New Technologies for High-Performance Lightweight Aluminum Castings

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NETL

Project ID # mat228

Overview

Timeline

- Start: January 2020
- End: December 2023
- Progress significantly impacted by COVID-19

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# Al alloy this provides a 75# 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)

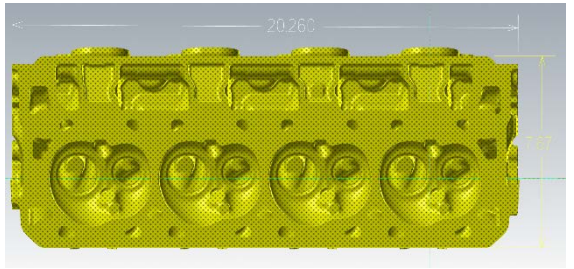
Relevance

- Al alloy castings can account for 300lbs 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 with new alloys.
  - 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

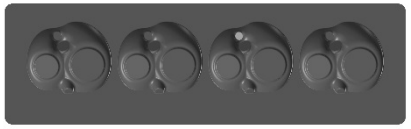
Typical Cylinder Head



[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, DAS, porosity and second phase quantification.
  - Fatigue properties.
  - Fractography on select test coupons.



Technical Accomplishments

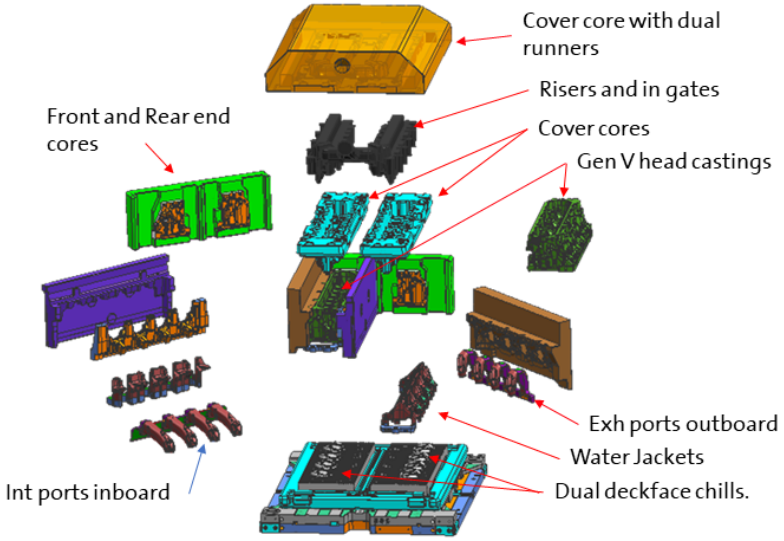
- A plate mold chill was developed to facilitate the refinement of the processing details and their impact on the casting.
- Used green sand casting and semi-permanent mold for the two halves.
- Material cast into the semi-permanent mold requires heat treating to facilitate machining.
- Fins were machined 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

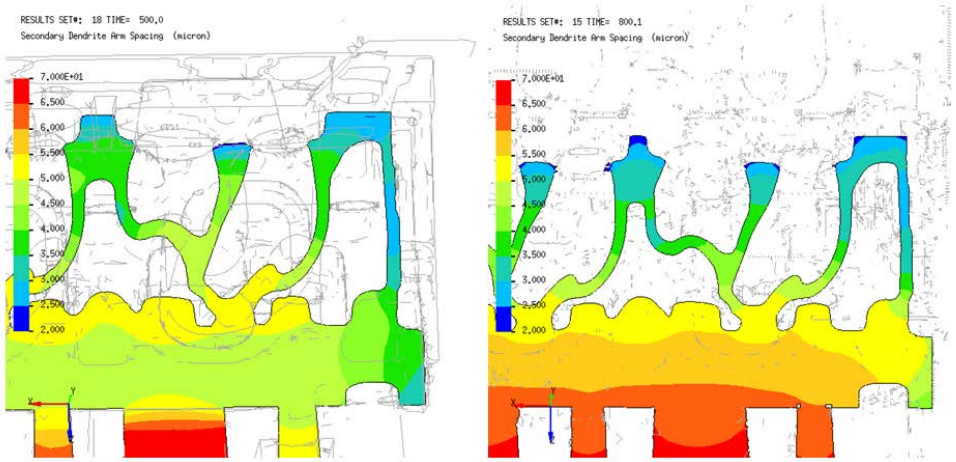
- A water-cooled deck face chill has been designed and built which incorporates the concepts developed on the simple plate chill including 1in fins (which are water cooled) on the underside of the chill surface.
- Used a semi-permanent mold for the two halves.
- Material cast into the semi-permanent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

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.



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



Baseline PAPSC

21-A45 Poured on 20Dec2022

750C Pour Temperature; Applied 5psi after rollover

Exhaust and Intake Side Views

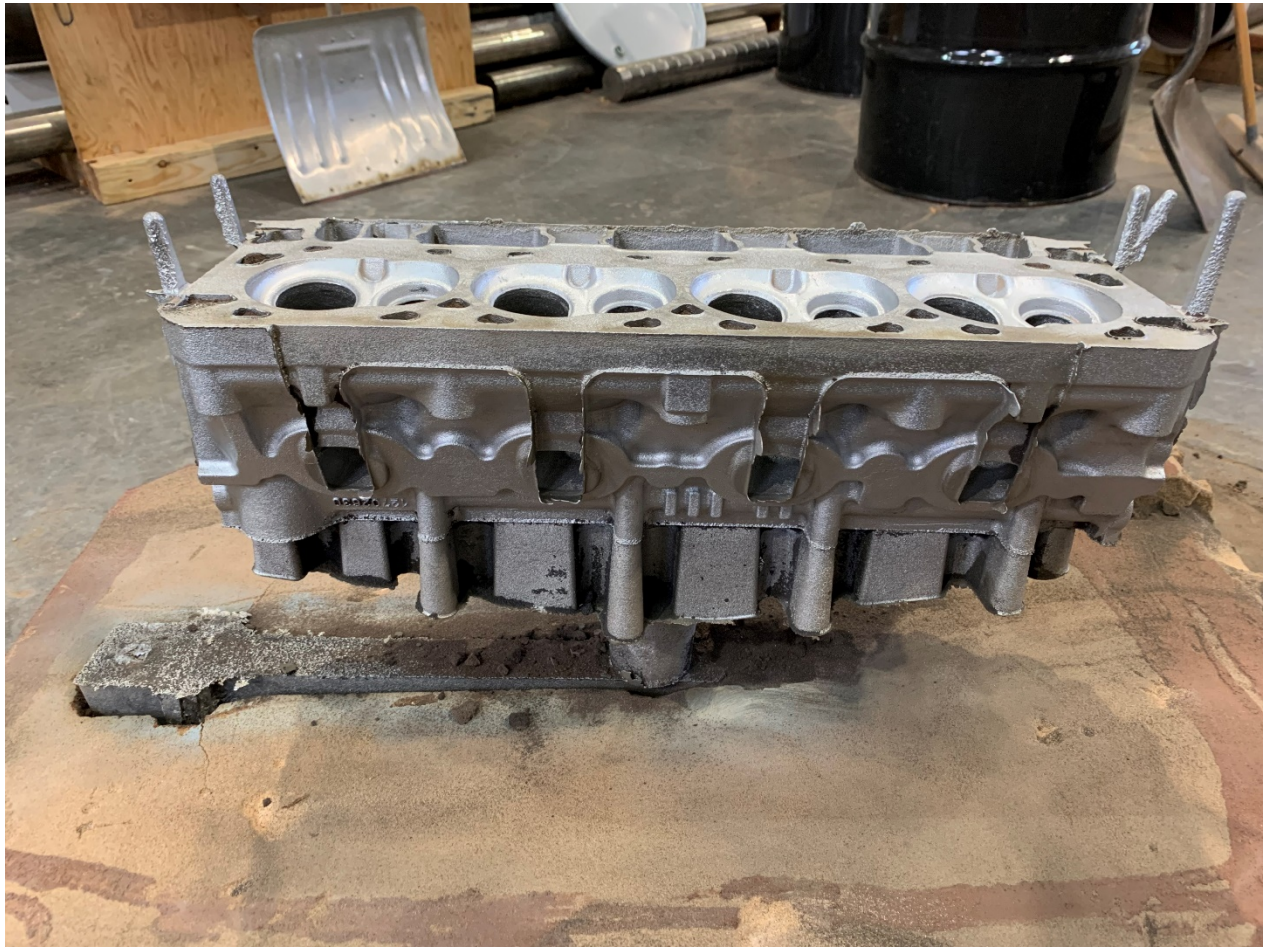
Fully Knocked Out

21-A37 Poured on 18Jan2023

770C Pour Temperature; Preheated Tundish; Applied 5psi after rollover

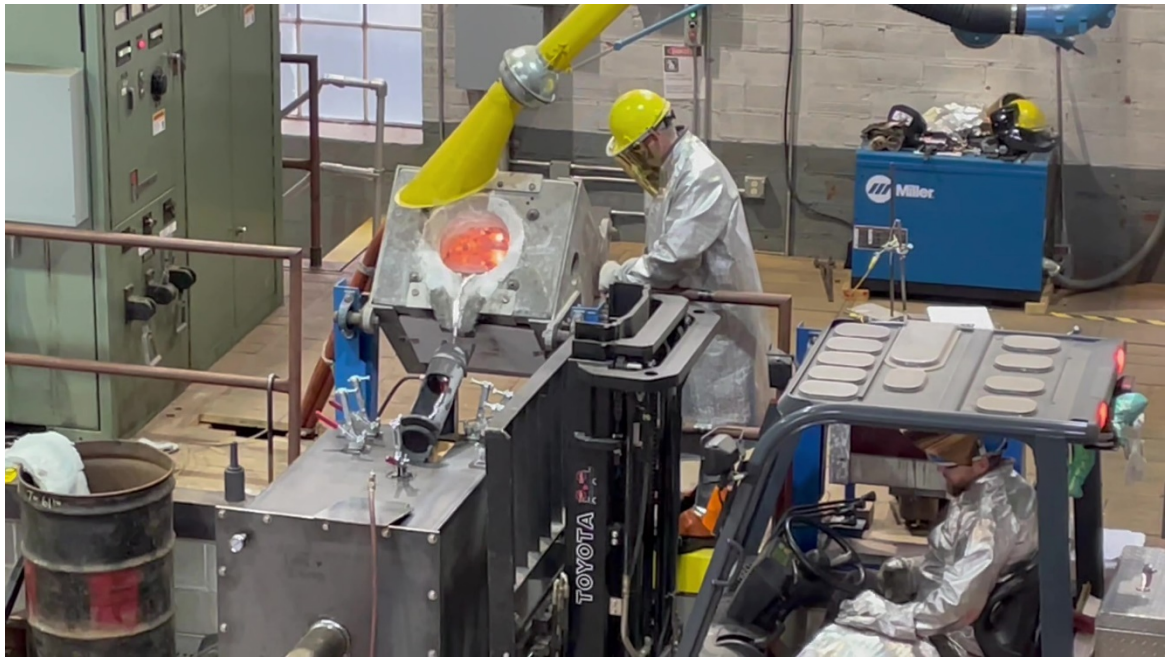
Exhaust and Intake Side Views

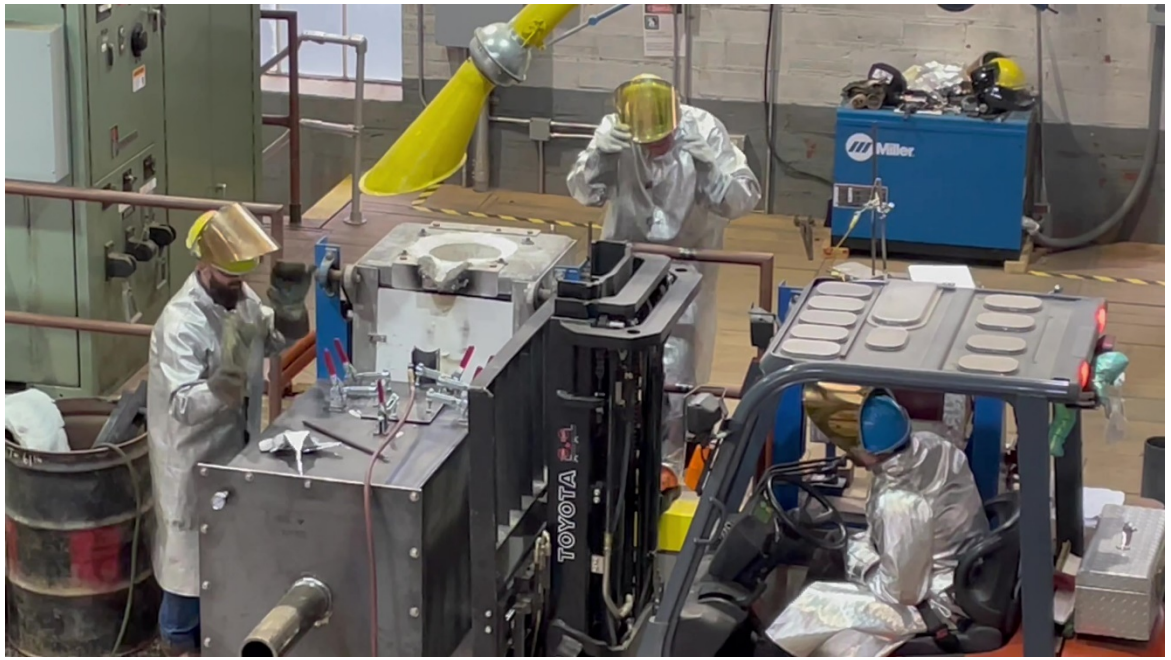
Fully Knocked Out



23-A17 Poured on 29Mar2023

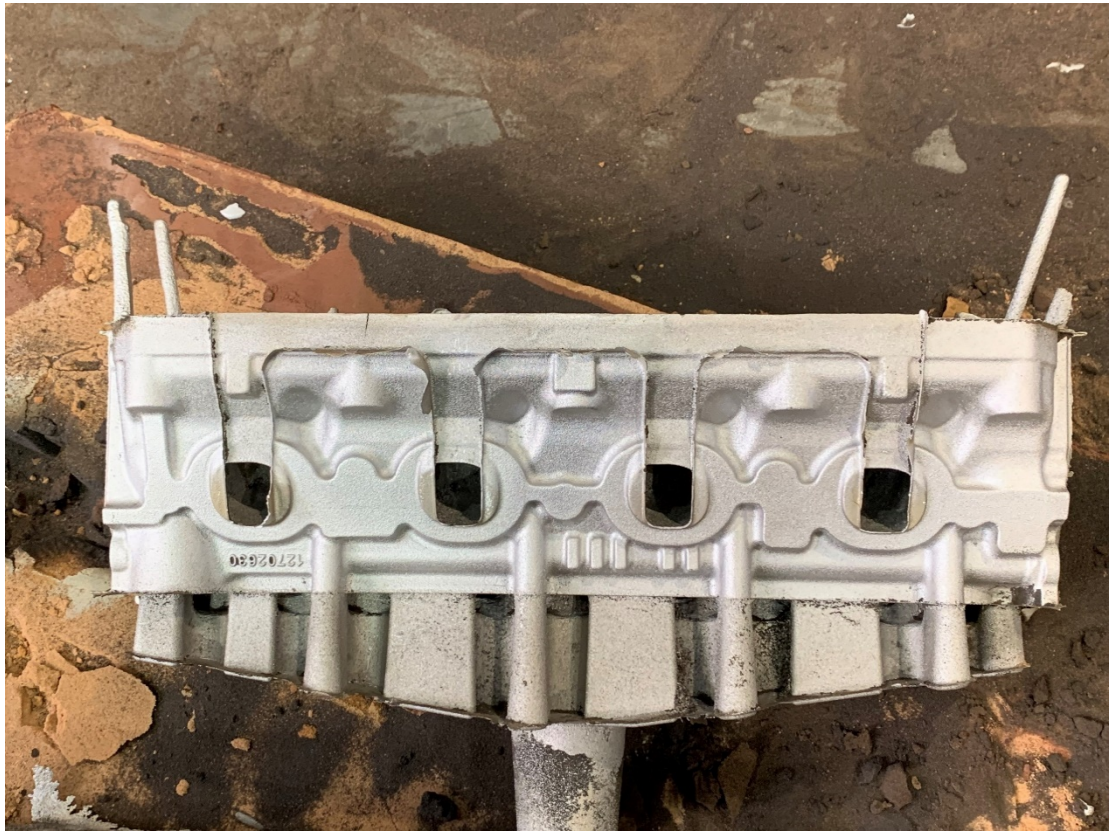
770C Pour Temperature; Preheated Tundish; Applied 25psi, no rollover





Exhaust and Intake Side Views

Fully Knocked Out

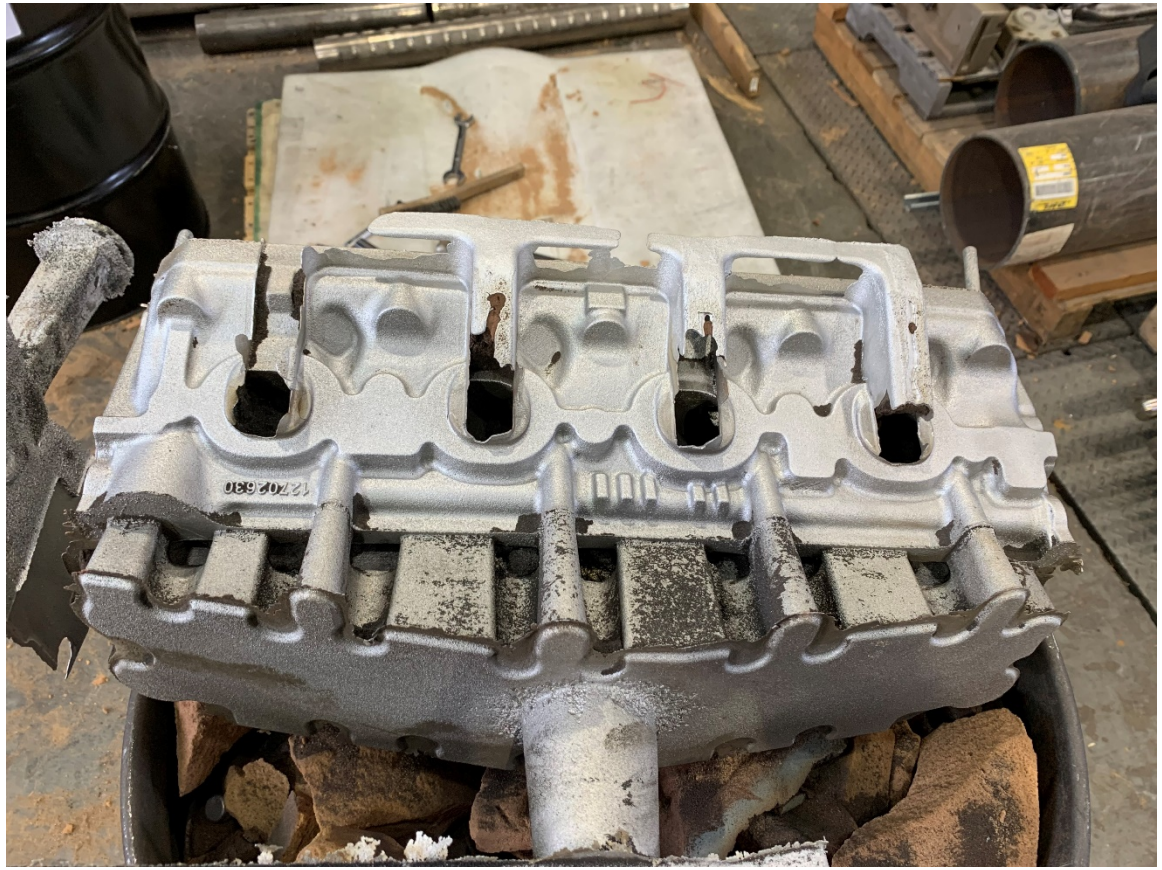


23-A20 Poured on 11Apr2023

770C Pour Temperature; Preheated Tundish and plug; Applied 7psi, no rollover

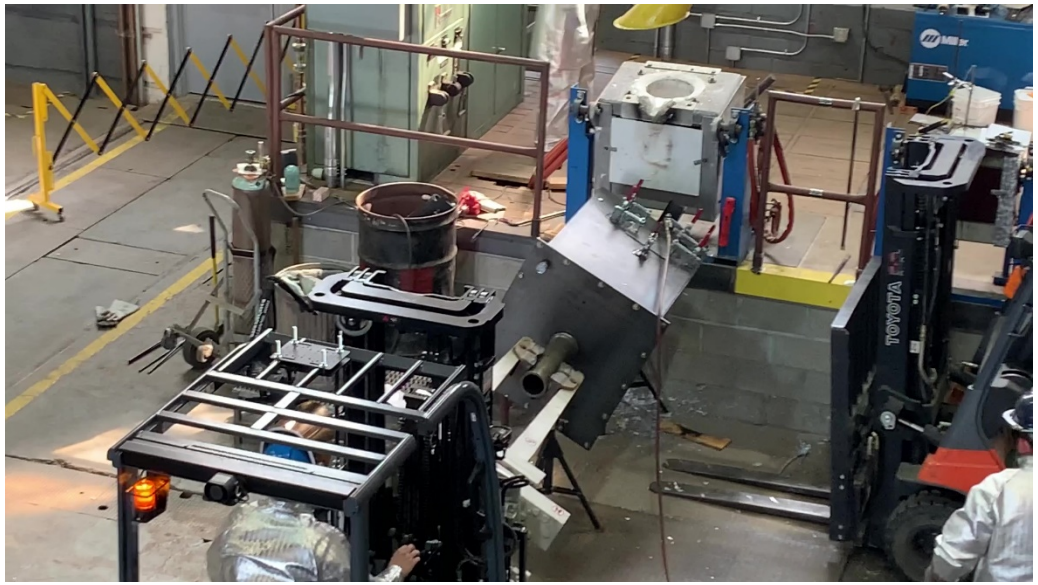
Exhaust and Intake Side Views

Fully Knocked Out



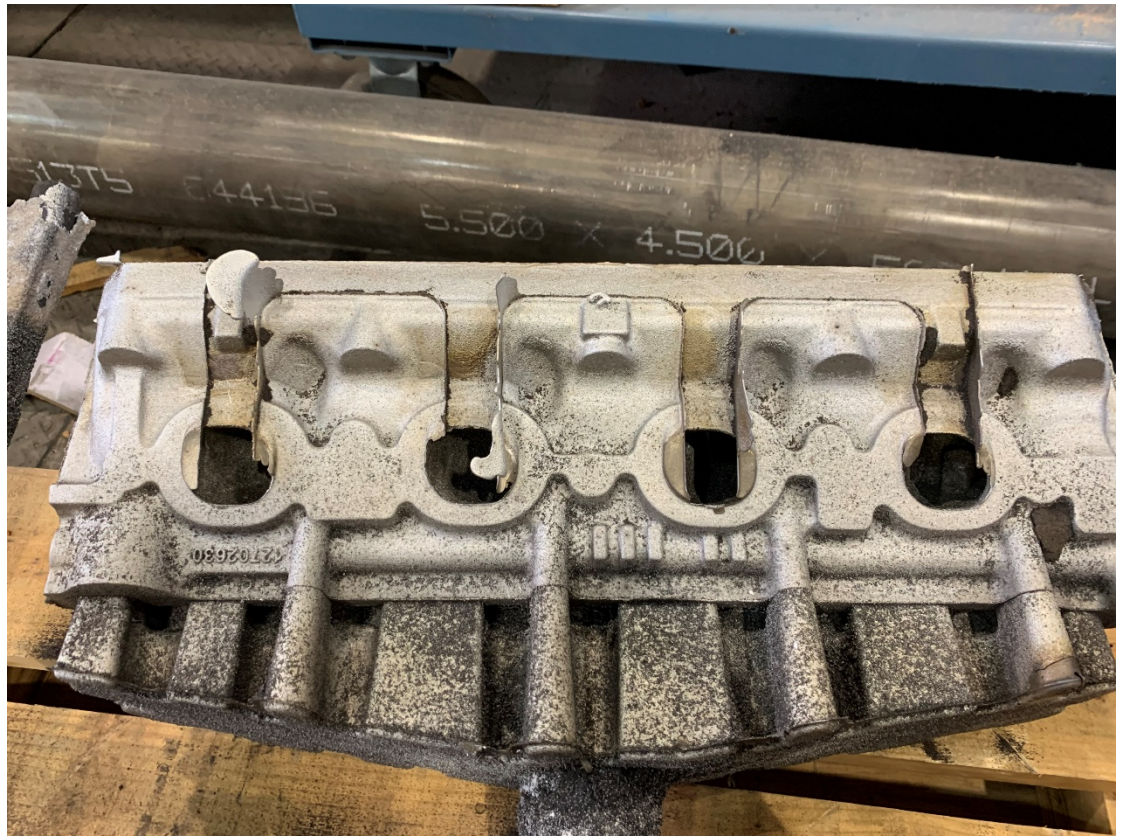
23-A47 Poured on 16Aug2023

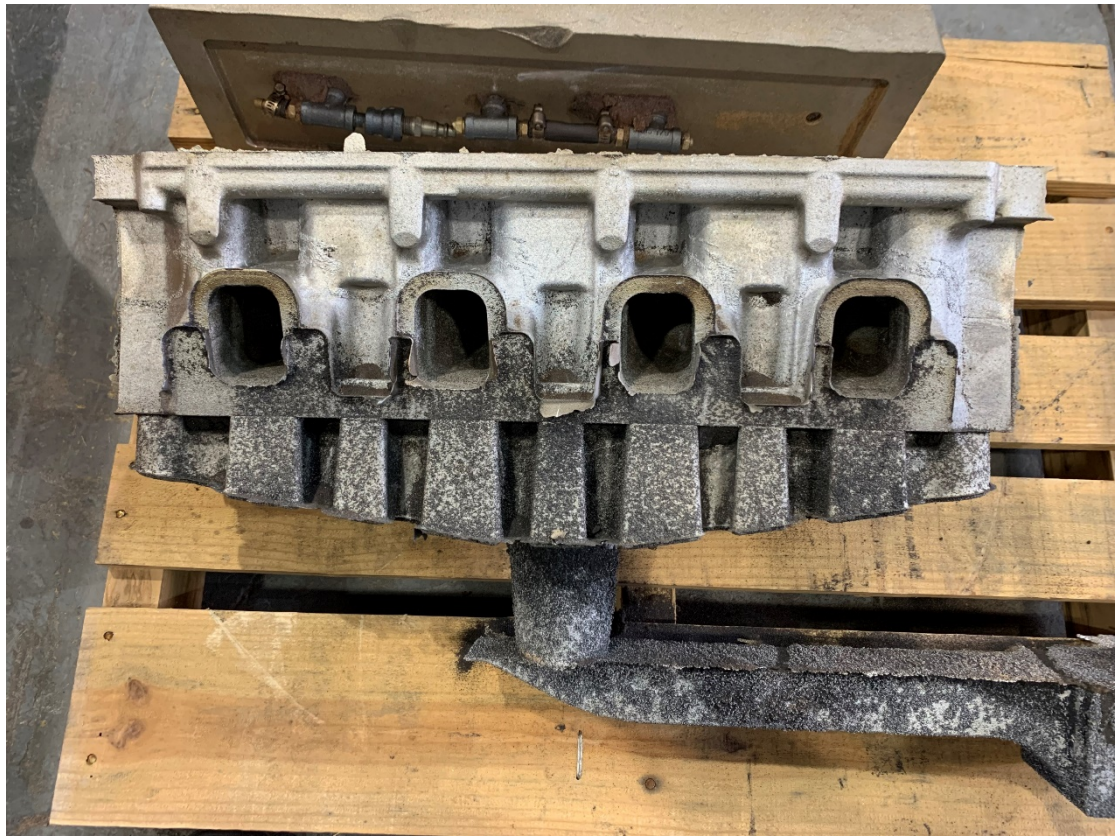
770C Pour Temperature; Preheated Tundish and plug; Applied 7psi, rolled over



Exhaust and Intake Side Views

Fully Knocked Out



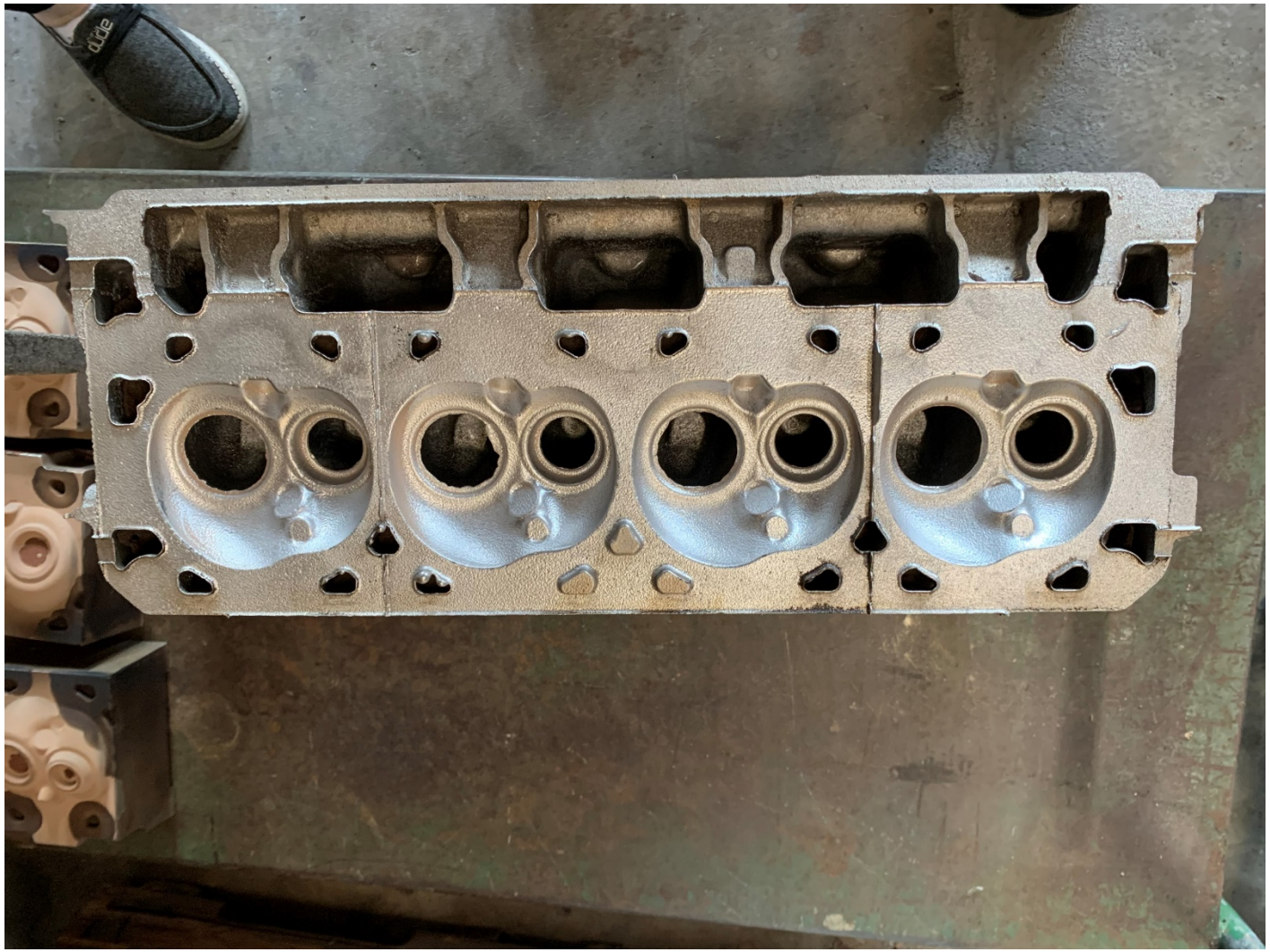


23-A48 Poured on 29Aug2023//Alloy Q

770C Pour Temperature; Preheated Tundish and plug; Applied 7psi

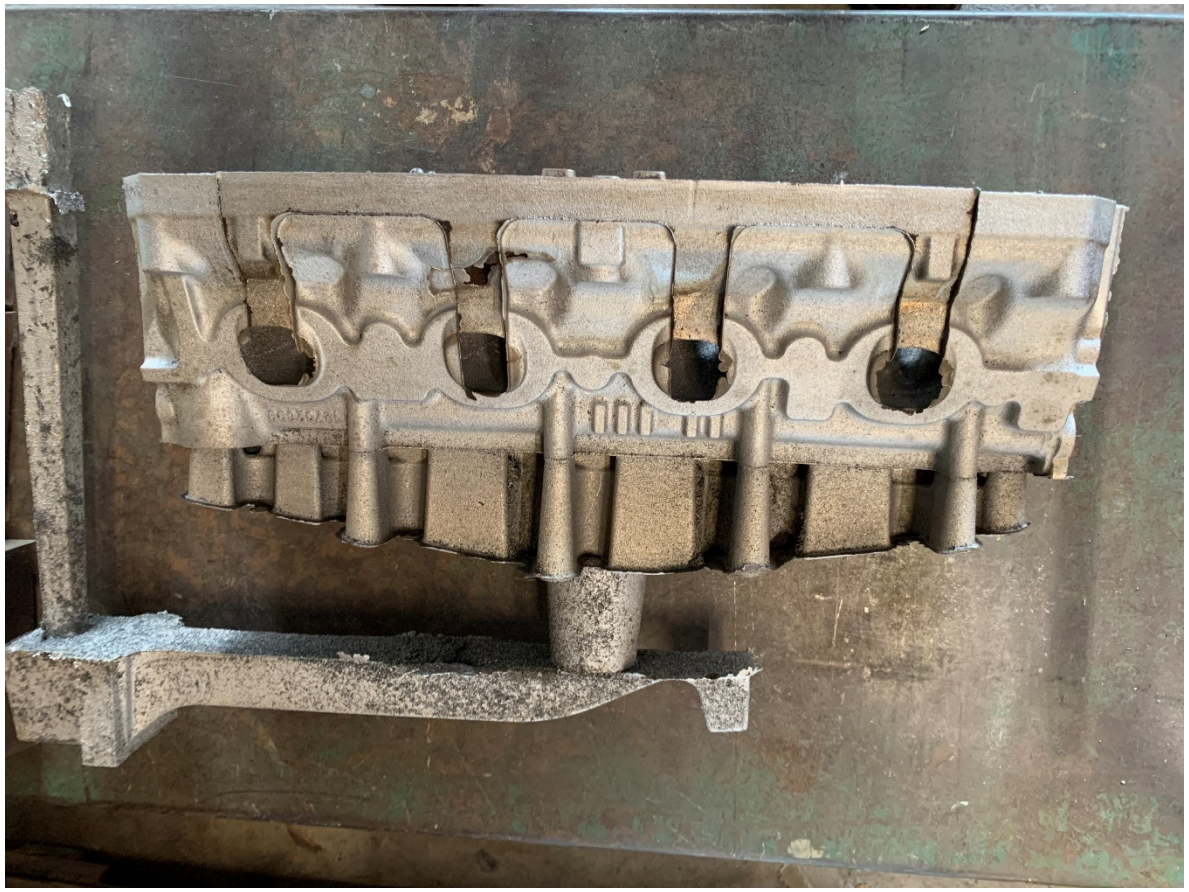
Deck Face View

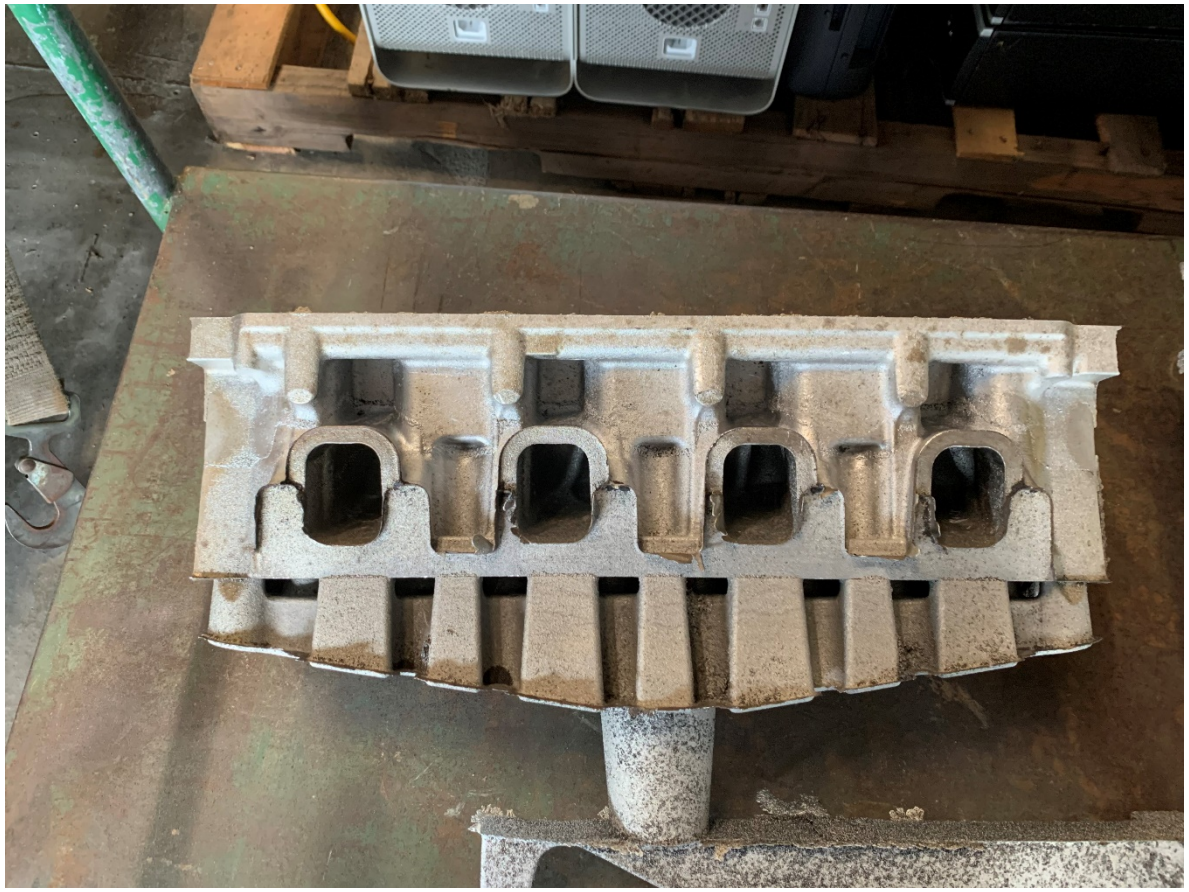
Fully Knocked Out



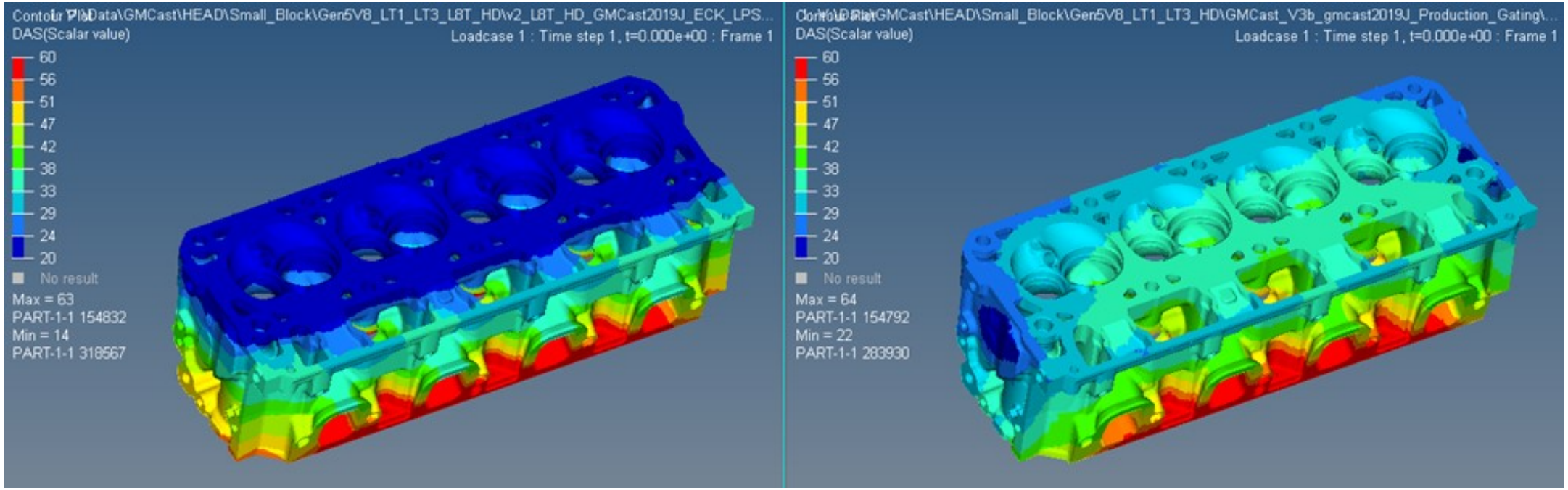
Exhaust and Intake Side Views

Fully Knocked Out





Cooling Rate Drives DAS

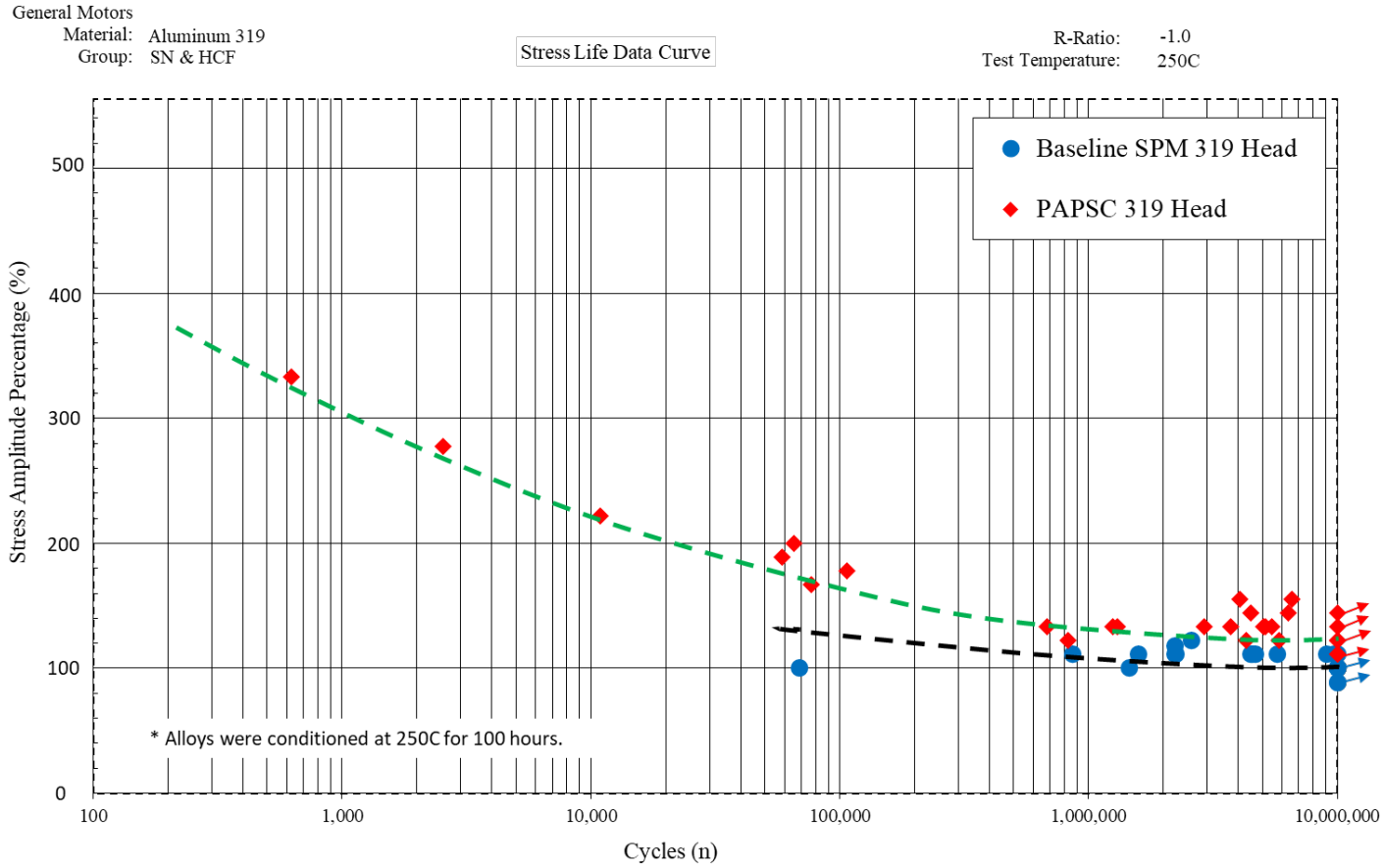


New PAPSC Process

Current Production

In the head made by new casting process (pressure-assist precision sand casting, PAPSC), the DAS values (dendrite arm spacing) in the deck face and combustion chambers are much more uniform and smaller than those in the production head made by semi-permanent mold (SPM) casting process.

Smaller DAS Improves Fatigue



Fatigue testing results show that the head made by new PAPSC process developed in this project has higher fatigue strength (>=25% in high cycle fatigue, HCF) in comparison with the head made in production by SPM process for the same 319 alloy. The improvement of low cycle fatigue (LCF) strengths is much more pronounced due to the refined microstructure and minimized porosity with the new casting process.

Summary

- This LightMat project involved combined efforts of NETL, GE and Eck Industries.
- Conventionally cast cylinder heads employ a semi-permanent mold which lacks microstructural control in the critical deck face region.
- The new PAPSC Process was designed in order to incorporate a chill in the critical deck face region and thus improve control over the scale of the microstructure.
- The new PAPSC Process reduced the DAS (Dendrite Arm Spacing) thus improving fatigue (>=25%) in the critical deck face region of the casting with the same alloy.