AUTOMOTIVE ALLOYS 1999

Edited By

Subodh K. Das
AUTOMOTIVE ALLOYS 1999

Proceedings of the symposium
sponsored by the Light Metals Division of
The Minerals, Metals & Materials Society (TMS)
held during the 1999 TMS Annual Meeting in San Diego, California
February 28 - March 4, 1999

Edited by
Subodh K. Das
AUTOMOTIVE ALLOYS 1999
TABLE OF CONTENTS

OVERVIEW

IS THE ALUMINUM CAR A FANTASY? ................................................................. 3
F. Katrak, D. Persampieri, M. Loreth, and J. Morton

OVERVIEW OF DOE’S PROGRAMS ON ALUMINUM AND MAGNESIUM
FOR AUTOMOTIVE APPLICATIONS ................................................................. 41
J. Carpenter, S. Diamond, S. Dillich, T. Fitzsimmons, J. Milliken,
and P. Sklad

ALCAR™ — A MODEL FOR HORIZONTAL R&D CONSORTIA ......................... 51
H.W. Hayden, G.B. Barthold, and S.K. Das

INNOVATIVE ALUMINUM APPLICATIONS FOR AUTOMOTIVE USE IN
EUROPE ........................................................................................................... 59
D.G. Altenpohl and P. Furrer

MECHANICAL SURFACE TREATMENTS ON HIGH-STRENGTH
MAGNESIUM ALLOYS FOR FATIGUE LIFE IMPROVEMENTS ..................... 77
M. Hilpert and L. Wagner

METALLURGICAL CHARACTERISTICS OF CONDUCTIVE HEAT
RESISTANCE SEAM WELDS ON ALUMINUM SHEET ............................... 87
J.E. Gould and L.R. Lehman

PRODUCING STEERING WHEEL FRAMES WITH AN AIMg5Si2Mn-
TYPE ALLOY .................................................................................................. 99
M.C. Wuth, H. Koch, and A.J. Franke

FUNDAMENTAL STUDIES

DUCTILITY AND FORMABILITY OF AUTOMOTIVE AI ALLOY SHEET ...... 113
T.R.G. Kutty, D.S. Wilkinson, J.D. Embury, and D.J. Lloyd

EFFECT OF Si ON THE AGEING BEHAVIOUR AND FORMABILITY OF
ALLOYS BASED ON AA6016 ................................................................. 123
S.M. Hirth, G.J. Marshall, S.A. Court, and D.J. Lloyd
MICROSTRUCTURAL STRENGTHENING IN Al-Zn-Mg-Cu ALLOYS USED IN AUTOMOTIVE BUMPERS .......................................................... 133
W.J. Poole, J.A. Saeter, J. Huang, G. Waterloo, and S. Skjervold

THE ROLE OF NATURAL AGING ON SUBSEQUENT PRECIPITATION DURING THE ARTIFICIAL AGING OF AA6111 ALUMINUM ALLOY ............... 143
S. Esmaeili, D.J. Lloyd, and W.J. Poole

A PROCESS MODEL FOR THE AGE HARDENING OF A 319-TYPE ALUMINUM ALLOY ................................................................. 153
C.A. Cloutier, P.M. Reeber-Schmanski, J.W. Jones, and J.E. Allison

OBSERVATION OF THROUGH-THICKNESS DEFORMATION BANDS IN AN Al 6111 ALLOY DEFORMED IN PLANE STRAIN TENSION ....................... 161
P.S. Lee, G. Jarvis, A.D. Rollett, H.R. Piehler, and B.L. Adams

TEXTURE EVOLUTION OF A STRIP CAST AA5XXX ALUMINUM ALLOY DURING ANNEALING .......................................................... 171
Y. Liu, Y.L. Liu, G. Liao, and J.G. Morris

IMPROVEMENT OF HOT DUCTILITY IN Al-Mg BASE ALLOYS CAUSED BY SMALL AMOUNTS OF ADDITIONAL ELEMENTS ............................. 181
K. Horikawa, S. Kuramoto, and M. Kanno

DEVELOPMENTAL STUDIES

OPTIMISED 6XXX ALUMINUM ALLOY SHEET FOR AUTOBODY OUTER PANELS .................................................................................. 193
R. Shahani, D. Daniel, J.C. Ehrström, J.L. Hoffmann, and B. Grange

MICROCHEMISTRY AND MICROSTRUCTURAL ASPECTS LEADING TO STRESS CORROSION CRACKING IN AA508 .......................................................... 205
J.S. Vetrano, M.J. Danielson, D.R. Baer, and R.H. Jones

DUCTILITY AND BENDABILITY IN 6000 SERIES AUTOMOTIVE ALLOYS ...... 211
D.J. Lloyd

THE EFFECT OF PRE-AGING ON ARTIFICIAL AGING RESPONSE IN Al-Mg-Si-Cu ALLOY 6111 ................................................................. 223
W.F. Miao and D.E. Laughlin

EFFECTS OF MINOR Sc AND Zr ADDITIONS ON COMMERCIAL Al-Mg-Mn ALLOYS ................................................................. 239
AGE HARDENING BEHAVIOR IN A COMMERCIAL 319-TYPE ALUMINUM ALLOY .................................................................................................................. 247
R. Jahn, W.T. Donlon, and J.E. Allison

APPLICATIONS

THE OPTIMIZED TENSILE AND FATIGUE PROPERTIES OF SEMI-SOLID 357 AND MODIFIED 319 ALUMINUM AUTOMOTIVE PARTS ......................... 265
S.C. Bergsma, X. Li, S.P. Paddon, and M.E. Kassner

MECHANISMS OF SOLDERING IN HIGH PRESSURE DIE CASTING OF Al-11Si-3Cu-1Fe ALLOY .............................................................................. 275
Z.W. Chen and M.Z. Jahedi

FICTION STIR WELDING MAGNESIUM ALLOYS ........................................... 285
G. Kohn, S. Antonsson, and A. Munitz

ROLL FORMING TECHNOLOGY FOR MANUFACTURING AXISYMMETRIC AUTOMOTIVE COMPONENTS - II: APPLICATION TO FABRICATION OF Al V96Ts3 AND 295 CAST ALLOY WHEELS ........................................... 293
C.K. Syn, D.R. Lesuer, T.G. Nieh, H.S. Yang, K.R. Brown,
R.O. Kaibyshev, F. Mushin, R.G. Mudarisov, and V.A. Nezorov

OPTIMISATION OF THE QUALITY OF HIGH PRESSURE DIE CAST MAGNESIUM ALLOYS .................................................................................. 305
A.K. Dahle, S. Sannes, D.H. StJohn, and H. Westengen

HIGH-CYCLE FATIGUE CRACK INITIATION SITE DISTRIBUTION IN A356.2 ............................................................................................................. 315
B. Zhang, D.R. Poirier, and W. Chen
PREFACE


This symposium is an effort to capture the ongoing research, development and testing activities for usage of aluminum and magnesium alloys in automotive application. The information contained in this publication showcases work at the industry, national laboratory, and university levels.

I wish to thank all of the authors and TMS staff for their hard work and consistent effort in producing this volume.

April 26, 1999

Dr. Subodh K. Das
2900 National City Tower
P. O. Box 32860
Louisville, KY 40232
Is the Aluminum Car a Fantasy?

Firoze Katrak, David Persampieri, Michael Loreth, and James Morton
Charles River Associates Incorporated
Boston, Massachusetts
Cars and light trucks have changed radically since the early 1970s

- Most cars are now unibody design, unlike in the 1970s when many of them were frames.
- Some light trucks now are unibody too, although a significant number (e.g., SUVs) are still body-on-frame.
- Vehicle structural weights* have declined significantly from roughly 3,330 lbs. to 2,800 lbs. now.

*Excluding rubber, glass, and fluids.
Cars and light trucks have changed radically since the early 1970s (continued)

- Aluminum's penetration has increased from 86 lbs. (3%) in 1976 to about 196 lbs. (7%).
  - Most of this aluminum penetration has been in transmission and engine block; and largely as castings, plus some forgings and extrusions.
  - Wrought aluminum (sheet) penetration is limited to A/C units and some (few) closure panels for car body.

- Plastics/composites usage has increased from 163 lbs. (5%) to 245 lbs. (9%).
  - Most of this penetration is in car interiors, and some in under the hood, but little in the body.

*Excluding rubber, glass, and fluids.
Cars and light trucks have changed radically since the early 1970s (continued)

- Thus steels have maintained their share of vehicle weight* at roughly 60-63%, and steels continue to be the material of choice for car body and closure panels.

*Excluding rubber, glass, and fluids.
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY?

- Aluminum ingot price
- Aluminum sheet price
- Heat treat vs non-heat treat aluminum sheet
- New steels and their prices
- Sheet thickness for steel and aluminum
- Cost of composites
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY? (continued)

- BIW design: unibody vs. spaceframe
- Formability
  - springback
  - surface finish
  - throughput
  - styling
- Handling
- Capital investment for aluminum or composites forming technology
- Joining technology choices
- Capital investment for aluminum or composites assembly technology
- Painting practices
- Manufacturing costs
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY? (continued)

- Performance of cars made from alternative designs or materials
- Safety
- Long-term appearance of external plastic components
- Fuel efficiency
- Fuel costs and uncertainties
- Car repair and maintenance
- Insurance
- Vehicle miles traveled
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY? (continued)

- Conflicting strategies of OEMs, Tier 1s, steel companies, plastics companies, and aluminum companies
- Human inertia in any changeover
- Learning curves and/or technological bottlenecks in alternative designs or materials
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY? (continued)
Aluminum and plastics/composites success in penetrating body and/or closure panels has been limited up to now; WHY? (continued)
What does the future hold? Can aluminum break through and displace steels in a significant number of car or truck bodies?

The answer depends on the future outcome of the same issues mentioned on the previous six pages. CRA's opinion of the outcome of these issues is summarized on the next three pages.
What does the future hold? Can aluminum break through and displace steels in a significant number of car or truck bodies? (continued)

<table>
<thead>
<tr>
<th>Problem</th>
<th>Long-term (2010) Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair and Insurance</td>
<td>Continuing education of the repair industry will result in no differences between aluminum and steel repair cost.</td>
</tr>
<tr>
<td></td>
<td>Insurance premiums will be somewhat higher in the short term. In the long term, insurance premiums will be comparable for steel and aluminum BIW because repair costs will be on a par.</td>
</tr>
<tr>
<td>Disposal/Recycling</td>
<td>The disposal/recycling industry is currently capable of separating aluminum alloys for reselling. Some infrastructure changes may be required if aluminum penetrates the high production run segment, but the recycling industry will have plenty of time (the average lifespan of a vehicle) to respond.</td>
</tr>
<tr>
<td>Safety</td>
<td>Aluminum vehicles currently appear to be as safe as their steel counterparts. There will be safety parity over the long run.</td>
</tr>
</tbody>
</table>
Most other technology bottlenecks will also be cleared by aluminum

<table>
<thead>
<tr>
<th>Problem</th>
<th>Long-term (2010) Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring-back and Stretcher Lines</td>
<td>A learning curve issue; as engineers gain expertise with aluminum, problem will disappear.</td>
</tr>
<tr>
<td>Handling of Aluminum Panels and Damage</td>
<td>Alternative handling practices, e.g., suction cups, are already in use. However, aluminum panels will always face somewhat higher rejection rate, especially at high production volumes.</td>
</tr>
<tr>
<td>Low Stamping Throughput and Productivity</td>
<td>Another &quot;learning curve&quot; issue; however, throughput for aluminum will always be lower than for steel.</td>
</tr>
<tr>
<td>Difficulty in Forming Intricate Stamped Shapes</td>
<td>Engineering knowledge will allow for shapes almost as intricate as the ones for steel.</td>
</tr>
<tr>
<td>High Spot Welding Costs for Aluminum</td>
<td></td>
</tr>
</tbody>
</table>

Likelihood for Low Medium High Volume Model-runs

<table>
<thead>
<tr>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
</table>

Very likely Possible Unlikely

Continued
Most other technology bottlenecks will also be cleared by aluminum (continued)

<table>
<thead>
<tr>
<th>Problem</th>
<th>Long Term (2010) Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for New Joining Technologies</td>
<td>Weld bonding and bond riveting practices already applied at low production volumes; probably somewhat more expensive in the long term for high production runs.</td>
</tr>
<tr>
<td></td>
<td>Steel will be shifting to weld bonding because of better performance in joints.</td>
</tr>
<tr>
<td>Capital Investment for New Joining Equipment</td>
<td>Riveting can use existing equipment with minor modifications. OEMs will also have to replace some of the joining equipment in the next 15 years.</td>
</tr>
<tr>
<td>Painting</td>
<td>New practices already in use achieve appearance levels equal to steel.</td>
</tr>
</tbody>
</table>

Likelihood for Low Medium High Volume Model-runs

Very likely

Possible

Unlikely
Thus the future battle by aluminum against steel will focus on the remaining issues:

- Car/truck body design
  - Frame vs. Unibody
- OEM and Tier 1 capital investment requirements
- Car/truck body manufacturing costs
- Aluminum sheet price and steel sheet price
- Government actions around the world
- Fuel price
- Strategies of aluminum companies and steel companies and car OEMs

We discuss each of these next.
hybrid designs consist of predominantly unibody designs where some structural parts of the BIW have been replaced/redesigned with extrusions and/or castings.

Most cars and some light trucks are unibody today, with many light trucks having frame design. Over the last decade, aluminum penetration has been through spaceframe or hybrid\(^1\) designs (e.g., Audi A8, Acura NSX, etc.), because these allow for the use of extrusions and castings, are cost-competitive for BIW manufacturing of small (40,000) production run models, and Alcoa/Audi etc. promoted spaceframes.

\(^1\)Hybrid designs consist of predominantly unibody designs where some structural parts of the BIW have been replaced/redesigned with extrusions and/or castings.
Frame or Unibody? (continued)

- In the OEMs' need to balance car/truck performance with costs, unibody design is the clear long-term solution over most types of frame designs because unibody:
  - Offers equivalent structural performance at a lower weight, mainly because it is a more "continuous" structure.
  - Achieves sustainable NVH performance over car life by effectively utilizing material (aluminum or steel) stiffness.
  - Delivers safety (crashworthiness, etc.) through selective use of higher-strength components in car body.
  - Is less expensive to manufacture across almost the full range of production run car models.

Therefore, for aluminum to significantly displace steel, its use must be demonstrated effectively in a unibody.

Will the Ford P2000 do this?
OEM and/or Tier 1 capital investment requirements

To the extent that over the long term a "new" design (for aluminum or steel car body) makes most of the existing car manufacturing facilities obsolete and requires almost all brand-new facilities/equipment, such designs will fail to be adopted in any significant manner. In fact, this will be a future limitation of the aluminum spaceframe design's continuing penetration in other than small (40K) production volumes.

Stampings, on the other hand, which are ideal for unibody design, have the added advantage that they significantly decrease new capital expenditure requirements by OEMs and Tier 1s. Future versions of the Alcan AVT and the Ford P2000 are likely to ultimately demonstrate the success of aluminum stampings.

Thus the use of aluminum sheet stampings over the long run will remove the barrier of unnecessary capital expenditures by OEMs.
Car and truck manufacturing costs: Today (1996)

Current (1996) Vehicle Costs and Margins - Steel BIW Vehicles

- Operating Income
- Non-Mfg Cost
- Non-BIW Mfg Cost
- BIW Mfg Cost
- BIW Material Cost

Although important, BIW material cost and BIW manufacturing cost are a small part of the overall vehicle cost; and, scrap devaluation is not a showstopper.

Note: The costs/margins displayed above are not meant to reflect the exact costs/margins for these platforms, but rather generic costs/margins for these vehicle types.
With today's technology, it is possible to manufacture an aluminum BIW structure; however, it is at a cost disadvantage to steel, especially in high production run car models.

### Current (1996) Vehicle Costs and Margins

<table>
<thead>
<tr>
<th></th>
<th>$40,000</th>
<th>$30,000</th>
<th>$20,000</th>
<th>$10,000</th>
<th>$0</th>
<th>($10,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPR</td>
<td>Steel</td>
<td>Aluminum</td>
<td>Steel</td>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPR</td>
<td>Steel</td>
<td>Aluminum</td>
<td>Steel</td>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPR</td>
<td>Steel</td>
<td>Aluminum</td>
<td>Steel</td>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Chrysler LHS**

**GM Eighty-Eight**

**Ford Taurus**

**Assumption:**
- Spaceframe aluminum design for low production runs, unibody for high ones, a combination of the two for medium production runs.

Note: The costs/margins displayed above are not meant to reflect the exact costs/margins for these platforms, but rather generic costs/margins for these vehicle types.