pouring temp, etc.)

Benefits

- DoW
  - Improve cost by reducing rework (20% increase in productivity)
  - Improve lead time by approximately two weeks
  - Increased capacity for castings due to less scrap
    - Enable more capacity at existing suppliers to make sourcing easier

"We used another sand source and had surface defects all over the place. Changed back and have none. We are participating so we can better predict if a supply change will cause a problem."
-Nic Tarzwell, Eagle Alloy

Milestones/Tasks

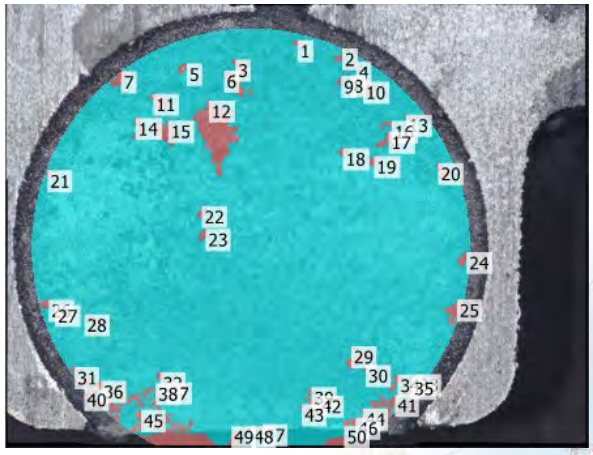
- Completed
  - Task 1: Development of Surface Analytics
  - Task 2.1: Aluminum and Process Variables
  - Task 2.2: Cast Iron and Process Variables
- In Progress
  - Task 2.3 Steel and Process Variables
- Planned
  - Task 3: Examination of coated surfaces

Technical Progress
Previous Year

- Quick reminder of previous progress
  - Created a series of 3D example defects from industrial castings
  - Proved out scanning system and created classifier
- Worked on aluminum predictive model
  - Completed this year

Technical Progress
Previous Year

- Employing Keyence 3D optical profilometer for scanning
- Using built in software for defect detection and quantification
- Results are then fed to classifier and prediction models

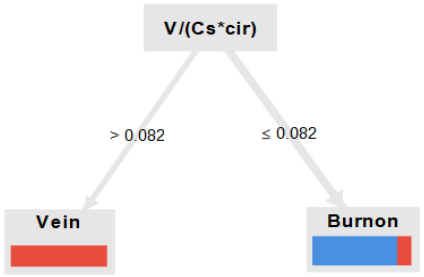


Technical Progress
Previous Year

- Classifier analysis found surface roughness was a VERY POOR method of classifying defects
- Macro level unitless measures provided a better classification approach
  - We do not notice roughness, but raised surface and length to width ratios

Accuracy results for decision tree

Class	Prediction	Recall
Burn-on	100.00%	95.24%
vein	88.64%	100.00%



Structure diagram for decision tree.

Technical Progress
Aluminum Process Variables

AMC
AMERICAN METALCASTING CONSORTIUM

- Initial work on prediction model attempted to predict the classifier factors
  - Not human understandable, but good to prove prediction
- Added additional experimental parameters
- Moved to predicting %defect area/area of defect
  - More understandable to an engineer

Technical Progress
Aluminum Parameters

- Metal
  - Alloy: 319
  - Pouring Temp: 1300°F, 1400°F
  - Head Height: 4”, 6”, 12”
- Sand Variables
  - 55-65 GFN on these sands
  - Types: silica sand, sintered ceramic, 3D printed
  - Binders: shell, no bake, sodium silicate (ester and CO_2)
  - Binder Levels: 1%, 2% (3% for shell and sodium silicate)
  - Compaction: no bake (manual & blown), shell (normal), sodium silicate (manual), and 3D printed

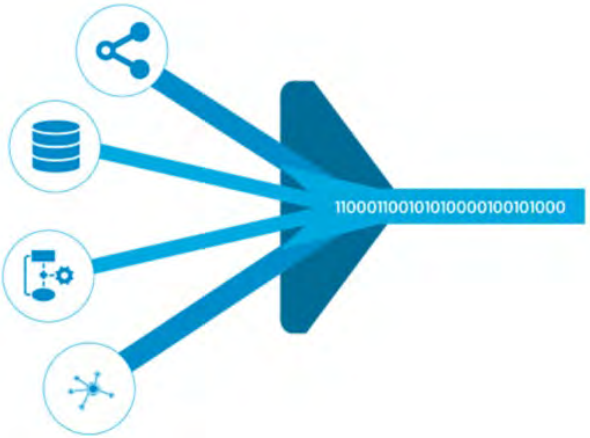
Technical Progress
AI Prediction Model

- Constructed a model with a much broader set of parameters
  - Last year's model data did not include shell or sodium silicate systems
- Focuses on defect area predictions to make it more understandable
  - Result will be more user friendly

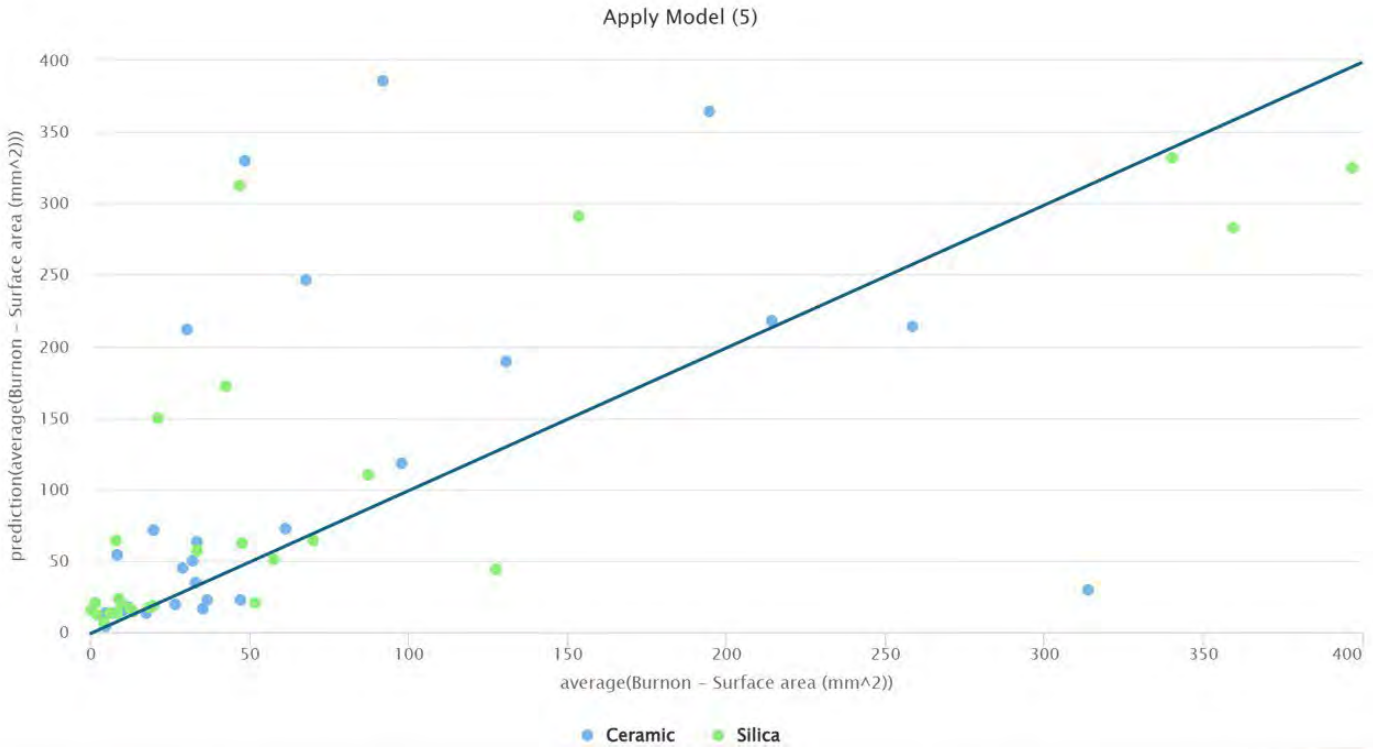
Technical Progress
Data Processing

AMC
AMERICAN METALCASTING CONSORTIUM

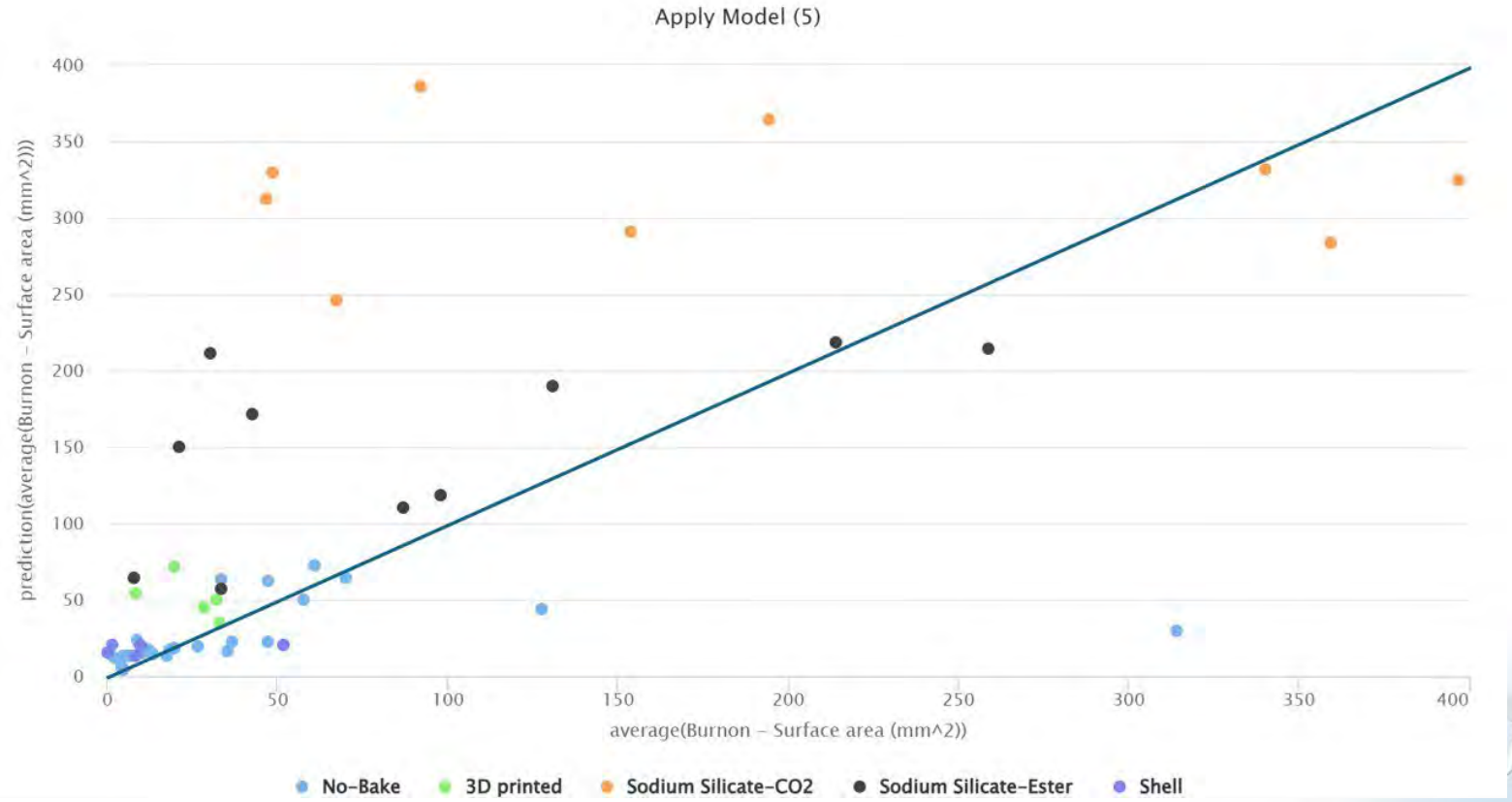
- You would think 300 cookies would be easy to process
- Significant effort to reduce manual processing was done
  - Process variable inputting
  - Tabulation of defects
- WMU had to program a large amount of automated software to do this



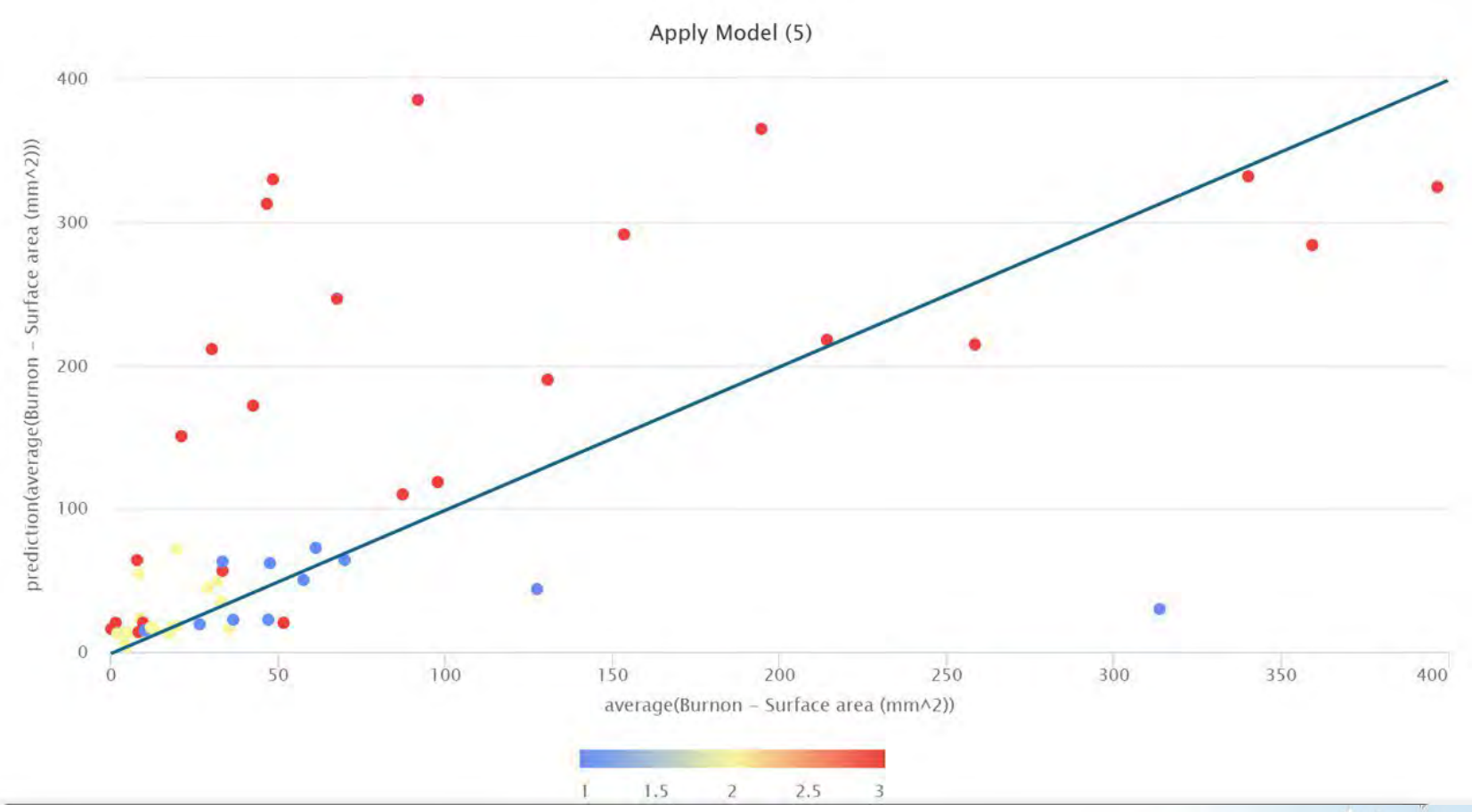
Technical Progress
Al Penetration Model



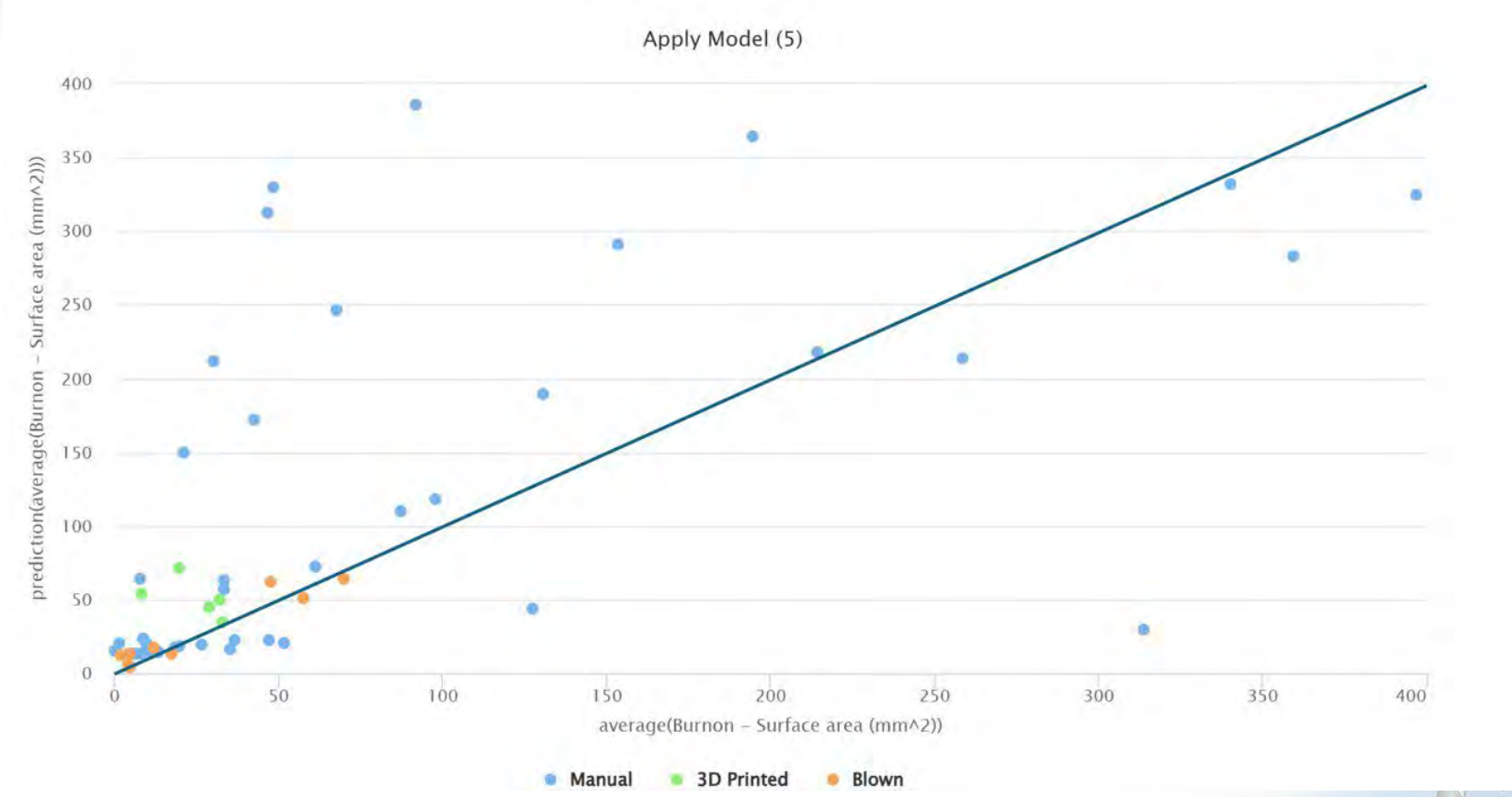
Technical Progress
Effect of Binder



Technical Progress
Effect of Binder Level



Technical Progress
Effect of Coremaking Process

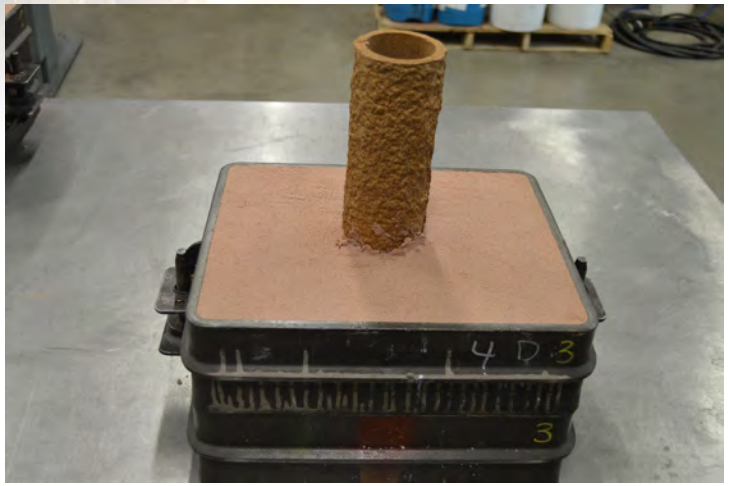


Technical Progress
Cast Iron Process Variables

AMC
AMERICAN METALCASTING CONSORTIUM

- Metal Variables
  - Alloy: Class 20 (4.4CE, 3.5C, 2.5Si), Class 40 (3.9CE, 3.2C, 2Si)
  - Pouring Temp: 2450°F, 2600ºF
  - Head Height: 4”, 12”, 20”
  - Replicates: 5 cookies (20 samples)
- Sand Variables
  - 55-65 GFN on these sands
  - Types: silica sand, 3D printed
  - Binders: Shell, No Bake (Alphaset), sodium silicate/ester, BioSet
  - Binder Levels: 1%, 2% (shell and sodium silicate/ester are only 3%)
  - Compaction: Manual

Technical Progress



- All cast iron molds have been poured
- Castings have been scanned
- Data analysis and prediction model in progress

Technical Progress
Vein Dilemma

AMC
AMERICAN METALCASTING CONSORTIUM

- Penetration and veins were observed in samples
- Bioset binder had been added to specifically provide veins
- Veins were only observed in the shell
  - Shell sand is from a different source than our normal
  - 12” head height only

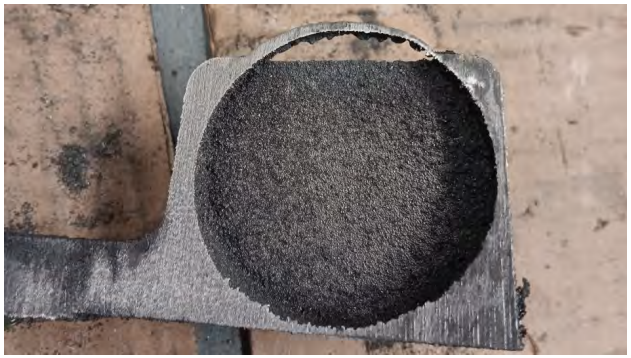
Shell samples at 20” head height.

Technical Progress
Sand Type

- Lack of veins in Bioset did not match perfectly with industrial experience
- Previous work by UNI showed that sand type may play the largest role in veining
  - Shell sand uses a silica sand from a different source
- Conducted an experiment with sand with a different source
  - Sand 1(WMU normal), Sand 2, AlphaSet, Bioset, 1% and 2%
  - Class 40 iron at 2450°F

Technical Progress
Sand Type Results

- Found no veins
  - You only get them when you don't want them
- Huge penetration difference!
- Silica sand source does matter



2 wt.% AlphaSet cookie made from Sand 1.

2 wt.% Alphaset cookie made from Sand 2.

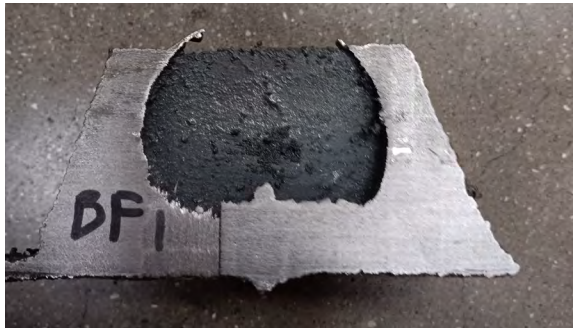
Technical Progress
Sand Type and Stress

- Does stress play a role?
  - UNI showed an effect on veining with sands
  - Test casting could be constrained to cause a stress
- Examined Sand 1 and Sand 2 using Bioset binder with a 500g load on cookies

Technical Progress
Stressed Cookie Results

AMC
AMERICAN METALCASTING CONSORTIUM

Sand 1



2 wt.% BioSet cookie 500g load.

2 wt.% BioSet cookie no load.

Sand 2

2 wt.% BioSet cookie 500g load.

2 wt.% BioSet cookie no load.

Technical Progress
Cast Iron Trial

- Original plan was to use a steel part
  - Model would not be developed in time
- Identified a DoW cast iron part
  - Core has traditionally had problems with penetration and veining
  - Regular production of product so easily can fit with research
  - Partnering with Charter Arrowcast
- Casting has a 25” pour height

Technical Progress
Cast Iron Trial Plan

AMC
AMERICAN METALCASTING CONSORTIUM

- WMU will run predictions for several core recipes
- Charter Arrowcast will place them in production
- Castings will be analyzed for defects and determine applicability of the defect prediction

Technical Progress
20” Experiments

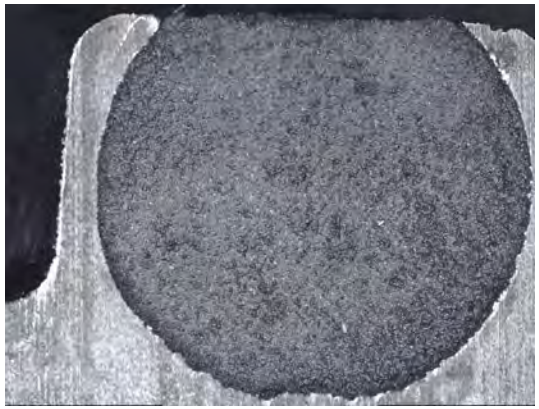
AMC
AMERICAN METALCASTING CONSORTIUM

- Original data was for 4” and 12” head heights
- Model prediction for iron trial was thought to be a stretch
- Conducted experiments on 20” head height
  - Max height we can safely do
  - Had to develop molding method for that height
- Castings have been poured

Technical Progress
Results

12” Head Height

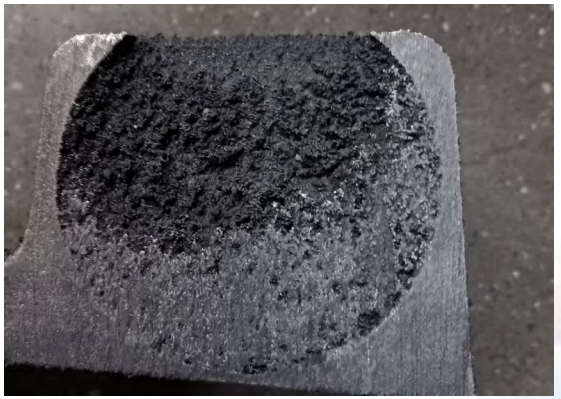
Shell



1 wt.% AlphaSet

20” Head Height

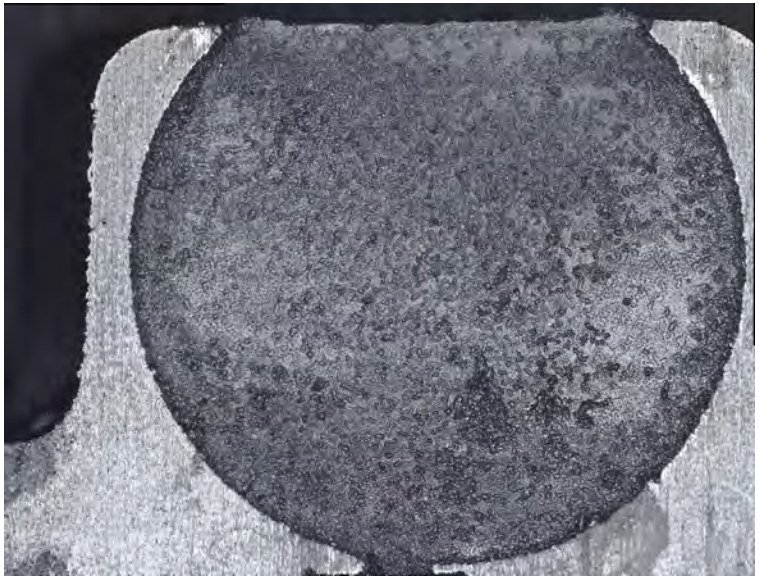
Shell



1 wt.% AlphaSet

Technical Progress

12” Head Height



1 wt. % Bioset

20” Head Height

1 wt. % Bioset

Technical Progress
Steel Experiments

- These have begun
- Metal Variables
  - Alloy: 1030, 4130
  - Pouring Temp: 2900°F
  - Head Height: 8”,14”, 20”
  - Replicates: 5 cookies (20 samples)
- Sand Variables
  - 55-65 GFN on these sands
  - Types: silica sand, ceramic, quartz sand
  - Binders: Shell, No Bake (Alphaset), BioSet
  - Binder Levels: 1%, 2% (shell only 3%)
  - Compaction: Manual

Project Plans

- Next 12 Months
  - Finish analysis of cast iron process variable experiments
  - Conduct industry trial
  - Conduct steel casting experiments and analysis
- Long Term (post 12 months)
  - Examine role of coatings on samples

Transition Plan

AMC
AMERICAN METALCASTING CONSORTIUM

- Conduct trials at industry partners for eliminating surface defects
  - Charter Arrowcast iron trials in Q3-Q4 2026
  - Steel trials Q3-Q4 2027
- Publish and present papers at AFS Metalcasting Congress
- Update AFS Mold Metal Interface Reactions (MMIR) committee on data found
- Guidelines from modeling results will be transitioned to the casting industry through AFS Virtual Knowledge Platforms

CHARTER CASTING

EAGLE Alloy, Inc.

MELLING
ENGINEERED ALUMINUM CASTINGS

MetalTechnologies™
More than metal.

Leveraging

- Utilizing previously developed test casting
  - Casting is in the final stages of being adopted as an AFS standard in the Mold and Core Handbook
- Leveraging existing literature on process relationships in penetration/burn-on and vein formation
- Working with industry on what are common process ranges to inform experimental design parameters

Project Metrics

AMC
AMERICAN METALCASTING CONSORTIUM

Description	Baseline	Threshold	Goal	How Measured	Target Date	Progress	How Demonstrated
Reduce metal-sand related surface defects	Amount of defects on existing part	45% reduction in defect count	50% reduction in defect count	Defects on industrial part	12/26	Started on proper measurement system for defects	Reduced defects on an industrial part
Improve identification of surface defect root cause	Average time to resolve surface defect cause	15% reduction in time to diagnose defect	20% reduction in time to diagnose defect	Survey partner foundries on typical time	12/26	Started on proper measurement system for defects	Measure time to reduce defect on industrial part
Improve productivity through reduced rework	Average finishing time for an industrial casting	15% increase in castings processed at same time	20% increase in castings processed at same time	Time required to rework selected industrial part	10/28	Initial discussion on measuring this	Increased number of castings produced based on current time
Improve lead time due to fewer defects	Average time for shipping a typical casting	1.5 weeks	Reduce by 2 weeks	Time from order to ship of selected industrial casting	10/28	None	Reduced time for a new industrial casting due to fewer defects

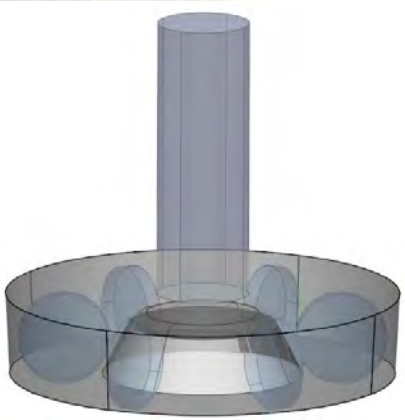
Acknowledgements

This research is sponsored by the Defense Logistics Agency Information Operations, J68, Research & Development, Ft. Belvoir, VA and DLA Troop Support, Philadelphia, PA.

Quantifying Process Relationships for Surface Defects on Chemically Bonded Sand Systems

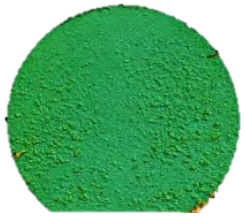
DLA - POC: DLAR.DPR@dla.mil

AMC
AMERICAN METALCASTING CONSORTIUM



Doughnut casting with test specimens

As-cast surface from casting trial



Surface point cloud

Problem

- Metalcastings produced in sand molds often contain surface defects related to the hot metal/sand mold interface which can result in scrapped castings or require significant grinding or welding to repair, reducing foundry productivity and increasing overall cost for energy, materials, and manpower

Objectives

- Reduce metal-sand related surface defects by 50%, improve identification of root cause of casting surface defects by 20%, improve productivity through lower rework by 20%, reduce lead time by two weeks

Benefits to Warfighter

- Improved casting surface quality and elimination of casting defects resulting in lower rework and reduced lead time

Description of Project

This project will determine process relationships affecting casting surface defects, enabling better process control, lower scrap rates, lower costs, and improved delivery times for critical DoW/DLA castings

Team: American Foundry Society, ATI, Western Michigan University

Milestones / Deliverables

- Create 3D printed test cookies and pour test castings
- Generate and examine surface defects in castings
- Document relationships between the defects and process parameters
- Transition results to industry through conferences, webinars, papers, and consultation with foundry personnel

ATI ADVANCED TECHNOLOGY INTERNATIONAL

WESTERN MICHIGAN UNIVERSITY

AFS