Aluminium mold repair
Overview

- **Best repair technologies according to defect size and location**
  - GTAW technologies
    - Principle
    - On aluminium products
    - Welding procedure
    - Choice of filler wires for GTAW on Alumold 500
    - Conclusions on technology and filler wire
  - Mechanical repair
    - Principle
    - Example of repair and effect on injected part
  - Laser, HVOF, Arc wire spray
    - Principles
    - Example of repair and effect on injected part
  - Synthetic table
Best repair technologies according to defect size and situation

- **Defect location and size:**
  - ✓ Non-grained visible zone:
  - ✓ Non visible zone:
  - ✓ Visible grained zone:
  - ✓ Small (< 2mm) or surface zone:

- **Possible repair technology:**
  - ✓ GTAW DC (with 4145 or 5xxx)
  - ✓ GTAW AC (with 5xxx)
  - ✓ Mechanical repair
  - ✓ GTAW AC
  - ✓ GTAW DC
  - ✓ Mechanical repair
  - ✓ Mechanical repair
  - ✓ GTAW AC or DC
  - ✓ Laser
  - ✓ HVOF
  - ✓ Arc wire spray
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GTAW technology

Principle

TIG = GTAW (Gas Tungsten Arc Welding)

- GTAW DC (Direct Current) usually used on steel and aluminium
- GTAW AC (Alternative Current) only on aluminium

The part emits electrons.
The electrode is heated.
The melting pool is cooled.
(ex GTAW AC case)

The electrode emits electrons.
The part is heated.
The penetration is increased.
(ex GTAW DC case)
GTAW technology
On aluminium products

- **Important aluminium welding recommendations:**
  - **Mechanical brushing** of mould surface before welding to remove oxides.
  - **No CO₂** as shielding gas
  - **Al welding: “hot” and “fast”** to avoid heat diffusion in the mould: current and speed maximum
  - In case of tungsten deposition in the weld, the contaminated area must be milled and cleaned.

- **DC GTAW:**
  - Difficult to use on Al products: arc length < 1mm, melting pool is very deep
  - Very effective on Al thick products: ➔ no preheat treatment

- **AC GTAW:**
  - Easy to use on Al products
  - A preheat treatment about 100°C is required to increase penetration. T<100°C to prevent altering the mould mechanical properties.
GTAW technology
Welding procedure (1): surface preparation

- **Surface preparation:**

  1. **Degreasing of the surface to be welded and the surrounding area:**
      - With an appropriate solvent like Evopred or something equivalent.
      - Note: chloride solvents are prohibited.
      - By wiping the area with a clean lint free.
      - The weld area must be completely dry before welding.

  2. **Removing of the oxide layer on the mould:**
      - By wire brushing with a stainless steel wire brush.
      - This brush should only be used on aluminium.

  3. **Removing of the oxide layer on the filler wire**
GTAW technology
Welding procedure (2): indications of welding parameters

**DC GTAW parameters:**
- Generator: AC/DC
- Current: $180 \, \text{A} < I < 200 \, \text{A}$
- Voltage: $150 \, \text{V} < U < 200 \, \text{V}$
- Electrode diameter: $\geq 4 \, \text{mm}$
- Nozzle internal diameter: $\geq 12 \, \text{mm}$
- He shielding gas
- Gas flow: $20 \, \text{l/min}$
- Filler material diameter: $\geq 3.2 \, \text{mm}$
- Arc length: $\leq 1 \, \text{mm}$. The melt pool is very deep.
- Electrode: W+Zr (no more W+Th according to safety rules)
- Sharpening angle of the electrode about $120^\circ$  

**AC GTAW parameters:**
- Generator: AC/DC
- Current: $200 \, \text{A} < I < 250 \, \text{A}$
- Voltage: $180 \, \text{V} < U < 240 \, \text{V}$
- Electrode diameter: $\geq 4 \, \text{mm}$
- Nozzle internal diameter: $\geq 12 \, \text{mm}$
- Ar 30% He 70% shielding gas
- Gas flow: $20 \, \text{l/min}$
- Filler material diameter: $\geq 3.2 \, \text{mm}$
- Electrode in pure W No electrode sharpening
- $1 \, \text{mm} < \text{Arc length} < 2 \, \text{mm}$
GTAW technology
Choice of filler wires on Alumold 500

5356 : 4-5% Mg
- Classical wire
- Good internal quality
- Some surface cracks
  SOLUTION: repeat welding and machining until the crack disappears
- Low hardness compared to parent metal
- No colour change / parent metal

4145 : 9-11% Si, 4-5%Cu
- Exotic wire
  SUPPLIER: Alcotec
- Good internal quality
- No surface crack
- Same hardness than the parent metal
- Present a colour change, visible on the injected part.
  SOLUTION: increase the polishing in GTAW DC

5180/5280: 5%Mg 2%Zn
- Semi exotic wire
- Bad internal quality
- Some surface cracks
  SOLUTION: repeat welding and machining until the crack disappears
- Same hardness than the parent metal
- No colour change / parent metal
GTAW technology
Choice of filler wires on Alumold 500: solutions

4145 GTAW DC on a non grained surface: the increase of polishing decreases the colour difference on the injected part.

5356 and 5180 GTAW DC and AC on a non grained surface: Repeat machining and welding until getting a perfect visual aspect.
## GTAW technology

### Choice of filler wires on ALUMOLD 500: conclusions

**Conclusions:**

- 4145 presents a good compromise of properties for Alumold 500.
- 5xxx (5356 and 5180/5280) could be the second choice.

<table>
<thead>
<tr>
<th></th>
<th>4145</th>
<th>5356</th>
<th>5180/5280</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weld mechanical properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gap of microhardness/mould metal</td>
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<td>NOK</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Surface quality</strong></td>
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<td></td>
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<td>No surface crack = no mark on injected part</td>
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<td>Limit</td>
<td>Limit</td>
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<tr>
<td><strong>Surface colour</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Change of surface colour</td>
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<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Internal quality</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal cracks</td>
<td>OK</td>
<td>OK</td>
<td>NOK</td>
</tr>
<tr>
<td><strong>Easy availability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classical filler wire</td>
<td>Limit</td>
<td>OK</td>
<td>Limit</td>
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</tbody>
</table>

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GTAW technology
Conclusions on this technology

- Manual and cheap technology

- **AC GTAW** is easier to use on Aluminium products, but requires a preheat treatment (not more than 100 °C):
  - ✓ Recommendation: using with 5xxx filler wire in repeating welding and machining until the surface crack disappears.

- **DC GTAW** is a more complex technical process, but more effective than the previous.
  - ✓ Recommendations:
    - using with 5xxx filler wire in repeating welding and machining until the surface crack disappears.
    - using with 4145 filler wire with a sufficient polishing

- Both GTAW processes must not be used in case of grained surface of the mould.
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  - Conclusions and synthetic table
Mechanical repair

Principle

- An insert in the same grade than the aluminium alloy mould part is mechanically assembly on the mould.

- **Mechanical repair by hooping**
  - The insert is slightly higher than the reparation place.
  - The insert is cooled (N2 liquid), and the mould is heated.
  - The insert is machined and grained.

- **Mechanical repair by screwing**
  - The hole in the mould is threaded
  - The insert is also threaded
  - The insert is screwed inside the mould.
  - The insert is machined and grained.
Mechanical repair
By hooping: mould preparation

1. Prepare the mould
   - Drill a hole containing the defect
   - Finish the hole with flat bottom and ream to obtain a good roughness
     ✓ Diameter will be function of the size of the defect
     ✓ Depth should be superior to 1.5 x diameter
Mechanical repair
By hooping: insert preparation

2. Prepare the insert

- Machine an insert from the same alloy
  - \( \varnothing \) insert = \( \varnothing \) hole + 0.02 mm
  - \( h \) insert = \( h \) hole + 10 mm
  - Make a chamfer to facilitate entry
Mechanical repair
By hooping: assembly

3. Assembly

- Best solution: insert must be cooled down in liquid nitrogen (77K / -196°C)
- Alternative: put the insert in a freezer and heat up the hole area with a flame (DO NOT heat too much to prevent from degrading the metal)
- Insert the pin inside the hole and wait the return to ambient temperature
Mechanical repair
By hooping: finishing

4. Finishing
- Mill the insert
- Polish as needed
- Locally chemical etch if required
- When possible, make a venting at the back of the insert (in case of gas pocket)
Mechanical repair
By hooping: complement

More informations

- Coefficient of thermal expansion for Al : 22.3 - 23.8 x 10E-6 / °C
  - example : Ø₀ = 10 mm
    \[ ΔT = \text{abs}(-196 + 20) = 216 °C \quad (\text{with liquid nitrogen}) \]
    \[ ΔØ = 10 \times (23 \times 10E-6) \times 216 = 0.05 \text{ mm} \]
  - it means a 10mm diameter pin will reduce by 0.05mm

- Compared to steel and its low coefficient of thermal expansion (12x10E-6/°C), this solution is particularly adapted to aluminium.
Mechanical repair
By screwing: mould preparation

1. Prepare the mould

- Drill a hole containing the defect

- Ream the hole to obtain a good roughness, and make a thread in the bottom (3-4 threads)
  - Diameter will be function of the size of the defect
  - Depth should be superior to 1.5 x diameter
Mechanical repair
By screwing: insert preparation

2. Prepare the insert

- Machine an insert from the same alloy with a **squared head** to screw
  - $\varnothing$ of the insert **tightened** near the surface (slight cone)
  - $h$ insert = $h$ hole + 10 mm
  - Make a chamfer to facilitate entry
Mechanical repair
By screwing: assembly and finishing

3. Assembly
- Screw the insert inside the hole and tighten

4. Finishing
- Mill the insert
- Polish as needed
- Locally chemical etch if required
- When possible, make a venting at the back of the insert (in case of gas pocket)
Mechanical repair
Example on a grained mould

- The insert is only visible in the weld
- No mark is visible on the injected part
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Laser, HVOF, arc wire spray
Surface repair technologies

- **Pulsed laser:**
  - Small heat affected zone
  - Accurated repair

- **HVOF (High Velocity Oxy Fuel):**
  - Molten metal droplets generated by combustion of $O_2$, ethen, acethylen, hydrogen, propan.
  - Throwing down on the mould

- **Arc wire Spray**
  - Molten metal droplets generated by an electric arc
  - Throwing down on the mould

- **Do not work for 5 mm defect:**
  - too high size of defect
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Conclusions: How can we repair a mould?

- If it is located in a chemical grained zone:
  - Better solution: mechanical repair

- If it is located in a visible non-grained zone:
  - Different solutions:
    - GTAW DC 4145
    - GTAW AC or GTAW DC 5356 in repeating the operation welding/machining until satisfying visual surface aspect
    - Mechanical repair

- If it is a very small zone:
  - GTAW processes
  - Arc wire spray and HVOF can be convenient

- If it is a non visible zone:
  - The more robust and the easiest solution is GTAW AC 4145 (or 5XXX).
<table>
<thead>
<tr>
<th>Repair technologies</th>
<th>+</th>
<th>-</th>
<th>Aspect of the injected part without graining</th>
<th>Aspect of the injected part with graining</th>
<th>Conclusions for non grained part</th>
<th>Conclusions for grained part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc Wire spray</td>
<td></td>
<td></td>
<td>Impossible to machine for 10 mm defect size (no metallurgical bonding between weld metal and base metal)</td>
<td>Not tested</td>
<td>- Non valid technology for defect of few mm - Interesting process for very small defect? Must be confirmed</td>
<td>- Non valid technology for defect of few mm - Interesting process for very small defect? Must be confirmed</td>
</tr>
<tr>
<td>HVOF</td>
<td></td>
<td></td>
<td>Impossible to machine or 10 mm defect size (no metallurgical bonding between weld metal and base metal)</td>
<td>Not tested</td>
<td>- Non valid technology for defect of few mm - Interesting process for very small defect? Must be confirmed</td>
<td>- Non valid technology for defect of few mm - Interesting process for very small defect? Must be confirmed</td>
</tr>
<tr>
<td>TIG AC</td>
<td></td>
<td></td>
<td>Requires preheating at roughly 100°C - Loss of base metal mechanical properties due to preheating</td>
<td>Marks on the injected part</td>
<td>- 5XXX can be used with repeat welding+machining to delete cracks - With 4145 can appear a difference of colour on the injected part</td>
<td>Non valid technology for grained part: all the filler materials present marks on the part</td>
</tr>
<tr>
<td>TIG DC</td>
<td></td>
<td></td>
<td>Requires trained welder (very short distance between weld pool and electrode 1mm) - Loss of base metal mechanical properties due to high heat input</td>
<td>Marks on the injected part</td>
<td>- 5XXX can be used with repeat welding+machining to delete cracks - 4145 can be used with sufficient polishing (&gt;320)</td>
<td>Non valid technology for grained part: all the filler materials present marks on the part</td>
</tr>
<tr>
<td>Mechanical repair</td>
<td></td>
<td></td>
<td>Good bonding between insert and mould - Loss of base metal mechanical properties due to heating of the mould</td>
<td>No marks on the injected part</td>
<td>Can be used</td>
<td>Can be used</td>
</tr>
</tbody>
</table>

Non OK, Limit, OK