Paint bake response of aluminium car body sheet alloy

Definition: Paint bake response (PBR) = Increase in yield strength (or hardness) caused by paint baking

Contents:
- Why aluminium body sheets
- Aging of AlMgSi alloys
- The challenge
- The solution
- Summary and outlook
Conflict of aims

Fuel consumption in l/100km (Average in Germany)

11
10
9
8
7
6

1250
1150
1050
950
850
750

Vehicle weight (VW Golf) in kg

Year


6
7
8
9

Safety, comfort, power

Environmental protection

Energy saving


AMAG
ALUMINIUM RANSHOFEN WALZWERK
Aluminium for car body applications

All-aluminium body:
- Extrusions
- Castings
- Sheets

Weight saving of about 30-40% compared to steel body

Steel body structure with aluminium parts:
- Sheets (engine hood, boot lid, doors, fenders)

Preferred sheet alloy in Europe: AA6016 (1.2%Si, 0.4% Mg)
Requirements for body sheets

Before forming:
- good formability:
  Yield strength: $R_{p0.2} < 130 \text{ MPa}$
  Elongation: $A > 24\%$

In service:
- high dent resistance:
  Yield strength: $R_{p0.2} > 200 \text{ MPa}$
  Elongation: $A > 12\%$

Artificial aging treatment necessary
i.e. forming in T4 condition
aging $\Rightarrow$ T6 condition in service
Age-hardening of AlMgSi alloys

Basic requirement: Decrease in solid solubility of the alloying elements with decreasing temperature.

- Dissolve the alloying elements within the single-phase region.
- Quenching to obtain a supersaturated solid solution (SSSS).
- Controlled decomposition of the SSSS to form finely dispersed precipitates.


Graph showing the relationship between Mg$_2$Si [Gew. %] and Temperature [°C] with three major points:
1. Dissolution of alloying elements.
2. Super-saturated solid solution (SSSS).
3. Controlled decomposition of SSSS.
Age-hardening of AlMgSi alloys

- Precipitation sequence: supersaturated solid solution → Cluster and/or Guinier-Preston I (GP-I) zones → GP-II zones (β“ needles) → β′ rods → β plates (Mg₂Si)

Aging is most effective if carried out immediately after quenching!
Paint bake response of aluminium car body sheet alloy

Production scheme of an aluminium body

Washing
Oiling

Press-forming

Washing
Acid cleaning

Assembling
Artificial aging
205°C / 30 min

Finishing

Painting
Paint baking
185°C / 20 min
The challenge: 185°C/20min instead of 205°C/30min
Methods to increase the PBR

Two known methods to reduce the detrimental effect of a RT delay, i.e. to increase the PBR:
- Pre-aging treatment shortly after quenching
- Reversion treatment in T4 condition

avoid / reverse GP-I formation and provide GP-II nuclei

change in the aging behaviour

Strength

Aging time

Pre-treated material

Conventional material
Reversion treatments

Solution treatment
Quenching
Storage at RT
> 7 d
Reversion
treatment
Storage at RT
> 7 d
Artificial aging
185°C / 20 min

Target area

Hardness before PB [HB]

Hardness after PB [HB]

200-300°C / 5-600s

without reversion

reversion is not as efficient as required
Pre-aging treatments 1 (PA1)

Solution treatment
Quenching
Pre-aging treatment
Storage at RT > 7 d
Artificial aging
185°C / 20 min

PBR, Hardness increase [HB]

Pre-aging time at 185°C [min]

- no delay after quenching
- 5 min delay after quenching
- 10 min delay after quenching
Mechanical properties, PA1

Pre-aging treatment: 10min RT + 8min 185°C

Strength [MPa]

- R_p0.2
- R_m
- A

Elongation [%]

T4
RT ≥ 7d

T6
205°C/30min

T4, pre-aged
RT ≥ 7d

T6, pre-aged
185°C/20min
Non-uniform deformation, PA1

T4-Q condition = pre-aging + 7 days RT-storage
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Pre-aging treatment 2 (PA2), Mechanical properties

- Solution treatment
  - Quenching
  - Pre-aging
    - 100°C / 8h
  - Storage at RT
    - > 7 d
  - Artificial aging
    - 185°C / 20 min

<table>
<thead>
<tr>
<th>Strength [MPa]</th>
<th>T4, pre-aged RT ≥ 7d</th>
<th>T6, pre-aged 185°C/20min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rp0.2</td>
<td>Rm</td>
<td>A</td>
</tr>
<tr>
<td>Elongation [%]</td>
<td></td>
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</tr>
</tbody>
</table>
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Effectiveness of PA2

- Solution treatment
- Quenching
- Pre-aging: 100°C / 8h
- Storage at RT: > 7 d
- Artificial aging: 185°C / 20 min

method 2 is very sensitive to a delay after quenching

Hardness [HB]

Delay at room temperature [min]

- before PB
- after PB

0.1 1 10 100 1000

Delay at room temperature [min]

0 50 60 65 70 75 80 85 90

Hardness [HB]
Combination of PA1 and PA2

- Solution treatment
  - Quenching
  - Pre-aging 1
  - Delay at RT < 20h
  - Pre-aging 2
  - Storage at RT
  - Artificial aging 185°C / 20 min

Yield strength [MPa]

Storage at room temperature [weeks]

- before PB
- after PB

Elongation in T4-Q condition: 23-25%, no non-uniform deformation
Summary and outlook

- AA6016 shows no PBR in normal T4-condition while pre-aged material shows a high PBR of 80-110 MPa

- Best pre-aging parameters are:
  RT-80°C / 3-10min + 160-190°C / 3-10min, continuous furnace treatment
  80-120°C / 5-12h, batchwise treatment
  (Patented in 2001)

Artificial aging treatment of car bodies can be avoided ➡️ saves time, money and energy!

- Elongation in T4-Q is still slightly lower than in T4 ➞ further investigations to improve formability