AMD 405: Improved Automotive Suspension Components Cast with B206 Alloy

USAMP

2008 DOE Peer Review Presentation

February 28, 2008

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This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Numbers DE-FC05-02OR22910 and DE-FC26-02OR22910.

Agenda

- ❑ **Project Participants**
- ❑ **Basic Concept**
- ❑ **Gaps**
- ❑ **Project Overview**
- ❑ **Project Accomplishments by Phase**
- ❑ **Risks and Challenges Remaining**
- ❑ **Conclusions**

Project Participants

- **OEMS**
  - Ford Motor Company - Jake Zindel
  - General Motors Corporation - Richard Osborne, Larry Ouimet and Kasi Goundan
  - Chrysler LLC - Eric McCarty and Bruce Cox
- **Current Suppliers**
  - Alcan International
  - Creative Concepts
  - GKS Engineering
  - NEMAK
  - Sync Optima
  - University of Windsor
  - Westmoreland MT Labs
  - Eck Industries
  - Ballard Brass and Aluminum
  - Mercury Castings
- **Suppliers withdrawn from program**
  - Hayes-Lemmerz

Basic Concept

- **Follow-on project to AMD 305**
- **3.5 Year Project**
- **$1,037K Total Budget ($584k Cash, $453k In-Kind)**
- **4 Phases**
- **B206 properties are desirable for suspension applications**
  - B206 (Al,Cu alloy) has similar mechanical properties as ferritic ductile iron.
  - B206 has superior mechanical properties compared to common aluminum suspension alloys such as forged 6061 and permanent mold A356.2.
  - Suspension alloys are typically designed to the yield stress and require elongations greater than 7% for impact and crash properties.

Mechanical Properties for Select Suspesion Materials

Material	Process	Temper	Tensile		Yield		Elongation	Hardness
			MPa	ksi	MPa	ksi	% min.	HB500
A356	Sand	T6	235	34	165	24	3.5	70 - 100
	PM	T6	255	37	180	26	7	80
A356.2	PM	T6	276	40	207	30	7	80 - 100
6061	Forging	T6	241	35	214	31	12	73
6061	Forging	T6	310 min.		270 min.		10% min.	
65-45-12	Sand		450	65	310	45	12	156-217
60-40-18	Sand		415	60	275	40	18	143-187
B206	PM	T4	430 - 450	62 - 65	250 - 260	36 - 38	18 - 22	
	PM	T7	445 - 455	64 - 66	370 - 390	54 - 57	9	

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Gaps

Risk/challenge	Plan to overcome challenge	Explanation
Castability and Hot Tearing	Determine effect of alloy composition on mechanical properties. Evaluate the effect of alloy composition on hot cracking and castability.	A206 is a difficult alloy to cast as it is sensitive to cooling rate and is susceptible to hot tearing.
Stress Corrosion Cracking (SCC) and Heat Treatment	Evaluate new, quicker, alternative methods for evaluating SCC. Optimize T4 and T7 heat treat processes for best mechanical properties with minimal SCC susceptibility.	A206, when artificially aged to peak properties (T6 temper), is susceptible to SCC but immune to SCC in the T4 and T7 tempers.
Cost and application	Cost Model B206 against materials/alloys used in suspension components. Evaluate semi-permanent mold and precision sand casting processes as low cost alternatives to permanent mold. Cast and test control arms and compare performance against target component.	Application of a material is dependent upon material and process cost and performance.

Project Overview

- **Phase 1: Alloy Composition** — Complete
  - Determine the effect of alloy composition on mechanical properties in the T4 and T7 heat treated conditions; and establish the feasibility of using less expensive versions of the alloy
- **Phase 2: Stress Corrosion Cracking and Optimized Heat Treat** — In Process
  - Study heat treatment of B206 alloy, and establish combinations of aging time and temperatures which produce desirable stress corrosion immunity. This portion of work will also determine the feasibility of using improved T7 heat treatment cycle to increase elongation in this temper
- **Phase 3: Cost Modeling** — Complete
  - Create cost models for automotive suspension components produced by different processes and different materials.
- **Phase 4: Production Casting Trials** — In Process
  - Produce control arm castings using two different casting processes. Test components produced in the T4 and T7 tempers, to provide required engineering information, and establish the feasibility of using cast B206 alloy components to replaced forged aluminum parts.

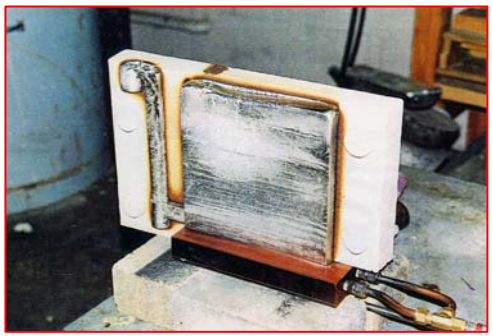
Phase 1 Accomplishments

- **Optimum Chemistries for T4 and T7 Tempers have been identified**
  - Statistically designed study of 16 B206 alloy variants
  - T4 Temper
    - Chemistry: 4.7 to 4.9% Cu, 0.35 % Mg and 0.2 % Mn.
    - Expected tensile properties: 250-260 MPa YS, 430-450 MPa UTS, and 18-22% el.
  - T7 Temper
    - Chemistry: 4.2 to 4.4% Cu, 0.15% Mg, 0.2% Mn, 0.10%Fe, 0.10%Si.
    - Expected tensile properties: 370-390 MPa YS, 445-455 MPa UTS, and ~9% el.
- **Notes:**
  - Castings which are heat treated to the T4 temper have a reasonable tolerance for the impurity elements Fe and Si. Depending on the desired elongation and the freezing rates in a casting, the maximum allowable limits for these elements can be increased.
  - Zinc additions have no beneficial effect in this alloy. On the contrary, a small loss of strength was noted when significant amounts of zinc were present. For this reason, the recommended maximum limit of Zn in B206 alloy is 0.05%.
  - It would be useful to increase the maximum limit for Mg from 0.35% to 0.55%. This would allow for an increase of 30 MPa in the yield strength of B206 alloy in the T4 temper.

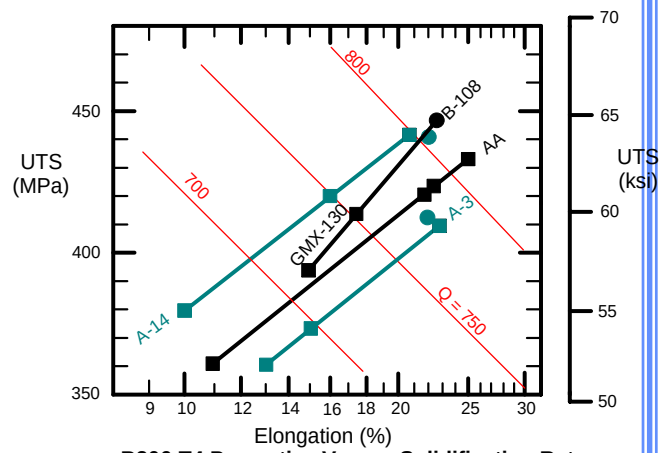
Phase 1 Accomplishments (continued)

❑ Cooling rate studies

- End Chill tests conducted at ALCAN to determine effect of cooling rate on cell size and resultant mechanical properties

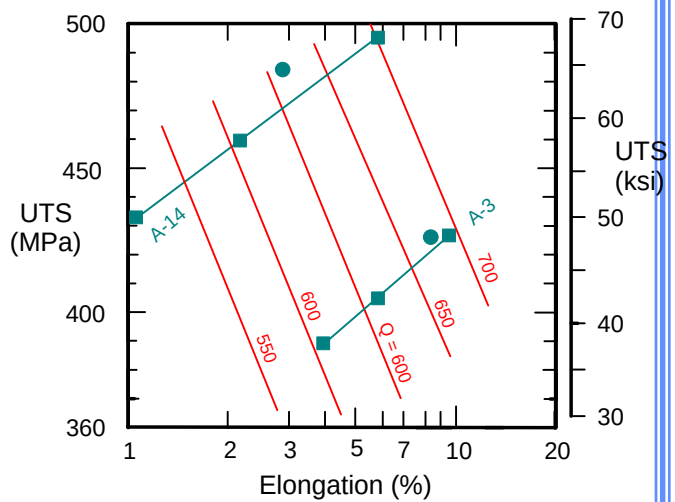


- Wedge castings cast by NEMAK to determine properties with respect to cooling rate



B206-T4 Properties Versus Solidification Rate

(Green lines are from this study. Black lines are from two permanent mold castings (AMD 305.)



B206-T7 Properties Versus Solidification Rate

(Squares represent tensile data from end-chill castings. Circles are for separately cast test bars.)

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Phase 1 Accomplishments (continued)

- **Hot Crack Test Castings**
  - Hot cracking susceptibility does not vary much over the chemistry range
  - Propensity for hot crack formation is much less in sand molds.

- **Casting and Design Guide for B206 Alloy developed**
  - B206 has a long freezing range where the best properties are achieved through steep thermal gradients (i.e. chills)
  - Due to sensitivity for hot tearing, B206 requires strategic placement of gates and risers to avoid hot spots.

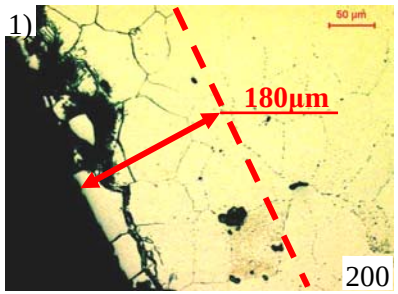
Phase 2 Accomplishments

- **The effect of heat treatment on hardness, tensile properties, corrosion and stress corrosion**
  - Electrical Conductivity Testing
  - Intergranular Corrosion Immersion Testing
    - Maximum corrosion depth
  - Tensile and hardness Testing

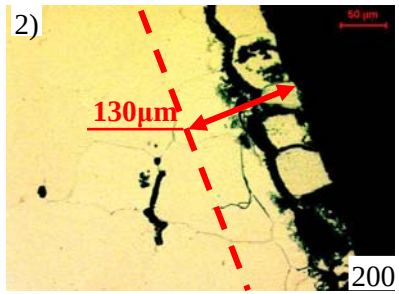
SCC Heat Treat Matrix		Time (hours)			
Standard Two Step Solution Heat Treatment					
	Heat to 493 - 504 ºC (820 - 940 ºF)	2			
	Gradually increase to 527 - 532 ºC (980 - 990 ºF)	8			
	Water quench to 66 ºC (150 ºF)				
Aging and Artificial Aging Heat Treatment Matrix					
	Natural Aging at Room Temperature	21	168		
	Natural Age for 24 hours and Artificial Age at 160 ºC	5	10	24	48
	Natural Age for 24 hours and Artificial Age at 180 ºC	2.5	5	10	120
	Artificial Age @150 ºC	0.5	1	2	8
	Artificial Age @200 ºC	0.5	1	2	8
Samples taken from the “bulb” end of the B206 permanent mold cast tensile test bars (ASTM B108)					

Phase 2 Accomplishments (continued)

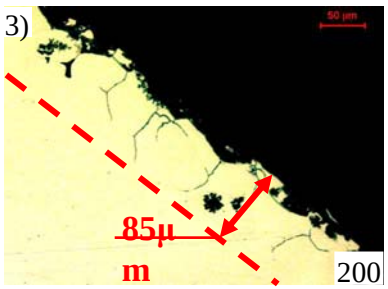
- **Intergranular Corrosion Immersion Tests**



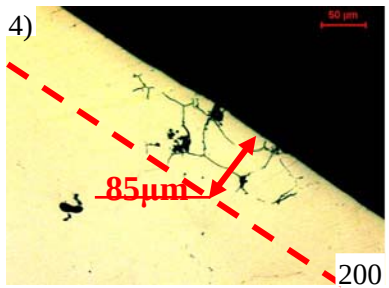
NA: 24hrs, AA: 160°C 24hrs



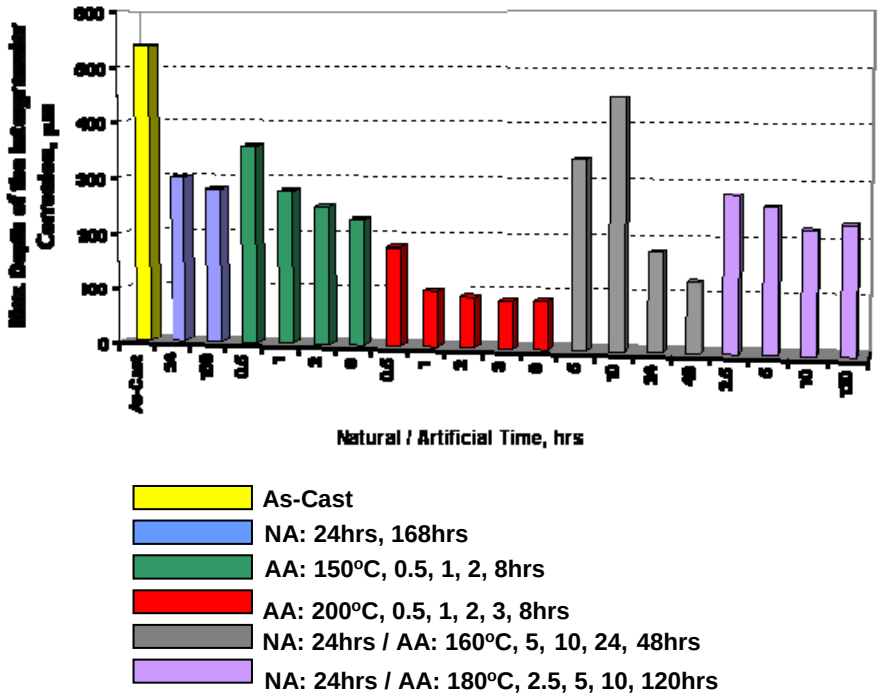
NA: 24hrs, AA: 160°C 48hrs



AA: 200°C 3hrs

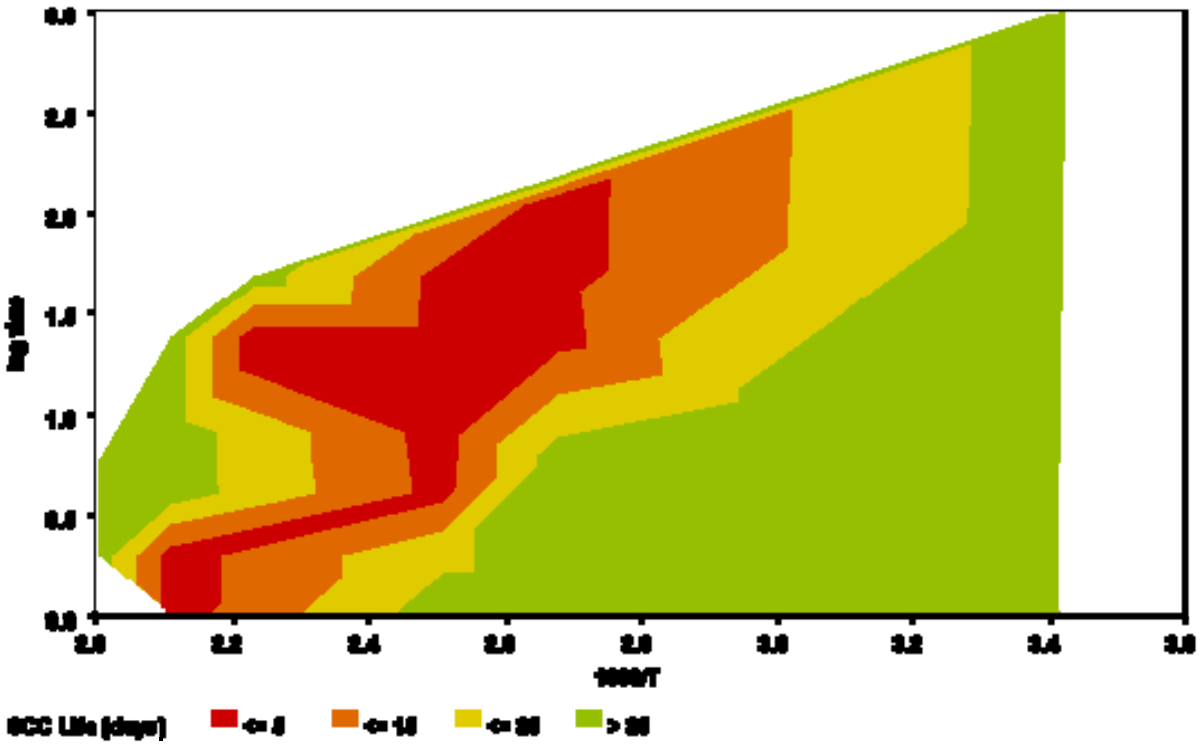


AA: 200°C 8hrs



Phase 2 Accomplishments (continued)

- **Percent elongation is sensitive to artificial aging temperature and time**
  - Lower temperatures and shorter times are best for improving elongation but possibly at the expense of corrosion



Arrehnius Contour Plot of the B206 alloy SCC data collected by Westmoreland Mechanical Testing and Research Inc.. SCC life is expressed as the log of AA time in hours as a function of the reciprocal of absolute AA temperature.

Phase 3 Accomplishments

- **Cost Model Developed**
  - The Model uses optimized designs based on expected properties

	356-T6	206-T4	206-T7
Mat'l Cost $/kg	2.00	2.20	2.20
Casting Weight, kg	4.89	4.57	3.9
Engr'd Scrap, kg	2.10	2.23	1.90
Melting & Handling, $/kg	0.5	0.5	0.5
Amortized Equipment, $/kg	0.00	0.00	0.00
Casting Oper. $/casting	9.78	10.05	8.58
Production Scrap, M/S	1.15	1.17	1.17
Solution Heat Treat, $/kg-hr	0.0110	0.0110	0.0110
Solution Heat Treat, hrs	6.00	10.00	10.00
Aging Heat Treat, $/kg-hr	0.0044	0.0044	0.0044
Aging Heat Treat, hrs	8.00	0.00	4.00
Cost of Heat Treatment, $/part	0.4949	0.5027	0.4976
Value of mass savings, $/kg	0.00	0.00	0.00

Base Cost, $/casting	25.64756	26.4233	22.61806
Difference		-0.77574	3.029499

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Phase 4 Accomplishments

- **NEMAK cast precision sand castings**
  - Cooling rate was insufficient to obtain desired properties
  - Significant porosity due to sand-binder reactions
- **NEMAK – Semi-permanent mold castings**
  - Machined aluminum drag used to increase cooling rate
  - NEMAK showed that it is feasible to achieve forged aluminum 6061-T6 tensile properties.
    - T4 control arms missed minimum yield by ~10%
    - T7 control arms missed elongation target

Target Control Arm Mechanical Properties			
	Ultimate Tensile Strength	Yield Strength	% Elongation
Forged 6061-T6	310 MPa Min	270 MPa Min	10% Min
B206-T4	412 MPa	253 Mpa	17.50%
B206-T7	417 MPa	359 Mpa	5.11%

* Note T4 and T7 castings used the same chemistry

Risks and challenges remaining

Risk/challenge	Plan to overcome challenge	Explanation
Optimum T7 Heat Treatment	Continue ongoing work at University of Windsor to develop an optimize T7 temper properties (increase elongation)	T4 Temper still runs the risk of SCC in high temperature applications. T7 temper is preferred for high temperature applications or applications in proximity to heat sources.
Validate B206 alloy using Semi-Permanent Mold	Cast fifty T4 and fifty T7 Pontiac Solstice control arms to desired properties and test for fatigue, mechanical properties and corrosion.	Complete Phase 4 of the project by casting semi-permanent mold castings to exceed minimum desired properties.
Validate B206 alloy using direct chill (Ablation) process	Cast fifty T4 and fifty T7 Pontiac Solstice control arms to desired properties and test for fatigue, mechanical properties and corrosion.	NEMAK trials demonstrated B206's sensitivity to cooling rate. The Ablation process has cooling rates similar to permanent mold and can achieve the desired mechanical properties for the targeted control arm.

Ablation Casting

- **Sand casting in a carwash**
  - Rapid cooling rate is ideal for B206 alloy where steep thermal gradients are needed to achieve optimum properties
  - Ablation cast B206 should be less susceptible to hot tearing since the mold is stripped away just ahead of the solidification front.
    - Unconstrained
    - Direct metal feed
  - The Ablation process may reduce or eliminate risers.
    - Less material = reduced cost

Conclusions

- **Project has or is addressing all technical barriers to using B206 alloy for suspension applications**
- **Alloy is capable of being cast in semi-permanent mold but sand casting requires significant chilling**
- **B206-T7**
  - can be cast in semi-permanent mold
  - is not susceptible to SCC
  - is less expensive than 356-T6 with design optimized
- **B206-T4**
  - can be cast in semi-permanent mold
  - is not susceptible to SCC
  - comparable to 356 with design optimized
  - low temperature applications desired to avoid detrimental artificial aging with respect to SCC