Magnesium Powertrain Cast Components Project (AMD 304)

USAMP
2008 DOE Peer Review Presentation
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Vision of the Project Team

“magnesium is ready for cost-effective, mass reduction of major powertrain components”

Mass reduction in the lower, front end of the vehicle:
- enhances performance
- improves fuel economy
  - through mass de-compounding
  - through powertrain downsizing
- reduces emissions
USAMP Magnesium Powertrain
Cast Components Project

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
2.1 Engine block, bore and journal strategies
2.2 Fasteners, gaskets, sealing
2.3 Coolant and corrosion
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
Significant challenges
• Overcoming higher thermal expansion of Mg for engine
• Robust corrosion protection – coolant and galvanic
• Casting sound components: eliminate casting defects

Task 5
Prototype casting – HPDC and LPPS

Task 6
Decision Gate
2001 2002 2003 2004 2005 2006 2007

Patent Application
Excised specimen Testing
Engine testing
Final Report

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Technology Development


- Take a scientific, technical, and economic snap shot (circa 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

- Decision Gate (October 2003)

Phase II (2004-2008)

- Demonstrate Mg readiness 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
Task 1 Accomplishments

- Identified creep-resistant alloys suitable for engine components
  - 7 HPDC and 3 SC alloys
  - Powertrain-specific test matrix
    - Thermo-physical properties
    - Static and dynamic thermo-mechanical properties
    - Atmospheric and coolant corrosion (hot surface and galvanic)
- Defined casting protocols and completed casting trials
- Completed testing and the electronic database
- Cost models for both HPDC and SC components
- Implemented a pair-wise analysis methodology for matching alloys to components

Mg Alloys Tested

**HPDC**
- Hydro AS21X
- Avisma AS31
- DSM MRI153M
- DSM MRI230D
- GM AXJ530
- Noranda AJ52
- Noranda AJ62X

**Sand Cast**
- AMT SC1
- DSM MRI202S
- Solikamsk ML10

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Task 2 Accomplishments

- Design a Mg version of the Al 2002 Duratec 2.5L
  - Bore strategy – using wear-resistant coatings in lieu of iron liners
  - Completed component designs
    - Front engine cover, oil pan, block, and rear seal carrier
  - Selected alloys for each component
    - Revised designs for alloy properties from Task 1
  - Exceeded the original mass reduction goal: 15%
  - Completed coolant testing and selected coolant for engine tests
    - ASTM B1384 and D4340
    - Completed head gasket corrosion testing and dirty oil testing
  - Selected fasteners

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A crank shaft support assembly for increasing stiffness and reducing thermal misalignment distortion in a crank shaft bore of an engine comprising different materials. A cylinder block comprises a first material and at least two crank journal inserts are insert-molded into respective crank journal regions of the cylinder block and comprise a second material having greater stiffness and a lower thermal coefficient of expansion than the first material. At least two bearing caps are bolted to respective crank journal inserts and define, along with the crank journal inserts, at least two crank shaft support rings defining a crank shaft bore coaxially aligned with a crank shaft axis. The bearing caps comprise a material having higher stiffness and a lower thermal coefficient of expansion than the first material and are supported on the respective crank journal inserts independently of any direct connection to the cylinder block.

19 Claims, 9 Drawing Sheets
Final Weight Savings (kg and percent)

<table>
<thead>
<tr>
<th>Component</th>
<th>Current Al</th>
<th>Mg Assembly</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block assembly</td>
<td>32.2</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Oil Pan</td>
<td>4.4</td>
<td>3.2</td>
<td>27</td>
</tr>
<tr>
<td>Front Cover</td>
<td>5.6</td>
<td>2.6</td>
<td>52</td>
</tr>
<tr>
<td><strong>Total Change</strong></td>
<td><strong>29!!!!</strong></td>
<td><strong>29!!!!</strong></td>
<td><strong>29!!!!</strong></td>
</tr>
</tbody>
</table>

Target was 15%
### USAMP Magnesium Powertrain Cast Components Project

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**Task 3**
- Building Mg scientific infrastructure: 5 Research Projects

**Task 4**
- Significant challenges
  - Overcoming higher thermal expansion of Mg for engine
  - Robust corrosion protection – coolant and galvanic
  - Casting sound components: eliminate casting defects

**Task 5**
- Prototype casting – HPDC and LPPS

**Task 6**
- Decision Gate
- Patent Application
- Excised specimen Testing
- Engine testing
- Final Report

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
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<th>2005</th>
<th>2006</th>
<th>2007</th>
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Task 3 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
Engine Block Casting

• Part cast by Fonderie Messier, Arudy, France

• Alloy is SC-1

• Cast in pan-rail up position using Low Pressure Sand Casting

• Fe/FeO spray bore and honing at Gehring
Oil Pan, Front Cover, and Rear Seal Carrier Castings

- Part cast by Intermet using HPDC process
  - Alloy is MRI 230D
  - 2.5 mm nominal wall thickness

- Part cast by Spartan LMP using HPDC process
  - Alloy is MRI153M
  - 3.0 mm nominal wall thickness
  - Friction stir welded plate on sump

- Part cast by Thixomat using Thixomolding process
  - Alloy is MRI153M
Component Testing

- Thread strength/torque tests – head bolts and mains (Ford Fastener Lab)
- Pulsator test for cylinder head life and gasket sealing (Dana)
- Ambient temperature cylinder and crank bore distortion (Ford Metrology Lab and Gehring)
- High temperature testing (Roush)
  - 100 hrs of thermal cycling between -40°C and 150°C
  - 100 hours at 150°C
    - Head and main bolt load retention
    - Cylinder and crankbore distortion and growth
    - Head gasket sealing surfaces
Engine Dynamometer Testing (Roush)

- Hot scuff
- Cold scuff
- 150 hour deep thermal cycle
- 300 hour high speed durability
- 480 hour key life thermal
- 675 hour engine system test

Test Engine on Dyno

Hot Scuff Engine Prep
USAMP Magnesium Powertrain Cast Components Project

Project Completion Timeline

- Component Casting
- Block Machining and Spray Bore
- BOM Assembly
- Engine Assembly & Test
- Excised Sample Test
- Final Report Writing

Timeline:
- 9/2006
- 3/2007
- 9/2007
- 3/2008

- Batch 1
- Batch 2

- Hot Scuff - pass
- 100 cycle Thermal - pass
- 100 hour Thermal – test completed - analysis
- Cold Scuff - pass
- Durability Testing

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Remaining Work

• Complete Durability Testing of Engines
• Perform Engine Tear-Down Analysis
• Analysis of Oil and Coolant
• Complete Excised Specimen Testing
• Complete Cost Model Analysis
• Complete Final Report
Magnesium Power Cast Component Final Deliverables:

- Ultra-light-weight, cost-effective, V-block, engine design using the most promising low-cost, creep-resistant Mg alloys
- Dynamometer-tested Mg-intensive engines to validate the FEA design performance and durability models
- Powertrain Mg alloy design database – cast and excised specimens
- Machinability assessment of the Mg alloys
- Cost model to enable determining the cost-benefit ratio
- OEM-common material specification for Mg powertrain alloys
- Stronger NA Mg research infrastructure to enable future developments in alloys, processes, and components
- Technology transfer of project results to industry
MPCC Project Team

Core Team: J. Allison, R. Beals, J. Hines, L. Kopka, R. McCune, W. Miller, L. Ouimet, B. Powell, J. Quinn, P. Ried

Product Design: Ford, GM, DCX, 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

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