New Technologies for High-Performance Lightweight Aluminum Castings

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2021 DOE Vehicle Technologies Office Annual Merit Review

Overview

Timeline

- Start: January 2020
- End: December 2021
- 30% Percent complete (as of Jan. 2021)
- No-cost Extension anticipated. Any proposed work is subject to change based on funding levels.

Budget

- Total project funding: $1M
  - DOE share: $500K
  - GM share: $500K

Barriers and Technical Targets

- Barriers addressed
  - Significant improvement in strength and fatigue resistance (>25%)
    - At 300 lbs Al alloy in a modern car this provides a 75 lbs weight savings opportunity.
  - Smaller displacement/lower emissions for the same power
    - Higher compression ratio
    - More valves/cylinder

Partners

- CRADA with GM
- Eck Industries (through GM)

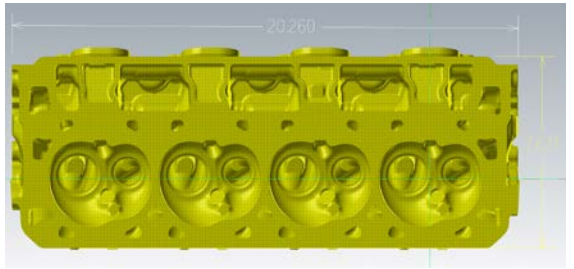
Relevance

- Al alloys can account for 300 lbs of mass on a modern vehicle.
- The goal of this project is to result in a significant (>25%) improvement in high temperature strength and fatigue resistance.
  - Allow higher compression ratio
  - More valves per cylinder
  - These changes facilitate the use of a smaller displacement engine for the same power output resulting in better fuel efficiency and lower emissions.

Objective

- Utilize PAPSC[1]
  - Fine scale dendrite arm spacing
  - Reduced/eliminated shrink porosity
  - Reduced/eliminated oxide inclusions
  - Lower cost

Typical Cylinder Head



[1]PAPSC (Pressure Assisted Precision Sand Casting), Wang et al., US patent application number 2020/0316676.

Approach

- Pressure-Assisted Precision Sand Casting (PAPSC) process development.
  - Simple plate mold.
    - Develop water-cooled chill plate (complete).
    - Develop vibratory option (in place).
    - Develop roll-over/pressure applications (concepts in place).
    - Casting trials scheduled for next quarter.
  - Cylinder head deck face chill
    - Water cooled deck face insert.
      - Parts designed, preforms made, currently being machined.
    - Incorporate the preferred processes developed with the plate mold.

- Microstructure and property characterization
  - Grain size, Dendrite Arm Spacing (DAS), porosity and second phase quantification. (Waiting for castings).
  - Tensile, fatigue, creep, and thermal mechanical fatigue (TMF). (Waiting for castings).
  - Fractography on select test coupons. (Waiting for tests to be completed).

Technical Accomplishments

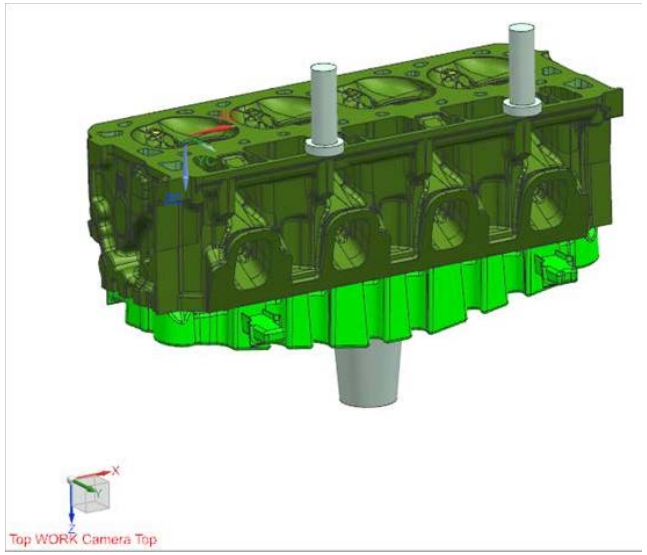
- A plate mold chill has been developed to facilitate the refinement of the processing details and their impact on the casting.
- Used green sand casting and semi-permanent mold for the two halves.
- Material cast into the semi-permanent mold requires heat treating to facilitate machining.
- Fins were machined into the underside of the chill that will be in contact with the aluminum plate casting. The fins are 1in tall which is significant. These are bathed in a flowing water bath during use.
- With the project starting January 2020, Covid-19 created many issues performing laboratory operations.

Technical Accomplishments

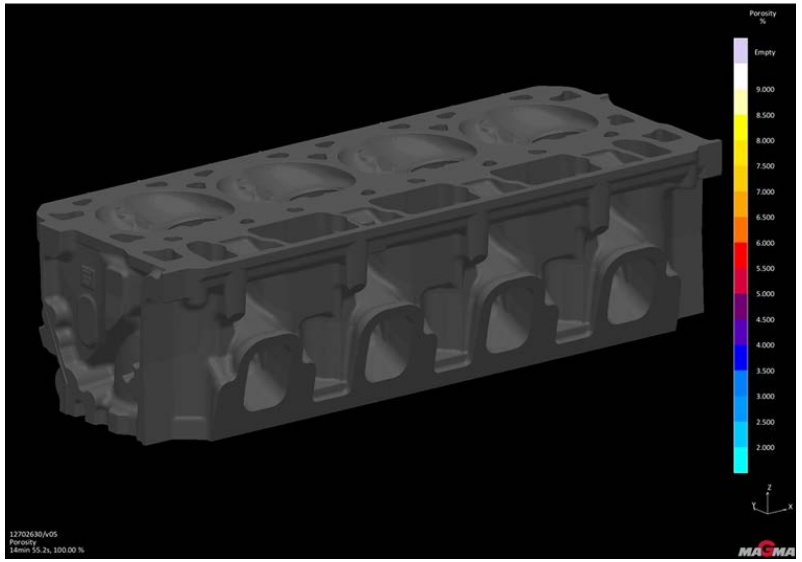
- A water-cooled deck face chill has been designed which incorporates the concepts developed on the simple plate chill including 1in fins (which are water cooled) on the underside of the chill surface.
- Used a semi-permanent mold for the two halves.
- Material cast into the semi-permanent mold requires heat treating to facilitate machining.
- A scrap section of material was machined to test out the machining program.
- Full size deck face chill is currently being machined.
- A repair protocol has been developed for the cast iron if needed.

Technical Accomplishments

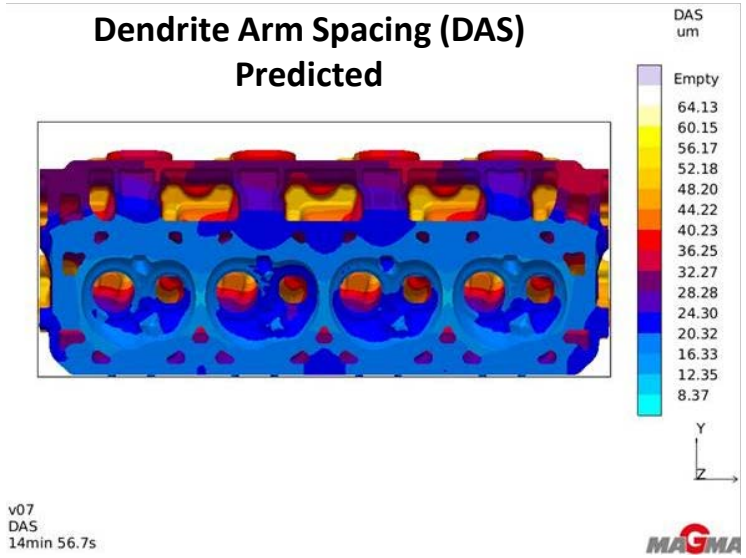
- A pressure assist precision sand casting process (PAPSC) has been proposed to cast high quality cylinder head
- An optimal design of gating, riser, and deckface chill for low pressure fill has been achieved through numerical simulations for the cylinder head
- With the optimal gating/riser/chill design and very low pressure mold filling profile, no isolated macro porosity was predicted in the head casting
- Micro porosity modeling considering hydrogen diffusion and interdendritic shrinkage is under way.



Low Pressure Fill Model Setup

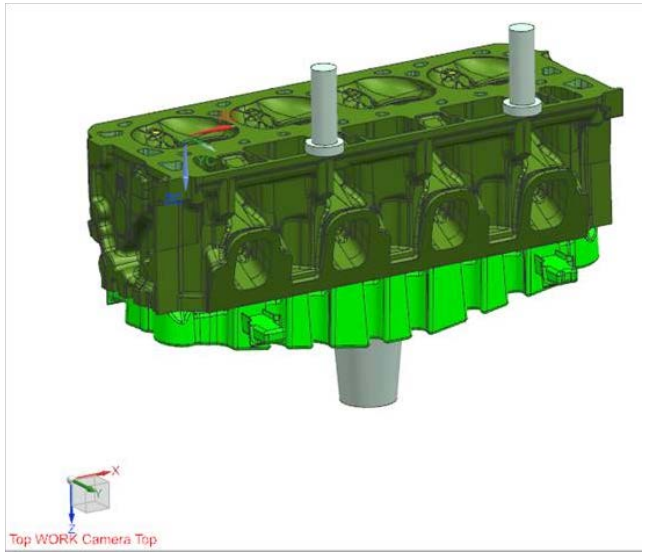


No Macro Porosity Predicted



Technical Accomplishments

- Note that this project was not previously reviewed.



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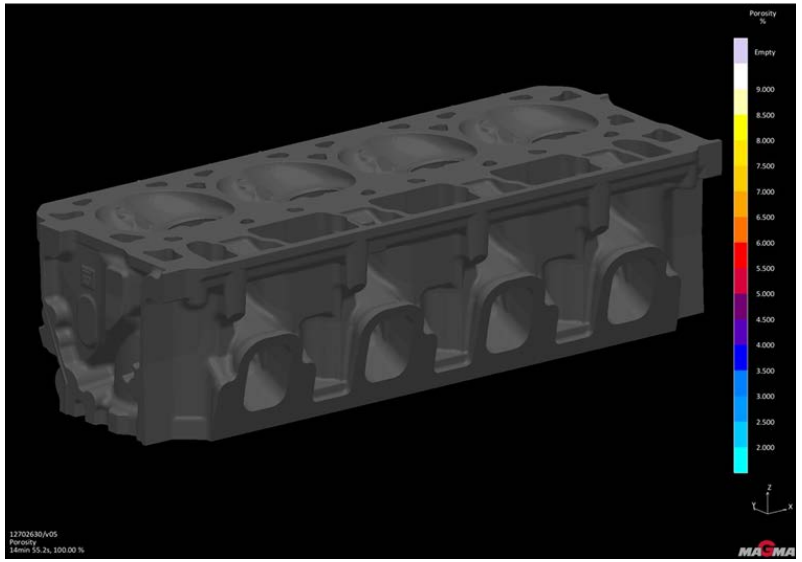

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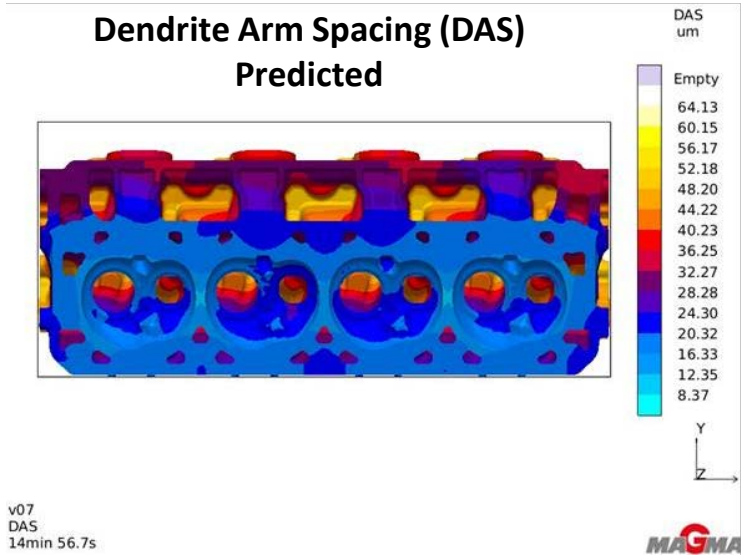
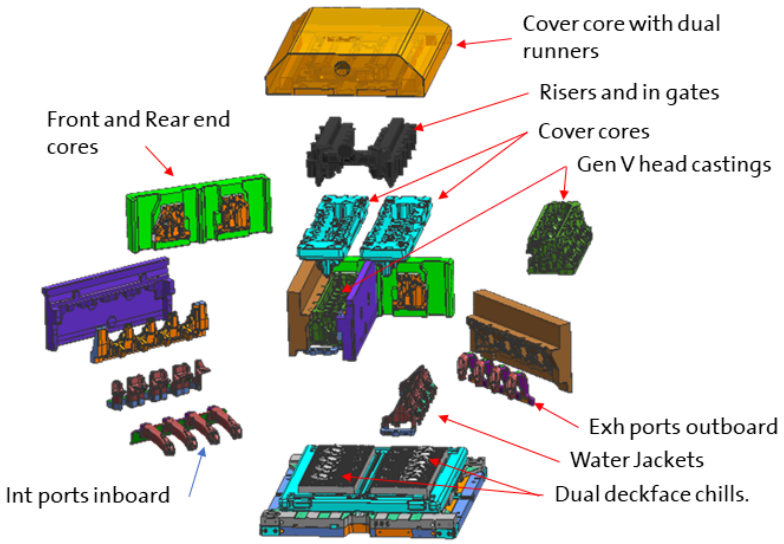
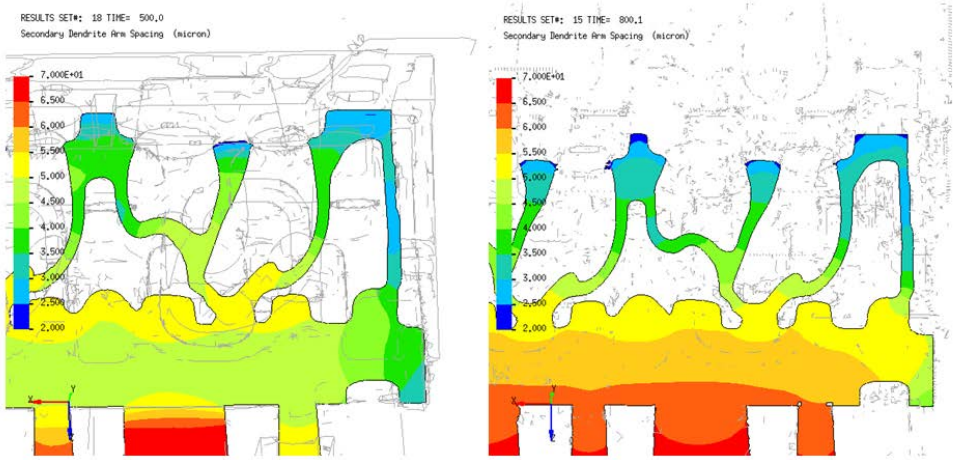


Collaboration

- General Motors (Qigui Wang, co PI)—brings to the team the critical needs of the final product, insight into Al casting and defects. An expert (originator) of the PAPSC process.
- General Motors (Andy Wang) – provides additional support in casting process modeling & microstructure prediction



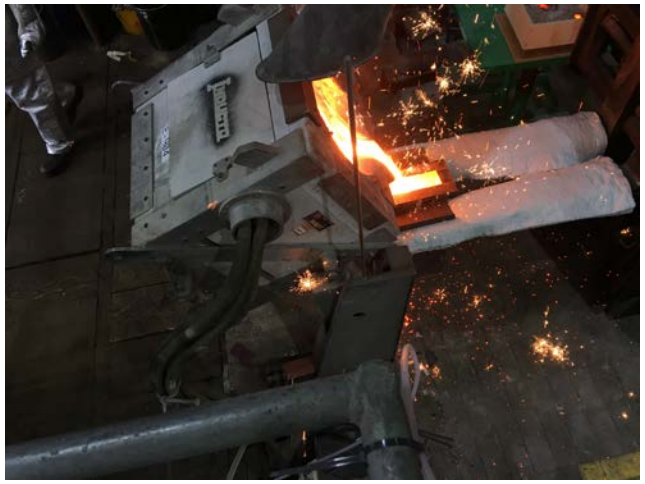
- Eck Industries (David Weiss, VP R&D, Dan Hoefert)—leading the modeling, precision sand cast molding design and manufacturing operations, insight into Al casting and defects.



PAPSC process refines DAS in the head Deck

Remaining Challenges

- Covid-19.
  - Mandatory work from home orders prevented lab work from occurring in 2020.
  - Subsequent stay at home orders issued for key team members.
- Equipment availability has not been a problem thus far.
- Getting the water flow rate required may be a challenge.
- Avoiding moisture condensation on the surface of the chill.
- Microstructural and mechanical property characterization.
- Need to explore no-cost extension on the order of 12 months.



Future/Ongoing Research

- Once completed, the deck face chill will be incorporated into a PAPSC molding of cylinder heads.
- Cylinder head castings will be evaluated for microstructure and mechanical properties.
- Additional PAPSC cylinder heads will be subjected to dyno cell testing for on-engine evaluation.
- Post dyno cell testing the cylinder heads will be further characterized as appropriate.
  - Microstructure
  - Mechanical properties
- Work will extend into 2022 if a no cost extension is allowed.
- Any proposed work is subject to change based on funding levels.

Summary

- Covid-19 has impacted the schedule of this project.
- Never-the-less, a water-cooled plate chill has been manufactured.
  - Initial experiments are expected in the next quarter.
- Component blanks for the deck face chill have been cast and heat treated.
- A single combustion chamber portion of the chill has been machined as a test of the CNC.
- The initial success here has given the green light to machining the full deck face chill.