Reducing The Weight Of Vehicle Components Via Lost-foam Casting Of Ductile And Austempered Ductile Iron

Sarah Jordan

Skuld LLC

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DE-SC0019845

OVERVIEW: SBIR PHASE I

Timeline

- Project start date: 7/1/2019
- Project end date: 6/30/2020
- Percent complete: 85%

Budget

- Total project funding: $200,000

Partners

- The Ohio State University

THE OHIO STATE UNIVERSITY

Barriers

- Iron castings need lightweighting with aggressive targets by 2025
  - Reduce weight of steering knuckles 25-35%
  - Reduce weight of brakes 50%
- Improved casting processes to prevent defects negatively impacting microstructure and ductility are needed.
- Increase castability of iron to 2.5mm +/- 0.75mm (Year 2050)

RELEVANCE

PROBLEM & IMPACT

- Ductile Iron (DI) typically forms brittle massive carbides in sections under 3mm thick.
- Ability to redesign thinner means iron castings can be lightweighted.
- DI is 9% lighter than steel with similar strength possible.
- At 1mm thickness, DI and its heat treated variation Austempered Ductile Iron (ADI) can even replace >3.8mm thickness aluminum with both a weight and cost savings.

OBJECTIVES

1. Show that lost foam casting can prevent defects of massive carbides, porosity, shrinkage, high nodule count in thin walled ductile iron (TWDI).
   - Targeting as thin as 1mm.
2. Develop method of smoothing surface to prevent surface defects and maintain dimensional control within 5%.
3. Show process is feasible in production processes.

MILESTONES

Month/Year	Description of Milestone	Status
October 2019	Produce TWDI lost foam molds for casting trials 1, 1.5, 2, 3, 4, and 6mm thick.	Complete
December 2019	Conduct trials of various methods to improve lost foam surface roughness.	Complete
December 2019	Cast samples under various process conditions at The Ohio State University's experimental foundry in lost foam and nobake molds.	16 heats completed. Additional were planned but delayed due to COVID-19.
March 2020	Measure hardness, tensile, x-ray radiography, metallography, chemistry, fluidity, and tolerance capability of castings.	Analysis completed for 12 heats

APPROACH

SBIR Phase I: Demonstrate feasibility of casting TWDI under 3mm and as thin as 1mm using lost foam casting process.

- Show that casting defects can be prevented.
- Improve foam surface roughness.
- Show that precision tolerances can be achieved.
- Demonstrate that fluidity is sufficient for gating parts.
- Determine feasibility in production environment.

PRIOR WORK

- Prototype valve component
- Redesigned from DI casting in green sand to TWDI in lost foam
- 75% weight reduction
- 44% cost reduction
- Technology approach
  - Lost foam casting is more insulative, less chilling
  - Ability to blow foams down to 1mm thickness

ACCOMPLISHMENTS: CASTING DEFECTS

Nodule Count Appeared Normal

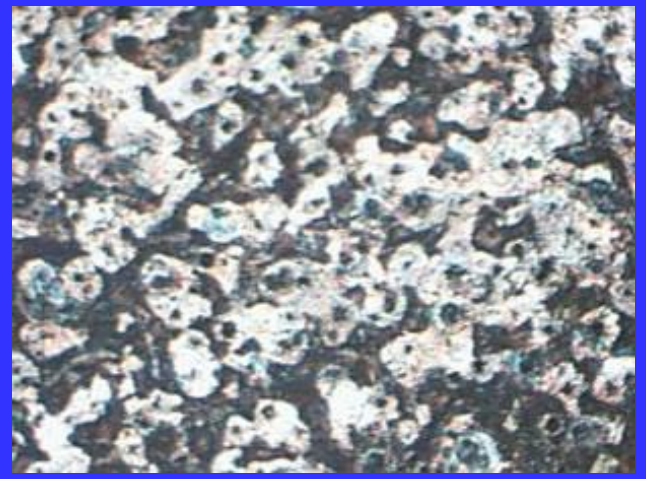
- 96 lost foam and 69 nobake samples
- All had nodule count 300 or less
- Average 176 nodules/mm^2

Porosity/Shrinkage

- Radiography testing showed 84.4% of samples had no or negligible porosity/shrinkage.

Massive Carbides

- Samples free of massive carbides as thin as 0.76mm
- 4 lost foam heats carbide free
- 9 nobake heats carbide free



Nobake sample cast at 1.8mm at 100X showing typical bullseye ferrite, 250 nodule count and no casting defects.

Eliminated massive carbide defects in **lost foam and nobake castings**. Chemistry/alloying appears key, not mold media.

ACCOMPLISHMENTS
SURFACE ROUGHNESS & TOLERANCES

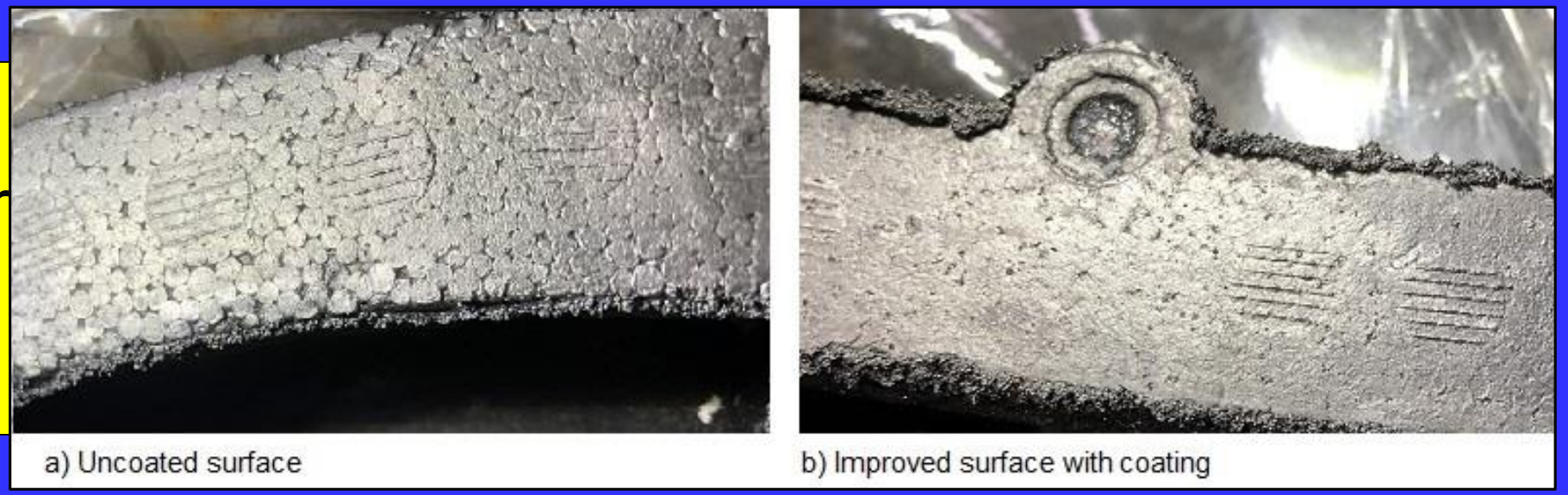
- Target roughness <5% thickness. For $Ra = \frac{1}{n}\sum_{i=1}^{n}\left|y_i^2\right|$ at 1mm that translates to maximum 984 µin Ra.

Sample	Foam µin Ra	Casting µin Ra
Uncoated	240	273
Best coating	65	178

- Dimensional variation <5%.

Nominal Thickness	Average Variation	% Tolerance Variation
1mm	0.058mm	5.8%
1.5mm	0.043mm	2.9%
2mm	0.056mm	2.8%
3mm	0.175mm	5.8%

Roughness and tolerances similar to investment casting.



a) Uncoated surface

b) Improved surface with coating

ACCOMPLISHMENTS
FLUIDITY & PRODUCTION FEASIBILITY

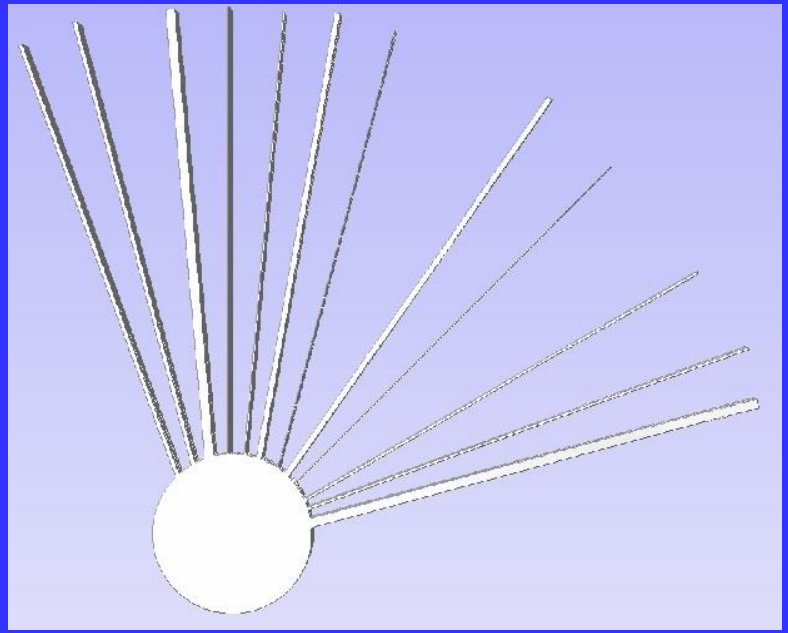
Skuld

Fluidity Length

- Target 2” minimum for gating
- Depending on superheat 1mm could achieve 8.94”

Process Control

- Process ranges and predictive model not yet determined.
- Results so far indicate tramp element carbide formers in standard scrap are not an issue.



Lost foam process appears feasible in production down to 1mm section thickness.

RESPONSES TO PREVIOUS YEAR'S REVIEWERS COMMENTS

- This is the first year that the project has been reviewed.

COLLABORATION WITH OTHER INSTITUTIONS

- The Ohio State University (Sub), Alan Luo
  - Materials Science & Engineering experimental foundry use
  - Personnel and equipment to melt trials heats
  - Optical emission spectroscopy (OES) for chemistry
- Worcester Polytechnic Institute, Surface Metrology lab
  - Three dimensional surface metrology
  - Technical support on roughness analysis
- American Testing Services provided X-ray radiography
- Miami Valley Materials Testing Center provided tensile testing and OES and combustion infrared detection chemistry analysis

REMAINING CHALLENGES & BARRIERS

- Lab scale furnace (100 lb.) made maintaining sufficient superheat difficult. Reason that lost foam which is more insulative had carbides in cases that the more chilling nobake did not.
- Process control ranges, e.g. time, temperature, chemistry requirements need determined.
- Predictive model to prevent defects during gating design is needed and the data so far is insufficient to determine.
- Full characterization of materials properties in thin sections is needed even if microstructure matches standard thickness DI.

PROPOSED FUTURE RESEARCH FY20/21

Phase I

- Complete testing of lost foam heats 13-16
- Conduct tensile testing of nobake samples
- Cast additional heats and samples under varying process conditions

Phase II

- Cast 400 heats in production scale furnace and characterize defects
- Determine process control requirements
- Measure hardness, tensile, Charpy, and fatigue properties
- Create predictive computational model for defect prevention
- Test TWDI and ADI in prototypes

Any proposed future work is subject to change based on funding levels.

SUMMARY

- Demonstrated feasibility of approach in lost foam and nobake casting for section sizes down to 1mm.
  - Ability to prevent casting defects
  - Ability to reduce surface roughness and remove foam bead appearance
- Redesigned prototypes saved weight and cost.
- Ultimate objective is to enable lightweighting of iron, steel, and aluminum castings, weldments, and machined components.
- Lost foam casting already achieves castability of iron goal by 2050 from Light-Duty Workshop Final Report.