Scalmalloy®
A unique high strength and corrosion insensitive AlMgScZr material concept

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ALU-Menziken, ALERIS, ALCOA, ALUnna, several colleagues & diploma thesis(students), public funded projects (WAFS, WEL-AIR, DATON, ENWERUM, ScaLA)
Corrosion ↔ Durability

Sources:
www.hsc.csu.edu.au
www.cctechnologies.com
hawaiicorrosionlab.org
Engineering material strength (simplification)

- 100 MPa
- 425 MPa
- 850 MPa

5xxx
6xxx
2xxx
7xxx
2xxxLi

Corrosion issues/Notch toughness
Perception of CFRP:
• If you have a weight issue ➔ CFRP is the solution
• Corrosion ➔ CFRP is the solution
• “Old” fashion ➔ CFRP is “hip”
• Nano technology ➔ CFRP is “nano” capable

Technical Driver in Aircraft Engineering
New Competition
Higher Strength in AlMgSc-Alloys

Fig. 4. Vicker microhardness as a function of aging time for Al–0.2 wt% Sc (open squares, from Ref. [2]) and Al–2 wt% Mg–0.1 wt% Sc (solid squares) at (a) 300 °C and (b) 350 °C. The dashed lines correspond to the curves for the Al–0.2 wt% Sc alloy translated upward by 210 MPa.
Higher Strength in AlMgSc-Alloys

Fig. 3. Microhardness of a 134 mm diameter Al–0.41% Sc alloy vs. annealing time at various temperatures.

Fig. 5. Microhardness of Al–0.4% Sc alloy (1) and Al–0.4% Sc–0.15% Zr alloy (2) ingots vs. annealing time at 350°C.
Higher Strength in AlMgSc-Alloys

Scalmalloy® regime

Temperature (K)

Hypoeutectic

Hyper-eutectic

Scandium, weight percent

933 K

0.38

0.52

932 K

(L)

(L) + ScAl₃

ScAl₃
Hypereutectic AlMgScZrMn-Alloys (since 2003)

Mg-content: 1,80 – 4,30% (higher Mg-contents are possible)

Sc-content: 0,70 – 1,40%

Zr-content: 0,22 – 0,55%

Mn-content: 0,30 – 0,70%

→ Sc / Zr ≈ 2 : 1

→ Mg-content ≤ 3,30% (in order to maximize corrosion resistance)

→ In the designation: ScalmalloyX® → X relates to the Sc-content
Why melt-sinning?:

• Very high solidification rates

• Relatively stable process ➔ much higher usable “powder” output

• Handling – storage of powder (flakes) / risk of surface contamination

• Industrial up-scaling
Meltspinning

Rapid Solidification

The meltspinning process
During the meltspinning process, molten aluminium hits a fast rotating wheel and almost instantaneously releases a continuous metal ribbon at room temperature. This ribbon is converted into flakes and finally into an extrusion product, after which a special heat treatment may be applied. The name Rapid Solidification Process stems from the sudden temperature drop that takes place at a rate of more than 1,000,000 °C per second as the aluminium comes in contact with the wheel.

Further processing by e.g. forging, machining and rolling.

Source RSP Technology
Scalmalloy® ⇔ Rapid solidification Video

Source RSP Technology
Scalmalloy®
From Melt → Material (Profiles)

<table>
<thead>
<tr>
<th>Scalmalloy0.7 (AlMg4.3Sc0.7Zr0.3Mn0.5)</th>
<th>Scalmalloy1.25 (AlMg3.9Sc1.25Zr0.55Mn0.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aging response (300°C/8h):</td>
<td>Aging response (300°C/8h):</td>
</tr>
<tr>
<td>as melt spun 117 HV0.05</td>
<td>as melt spun 192 HV0.05</td>
</tr>
<tr>
<td>Aged: 157 HV0.05</td>
<td>aged: 212 HV0.05</td>
</tr>
</tbody>
</table>

Scalmalloy0.7 – flakes: Oxide layer (ESCA) ≈ 25 nm, consisting of Al₂O₃ and MgO (Spinell) (after about 4 weeks of handling (transport & storage))
Scalmalloy® Manufacturing Chain

Extrusion ratio tested $\approx 8,0 - 36 : 1$ (depending on geometry)
- Round bar (several extrusion temperatures 300 - 380°C)
- Aerospace profile bar extruded at 360 - 380°C
Scalmalloy® Strength Evolution

Tensile strength of Scalmalloy 0.7 - 1.25 - 1.4 profile material (mean values), extrusion temperatures 320 - 350°C

Scalmalloy®

=> High strength & ductile material with exceptional high notch toughness => low density ($\rho \approx 2.65 \text{ g/cm}^3$) => very good tensile length and notched fatigue
Strength evolution in extruded AlMgSc alloys (0 < Sc < 1,0wt%)  
(=> 0,1wt% Sc = ca. 45 MPa strength increase)

Scalmalloy® Yield Strength Estimation

AlMg4,3Sc0,7Zr0,3Mn0,5

=> 315 MPa
Strength evolution in extruded AlMg-type alloys (0 < Mg < 5%) (annealed temper (extruded in temperature range 300 - 350°C))

Scalmalloy® Yield Strength Estimation
AlMg4,3Sc0,7Zr0,3Mn0,5

135 MPa <=

Scalmalloy®

Yield Strength Estimation
AlMg4,3Sc0,7Zr0,3Mn0,5
Strength capabilities of AlMg4,3Sc0,7Zr0,3Mn0,5:

- UTS ≈ 500 MPa
- YS ≈ 450 MPa
- A > 15%

Easy UTS approximation via HB

⇒ Factor ≈ 3,5!
Scalmalloy®

⇒ Unique combination of strength & notch toughness by ultra fine ("nano-sized" (2 – 4 nm)) micro structure of coherent $\text{Al}_3\text{Sc}$ (and $\text{Al}_3\text{Sc}_x\text{Zr}_{1-x}$) phases

Scalmalloy®

As cast

Aged at 300°C/8 h

Aged at 300°C/8 h

Scalmalloy®

Physical Strength Evolution
Scalmallo® Corrosion Behaviour II

(IGC test ASTM G67 (sensitize 150°C/250 h)

AA5182

Scalm. 1.25

Scalmallo® with adjusted Mg-content is obviously immune against IGC compared to established 5xxx alloys and allows applications with temporarily exposures between 75 – 250°C
Scalmalloy® Material Processing (i.e. Welding)

**HV = 80**

**HV = 116**

AlMgSc allows converting "under-matched" weld zone into "over-matched" weld zone by selected post weld heat treatments at 300 – 325°C (= stress relief and final shaping possibility)!!
Scalmalloy® New Designs ➔ higher Performance

“Standard-AlMgSc” and Scalmalloy®

Exceptional high corrosion resistance

\[ \text{Component} \rightarrow \text{design} \]

\[ \text{Manufacturing} \rightarrow \text{welding process} \]

Special Sc related metallurgy

⇒ New („old“) high performance designs with 10-20% weight reduction capacity
Next targets:

1. Improvements of the melt-spin rapid solidification process & process chain (strength window 450 – 750 MPa)

2. Ongoing material assessment (static – dynamic - corrosion)

3. Extending the thermal working window limits (375 °C → 400 – 425 °C) → improved alloying i.e. Zr + Hf (?)

4. Clarification of melting anomalies when Sc + Zr amounts exceed 2.5 wt% (“colloid melts”)

5. Overcome current extrusion limits (i.e. hydro-static extrusion or allow higher overall extrusion temperatures)

6. Evolution of Sc master alloy price (s.a. “red mud deposits”)
Scalmalloy® Challenges ⇔ Limits
⇒ Improved Melt-spin Processing

Improved melt-spin parameter secure better super saturated matrix enabling improved aging response ⇒ 700+ MPa appears feasible!!