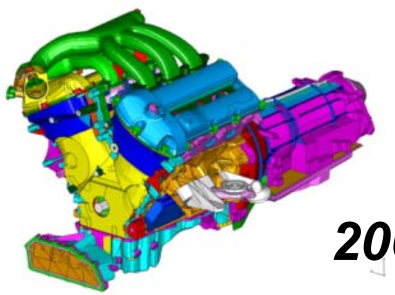
Magnesium Powertrain Cast Components

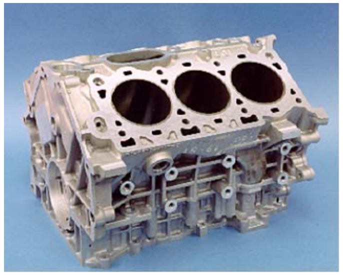
Project ID lm_16_quinn

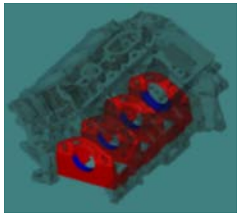
AMD 304



2009 DOE Merit Review Presentation

Prepared by: Bob R. Powell, Project Leader, GM
Presented by: James Quinn, General Motors





From aluminum to magnesium

Acknowledgement

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Overview

Timeline

- Start: Jan. 1, 2001
- End: Sept. 30, 2009
- 95% complete

Budget

- Total project funding
  - DOE share $4.3 M
  - USAMP share $6.6 M
- Funding received in FY08: $161.7K
- Funding for FY09: $124K
- Funding for FY10: $0 (Complete)

Barriers/targets

- Demonstrate technical feasibility of creep-resistant Mg alloys for replacing Al in major powertrain cast components; achieve 15% mass reduction
- Demonstrate cost-effective mass reduction; achieve <$2/lb mass saved
- Identify and address potential technical show stoppers

Partners

- **OEMs**: Chrysler, Ford, GM
- **Companies:** 36
- **Prof. Organizations:** 2
- (see next slide for complete list)

MPCC Project Team

Core Team:	Chrysler LLC, Ford, GM
Product Design:	Ford, GM, Chrysler LLC, Magna Powertrain
Alloy Suppliers:	AMC, Dead Sea Magnesium, GM, Noranda, Norsk-Hydro, Solikamsk, VSMPO-Avisma
Casters:	Eck, Gibbs, Intermet, Lunt, Meridian, Nemak, Spartan, Thixomat
Bore Treatment:	Gehring, Flame Spray
Tooling:	Becker, Delaware, EXCO, HE Vannatter
Coolants:	Ashland/Valvoline, ChevronTexaco, Honeywell/Prestone, INTAC
Fasteners:	RIBE
Gaskets:	Dana/Victor Reinz
Testing Labs:	Amalgatech, CANMET, Stork, Westmoreland, Quasar
Casting Modeling:	EKK, Flow Science, MAGMAsoft, Technalysis
Professional Organizations:	IMA, NADCA
Project Administration:	Ried and Associates

Overall Project Objectives

Phase I (2001-2003)

- Take a scientific, technical, and economic snap shot (2002) of magnesium alloys and determine their readiness for structural powertrain components

  Criteria and Objectives
  - **15% mass reduction for cast components of V6 engine – Mg replacing Al**
    - **Cylinder block, bedplate, structural oil pan, front engine cover**
  - **Cost effectiveness - < $2/lb mass reduced**
  - **Technical showstoppers – identify/assess; e.g., corrosion, creep, castability**

Phase II (2004-2008)

- Demonstrate Mg readiness and cost effectiveness by designing, casting, assembling, and testing a magnesium-intensive powertrain
- Initiate fundamental research
  - **To address showstoppers**
  - **To close critical scientific/technical gaps for future Mg powertrain applications**

FY2008 Project Objectives

- Sub-assembly testing of Mg engine components
  - Predict in-service material changes
- Engine dynamometer testing, teardown, and analysis of Mg-intensive engines
  - Demonstrate performance and durability
- Testing of specimens excised from cast Mg components; include in cast specimen electronic database for Mg component design
- Compute cost of mass reduction using IBIS cost models and manufacturing data developed in project
- Complete final report

USAMP AMD 304 – Magnesium Powertrain Cast Components

Task 1

Alloy evaluation and selection for each engine component

1.1 Test matrix and test program
1.2 Castability trials
1.3 Electronic database
1.4 Alloy selection for prototype components – pair-wise analysis

Task 2

Engine component design and cost modeling – phases 1 & 2

2.1 Engine block, bore and journal strategies
2.2 Fasteners, gaskets, sealing
2.3 Coolant and corrosion – coolant selected April 2006
2.4 FEA design, integration and analysis
2.5 Component casting and casting analysis
2.6 Technical cost modeling

Task 3

Building Mg scientific infrastructure: 5 Research Projects

Task 4

Casting operations – HPDC & LPPS

Task 5

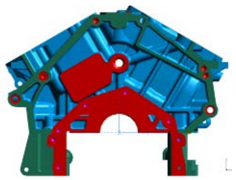
Excised specimen evaluation

Engine Testing

Task 6

Final Report

Significant challenges
- Overcoming higher thermal expansion of Mg for engine
- Robust corrosion protection – coolant and galvanic
- Casting sound components: eliminate casting defects



Alloy selection for components

Phase 1 Review Decision Gate

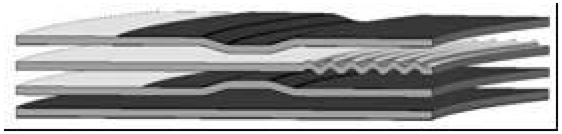
Patent application and award

2001	2002	2003	2004	2005	2006	2007	2008

FY2008 Milestones – Sub-assembly Testing

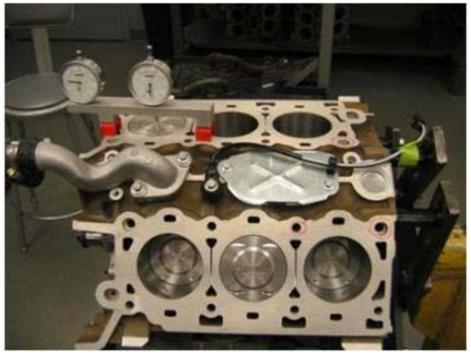
- Passed pulsator testing of head gasket
  - Validated cylinder head life and design for sealing Al head on Mg block

Schematic of Dana/Victor Reinz design for MPCC gasket



- Passed cyclic and static thermal aging
  - Head and main bolt load retention
  - Cylinder and crank bore distortion and growth acceptable
  - Head gasket sealing surfaces stable

FY2008 Milestones – Engine Testing – slide 1 of 3



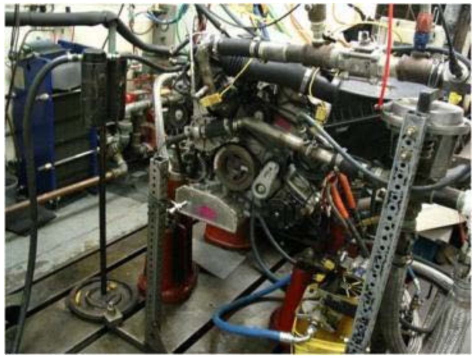
- Passed hot and cold scuff tests
  - Piston/ring packs compatible with bore
  - Wear resistance of sprayed bore coating
  - Adhesion of coating
  - Low lubricant conditions
  - Iron liners not required

Normal piston wear

- Passed 675 hr high speed durability test of Mg oil pan and front cover on Al block
  - No failure of Mg parts or loosening of bolts
  - No corrosion or abnormal noise and vibration

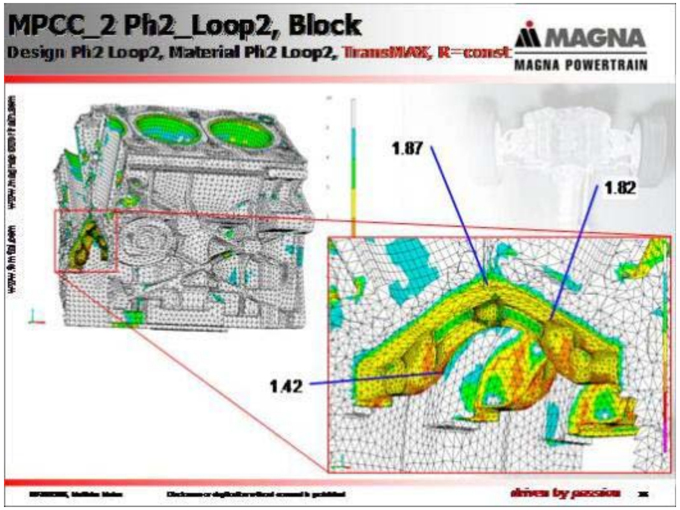
FY2008 Milestones – Engine Testing – slide 2 of 3

- Passed 672 hr test of coolant corrosion resistance of Mg block (Ford BL 102-02 variant)
- Test designed to simulate an on-road engine cycle for a small Ford vehicle and used to determine coolant corrosion in system
- Ran at reduced load to protect engine
- Engine runs 16 hours and soaks 8 hours - 42 days
- Coolant samples every 96 hours
- Tear down inspection of water passages ongoing
  - Initial inspection – excellent



FY2008 Milestones – Engine Testing – slide 3 of 3

- Deep Thermal Shock Test – bulkhead failure during break-in
- Completed root cause analysis
  - Failure at Fe insert/Mg bulkhead interface

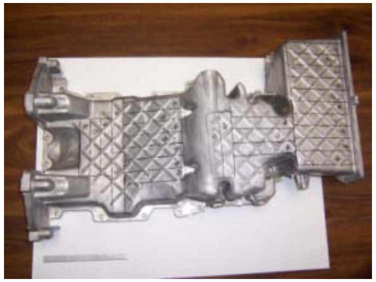


  - Original FEA did not predict failure
  - New FEA (using insights from from root cause analysis) does predict failure
  - Offer design alternatives to prevent failure in future

FY2008 Milestones – Excised Specimen Testing

- Excise specimens from cast components and test, to develop full mechanical and corrosion database with the accompanying design guide
  - X-ray, visual, die penetrant inspection
  - Tensile testing at 25, 125, and 150C

  - Cylinder Block – AMT SC1 alloy
  - Structural Oil Pan – MRI 153M
  - Front Engine Cover – MRI 230D
  - Rear Seal Carrier – MRI 153M



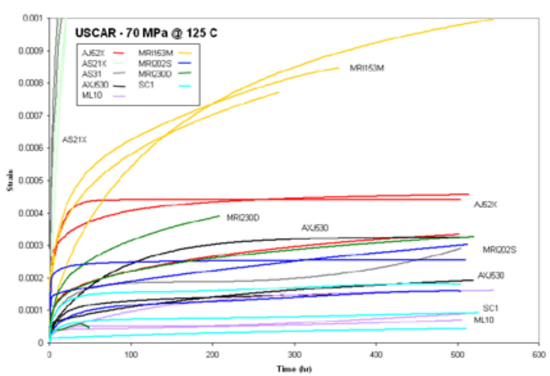
Cast Specimen Database

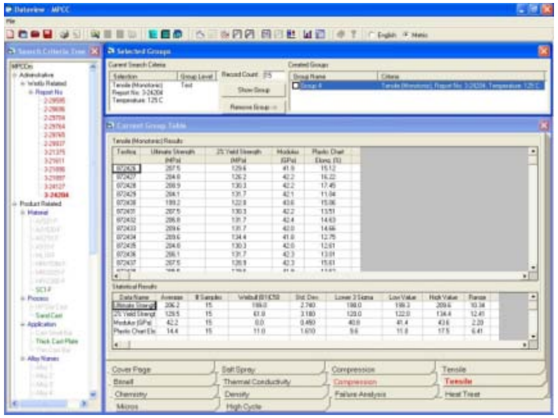
- Identified creep-resistant alloys suitable for engine components
  - Powertrain-specific test matrix
  - Thermo-physical properties
  - Static and dynamic thermo-mechanical properties
  - Atmospheric and coolant corrosion (hot surface and galvanic)

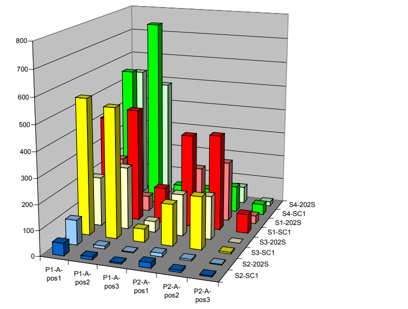
Mg Alloys Tested

HPDC
- Hydro AS21X
- Avisma AS31
- DSM MRI153M
- DSM MRI230D
- GM AXJ530
- Noranda AJ52

Sand Cast
- AMT SC1
- DSM MRI202S
- Solikamsk ML10

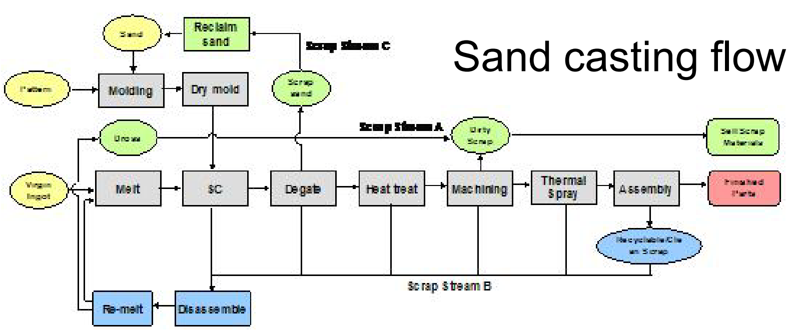




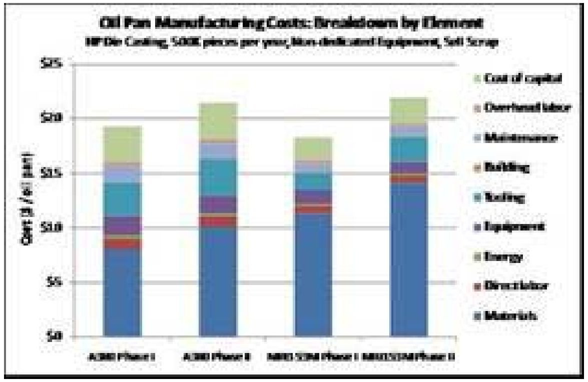


FY2008 Milestones – Cost of Mass Reduction

- Goal of project was cost-effective mass reduction
- Cost models built for sand casting and die casting
- Data acquired from tooling build and casting of Mg engine components
- Models predict component cost and show cost contributors
- Cost of 29% mass reduction of Mg components was \$4/lb
  - ~ the cost of a gallon of gas when model was run
  - Mg ingot primary cost factor (increased 50% from 2003 to 2008)



Sand casting flow sheet



FY2008 Milestones – Final Weight Savings

(kg and percent)

Component	Current Al	Mg Assembly	% change
Block assembly	32.2	24	25
Oil Pan	4.4	3.2	27
Front Cover	5.6	2.6	52
Total Change			29!!!!

Donor Engine Weight (with exhaust and flexplate) = 176.8 kg (389 lbs)

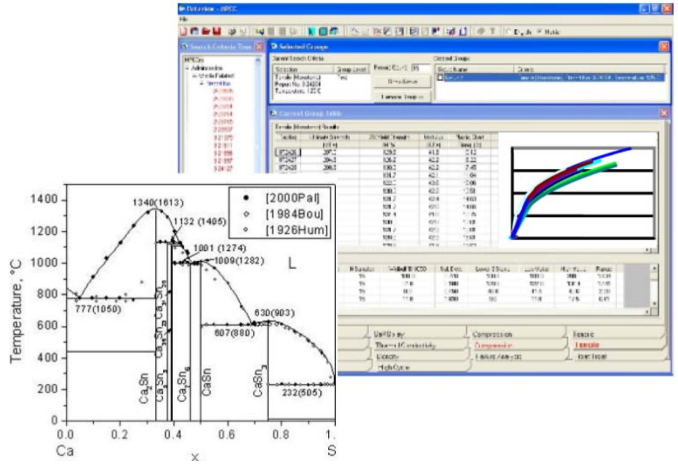
Mg Engine Weight (with exhaust and flexplate) = 163 kg (360 lbs)

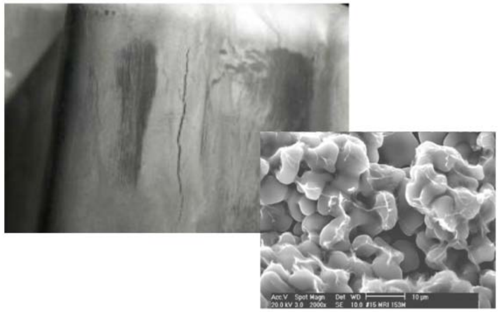
USAMP AMD 304 –
Magnesium Powertrain Cast Components

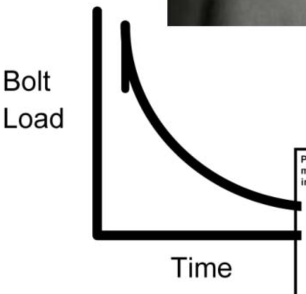
Task 3 Fundamental Mg Research

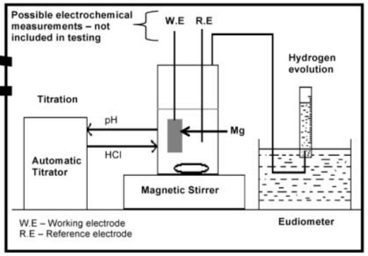
- Address MPCC-identified critical gaps in fundamental science of Mg for powertrain applications and initiate research in these areas
  - **Computational Thermodynamics and Alloy Development**
    - **Penn State – Z.K. Liu**
    - **Mg-Al-Ca, Mg-Ca-Sn, Mg-Ca-RE**
  - **Hot Tearing Behavior of Mg Alloys**
    - **CANMET – D. Emadi**
    - **Effects of Ca and Sn on AM50**
  - **Creep and Bolt-Load Retention of High Temperature Mg**
    - **Michigan at Ann Arbor – J.W. Jones**
    - **Models and mechanisms of creep; microscopy**
  - **Corrosion Evaluation Methodologies and Mechanisms**
    - **Michigan at Dearborn – P.K. Mallick**
    - **Methodology comparison; RBS of corrosion product**
  - **Recycling**
    - **Case WRU – D. Schwam**
    - **Industrial survey to identify issues**
  - **Alloy Development and Structure-Property Relationships**
    - **No proposal funded**

- Summary Article Published by TMS
  - **JOM – August 2007 pp. 43-48**









Future Work

- Complete metallographic analysis of water jacket in coolant corrosion test block
- Conduct systematic NVH assessment of Mg-intensive engine vs. Al production engine
  - Add-on project recommended because the Mg-intensive engine sounded very good during engine testing
  - Recommended by OEM NVH experts
- Complete and distribute final report in FY2009
  - Internal to project team members
  - External publications – technology transfer to NA industry, labs, and universities

Summary

1. MPCC project build on vision –

   "magnesium is ready for cost-effective, mass reduction of major powertrain components"
2. Project achieved 29% mass reduction for replacement of Al components with magnesium at a cost of $4 / lb ($1.79 / kg)
3. Able to physically test the Mg components and assembled engines
4. Passed four engine tests; failed bulkheads during break-in on DTS test
5. Root cause analysis identified design alternatives
6. Thermal expansion mismatch between Mg and Fe is a significant, but addressable challenge: US Patent 7,288,528 issued to USAMP
7. Neither corrosion nor creep proved to be show stoppers
8. NVH design strategy yielded encouraging results; work in progress
9. Seed-funded fundamental Mg research has become project legacy.